PART I

On the theory of externalities

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Preface to the second edition

Since the publication of the first edition of this book in 1975, there have been several important contributions both to the theory of externalities and to the design of policy instruments making use of economic incentives for environmental management. Perhaps most important has been the emergence of instruments that control quantity directly rather than through price adjustments; these measures represent an alternative to the standard Pigouvian prescription for a unit tax on activities with detrimental external effects. Since publication of the seminal paper by Martin Weitzman, economists have explored the properties of a system under which the regulatory authority issues a limited number of transferable permits. This work has shown that in a setting of uncertainty, the expected gain in welfare may be higher or lower under such a permit system than under a tax regime, depending on the shapes of the control cost and damage functions. The choice of one system over the other thus depends on the way damages and control costs change with the level of pollution.

At the same time, there has been growing interest at the policy level in the use of transferable permit systems for the attainment of our environmental standards. In the United States, the Environmental Protection Agency has introduced the Emissions Trading Program for the regulation of air quality; this program allows polluters (subject to certain restrictions) to trade emissions entitlements. Environmental economists have studied emissions trading and have, more generally, investigated the properties of a number of variants of transferable permit systems. From these efforts is emerging the exciting prospect of an effective system of market incentives for protection of the environment. Economists have long argued that economic incentives have an important role to play in environmental policy; there are now cases where such incentives are being embodied in actual environmental legislation.

In the revision of this book, we have devoted considerable attention to the use of quantity instruments for environmental management. Two of the three wholly new chapters address this topic. The first half of the book, which deals with the theory of externalities, has been augmented by a chapter based on the work of Weitzman and others describing the relative welfare gains promised by quantity and price instruments where the environmental authority is uncertain about the true damage and abatement cost functions. In the second half of the book, where we address more directly the design and implementation of policy measures, we present a new chapter on systems of transferable discharge permits and their potential for attaining a predetermined level of environmental quality at the least cost. We investigate a number of alternative permit systems and contend that one, the pollution offset system, is the most promising of such systems for the achievement of our environmental targets.

The second edition has also allowed us to explore some further topics in environmental policy, to update various results, and to correct mistakes from the first edition. The third new chapter in the book considers the setting of standards for environmental quality and asks whether such standards should be set by national or "local" authorities. There is a real conflict between the desire to tailor environmental measures to particular local conditions and the fear that economic competition for jobs and incomes will lead local governments to compete in environmental degradation as a means to attract new industry. We explore this conflict in the context of a model of interjurisdictional competition; although the issue is admittedly a complicated one, we believe that the analysis provides a persuasive case for the introduction of some local variation in environmental measures.

We should also note that in response to a series of articles by A. Myrick Freeman and others, we have reworked Chapters 3 and 4 to correct our treatment of depletable and undepletable externalities. As Freeman showed, our claims concerning the different policy implications of these two types of externalities were incorrect. We think that (thanks to this assistance) we have it straight now. We have also corrected and extended our treatment of the taxation of monopolists and of the use of subsidies for pollution abatement. Finally, we have introduced some new material on the redistributive properties of environmental measures and on environmental policy in an international economy.

In order to keep the book to a reasonable size, we have deleted the three concluding chapters from the first edition, which examined the provision of public services and the tax system. While the public sector obviously makes a crucial contribution to the quality of life, these chapters turned out to be somewhat peripheral to the interests of most readers.

We are grateful to several economists for their assistance in this revision. In particular, we wish to thank Peter Coughlin, Robert Schwab, and Eyton Sheshinski for their invaluable help with the new material.

Preface to the first edition

This book is one of a pair of companion volumes devoted to the study of economic policies to enhance the quality of life.* Our willingness to embark on so considerable a subject only reflects our conviction that economists as a body have already made sufficient headway on these problems to make such an undertaking worthwhile. We believe, in short, that this is a subject on which economists have a great deal to say that is useful; these books are intended both to bring that material together and to carry the investigation some stages further.

This volume is primarily theoretical and is consequently addressed to our fellow economists. However, it is not meant to be theory for theory's sake. Here our prime concern is policy; we are interested in the theory as a means of understanding the complexities of environmental programs.

The orientation of the other book is primarily empirical; there we will present and evaluate pertinent data and experience for guidance in the choice of policies for environmental protection and for the improvement of other aspects of the quality of life. Though it will be less technical than the theoretical volume and will consequently address itself to a broader audience, we intend it to provide the empirical counterpart to the theoretical structure developed in this book.

Our most direct debt is that to the National Science Foundation, whose support has made our work on the two volumes possible. In particular, the collection and analysis of the empirical materials in the companion volume has, predictably, proved to be a long and difficult undertaking which would have been impossible without the Foundation's generosity.

Happily, intellectual debt does not carry with it the threat of bankruptcy, for in writing this volume the debts we have accumulated have been numerous and heavy. Our deepest obligations for help above and beyond what might reasonably be asked of anyone, are those to our colleagues, David Bradford and Elizabeth Bailey. Their painstaking reading of the

*The companion volume is W. Baumol and W. Oates, *Economics, Environmental Policy, and the Quality of Life* (Englewood Cliffs, N.J.: Prentice-Hall, 1979).

entire manuscript and their extensive and valuable suggestions and comments have resulted in enormous improvements both in substance and in exposition (and, incidentally, have added considerably to the labor of revision).

Professor Bradford also contributed more directly by his co-authorship of an article which served as the basis for Chapter 8 and by his authorship of Appendix B to Chapter 8. A second such contribution was provided by Dr. V. S. Bawa of Bell Laboratories, who in his very illuminating appendix to Chapter 11 solved some basic problems underlying our discussion in that chapter.

We also owe special thanks to Lionel Robbins for urging us to undertake this project (though there have been moments when we doubted whether this was cause for gratitude) and to Robert Dorfman and a number of advanced students at the Stockholm School of Economics for detecting some critical errors in our arguments.

For their very useful comments on particular parts of the analysis, we are also most grateful to Polly Allen, Hourmouzis Georgiades, Peter Kenen, Harold Kuhn, Edwin Mills, Herbert Mohring, Richard Musgrave, Fred Peterson, Robert Plotnick, Michael Rothschild, Ralph Turvey, and Edward Zajac. The opportunity to work through these materials in two separate lectures delivered by one of us at the Stockholm School served as a stimulus for our ideas and the completion of this book, and for this too we are most grateful.

Finally, for patience, good humor, skill at deciphering our hieroglyphics, and for ability to produce order out of chaos, we want to thank Sue Anne Batey, who has acted as research assistant, secretary, and a repository of sanity, and who, we trust, will not be excessively embarrassed as she types these words.

CHAPTER 1

Introduction: economics and environmental policy

When the "environmental revolution" arrived in the 1960s, economists were ready and waiting. The economic literature contained an apparently coherent view of the nature of the pollution problem together with a compelling set of implications for public policy. In short, economists saw the problem of environmental degradation as one in which economic agents imposed external costs upon society at large in the form of pollution. With no "prices" to provide the proper incentives for reduction of polluting activities, the inevitable result was excessive demands on the assimilative capacity of the environment. The obvious solution to the problem was to place an appropriate "price," in this case a tax, on polluting activities so as to internalize the social costs. Marshall and Pigou had suggested such measures many decades earlier. Moreover, pollution and its control through so-called Pigouvian taxes had become a standard textbook case of the application of the principles of microeconomic theory. Economists were thus ready to provide counsel to policy makers on the design of environmental policy.

However, things have proved not quite so simple as this. First, at the policy level, environmental economists have been dismayed at their modest impact on the design of environmental measures. Rather than introducing the economist's taxes or "effluent fees" on polluting activities, policy makers have generally opted for the more traditional "command-and-control" instruments involving explicit limitations on allowable levels of emissions and the use of specified abatement techniques. Pricing measures for the regulation of pollution have been rare.

Second, the profusion of literature on the theory of externalities and its applications to environmental management suggests that there were more than just a few loose ends to the available analysis. This literature over the past three decades runs into hundreds of papers. These papers explore the properties of the Pigouvian solution, its limitations, and the potential of a number of alternative policy instruments, including subsidies for pollution abatement, deposits for damaging materials, and systems of marketable emission permits. There is much more to the economic theory of environmental regulation than simply the introduction of a tax equal to "marginal social damage."

Our intent in this book is twofold. First, we seek to provide a systematic treatment of the theory of externalities and its implications for the design of environmental policy. This is our objective in Part I, where we offer a definition of externalities and then explore how externalities impinge on the efficient functioning of a market economy. We find that, properly interpreted and qualified, the Pigouvian prescription for regulating externalities retains its validity. With full information, a set of Pigouvian taxes equal to marginal social damage can sustain an efficient outcome in a competitive setting. However, as we find in the later chapters in Part I, this result is subject to numerous qualifications that raise troublesome concerns about the robustness of the Pigouvian approach. In particular, the existence of uncertainty concerning the magnitude of social damages and of abatement costs, the presence of imperfectly competitive elements in the economy, and the likelihood of nonconvexities that can undermine the required second-order conditions generate serious reservations about the simplistic use of the Pigouvian formula. Each of these issues is the subject of a chapter in Part I. We emerge from Part I with the sense that although the theory of externalities can go some distance in explaining the existence of environmental abuse, it still leaves us several steps removed from a workable set of corrective policy measures.

In Part II, we move away from the pure theory of externalities to our central concern with the application of economic analysis to the design of a viable and effective environmental policy. We begin by placing the design and implementation of policy measures in a typical administrative setting in which the environmental authority first determines a set of environmental standards or "targets" (e.g., allowable concentrations of pollutants) and then establishes a regulatory framework to attain these standards. Within this setting, we explore systems of fees and of marketable emission permits to achieve the predetermined standards for environmental quality. We then consider a further policy instrument, subsidies, which although often attractive to the regulator, have a serious allocative deficiency compared to fees or permits. In the remainder of Part II, we examine other important issues in the determination of a feasible and effective program for environmental management: the distributive implications of environmental measures, international dimensions of environmental policy, and the structuring of regulatory authority among different levels of government. We find important roles for both national and local governments in the environmental arena.

Our objective in Part II is thus to try to bring economic analysis to bear more directly on the concerns of the policy maker. This reflects our conviction that economics has much to contribute to improved programs for the control of pollution. The widespread concern over the current state of the environment and the limited success of existing policy have generated renewed interest in the effectiveness of alternative approaches to environmental protection. It is our sense that a wider use of economic incentives can significantly increase the effectiveness of measures for pollution control both in terms of attaining our environmental targets and in doing so with enormous cost-savings relative to current command-and-control policies. This is not, however, to be achieved by some simple, universal remedy such as a uniform effluent fee. Rather, as we hope this volume makes clear, there exists a substantial range of policy instruments, each with its particular strengths and weaknesses. An enlightened and effective program of environmental management must incorporate these instruments into an integrated set of policies that draws on the strengths and, where possible, avoids the weaknesses of the individual policy measures.

CHAPTER 2

Relevance and the theory of externalities

By bringing to light sources of error in the formulation of both actual and proposed policy, and by helping us to deal with the critical problem of allocative efficiency, externalities theory provides guidance to the practitioner. Part II of this book explores some of the more concrete policy issues to which the analysis can be applied; in doing so, it deals with several topics that have not been the subject of much formal analysis.

But before coming to these applications, we first reexamine the theoretical underpinnings of the analysis. We shall argue in Part I that a number of widely held views about the theory of externalities are unfounded. The analysis also points out several (frequently undetected) booby traps that threaten the unwary in the use of the theory and have significant implications for policy.

We have not tried in this book to provide a comprehensive review of the externalities literature. Because we are interested primarily in materials relevant to the pressing problems attributable to externalities, we have deliberately avoided some of the theoretical issues that have received a great deal of attention. More will be said about these omissions later in this chapter.

1 Outline of Part I

In Chapter 3, we introduce our treatment of externalities with a nontechnical discussion of the issues and a preview of the major results from the formal analysis. We begin with a definition of externalities and then proceed to some important distinctions among various classes of externalities; here, we differentiate between "technological" and "pecuniary" externalities and those of the "public" and "private" varieties. We also explore the basic policy prescriptions for the regulation of externalities, including both incentives for the sources of externalities in the form of Pigouvian taxes (subsidies) and the possibility of supplementary fiscal inducements for the victims (or beneficiaries) of the external effects.

In Chapter 4, we turn to the formal analysis of externalities. We begin with the specification of a basic model that incorporates external effects and then derive the first-order conditions for a socially optimal outcome. By comparing these conditions with those characterizing profit maximization by firms and utility maximization by individuals, we are able to derive a set of policy measures that will ensure the compatibility of the two sets of conditions. In particular, the theorems demonstrate the need for a set of Pigouvian taxes (subsidies) on the generators of an externality to induce them to take proper account of the full range of social costs (benefits) that their activities entail. Although this is a familiar result, the analysis also establishes some less widely known propositions concerning the treatment of recipients of externalities. In particular, these propositions provide an answer to the question of whether the victims of a detrimental externality should be compensated for the damages they suffer or, as Coase has suggested, whether they should be taxed for the sake of improved resource allocation.[1]

It should be noted that, with one or two exceptions, our analysis of welfare maximization will utilize a weak criterion, Pareto optimality, which sweeps under the rug the issue of distribution. At a later point, distributive problems will be considered explicitly and the dangers of the Paretian approach will be commented upon. Yet, as has so often proved true, the Pareto criterion will permit us to draw a considerable number of conclusions of greater significance than the weakness of the underlying premise might lead us to expect.

Chapter 5 extends the analysis to a setting in which there exists uncertainty as to the magnitude of the benefits and costs of pollution abatement. We find there that an alternative policy instrument, marketable emission permits, promises greater welfare gains, under certain circumstances, than does a system of Pigouvian fees.

Chapters 6 and 7 examine a number of additional topics in the theory of externalities. We explore the problem that market imperfections create for the implementation of tax-subsidy policies that correct the distortions caused by external effects. We also provide a formal proof of the proposition that, with convexity of production and utility functions, the presence of external costs in a particular activity leads unambiguously to a competitive equilibrium with activity levels exceeding those that are optimal, and that the reverse holds for external benefits.

However, Chapter 8 shows that, if externalities are sufficiently strong, the second-order concavity-convexity conditions must necessarily be violated, so that a world in which externalities are important may be expected to be characterized by a multiplicity of local maxima. This may,

[1] See R. H. Coase, "The Problem of Social Cost," *Journal of Law and Economics* III (October, 1960), 1–44.

of course, complicate enormously, and perhaps render totally impractical, attempts to reach even a state of Pareto optimality, whether through global tax-subsidy measures or via central planning and direct controls.

Chapter 9 is something of a digression, exploring briefly the optimal pricing of exhaustible resources. Although it is not directly related to the issue of externalities, the matter of exhaustible resources and their use has important implications for environmental quality and the well-being of future generations. Here we find that conventional analysis provides a number of interesting propositions about intertemporal pricing patterns for resources that are fixed in supply. Some of the theorems seem counterintuitive on first glance; we show, for example, that under certain fairly general conditions, an optimal pattern of usage for an exhaustible resource requires a declining price over time.

2 An omitted area: existence theory

As we suggested earlier, our exclusive concern with the theory of policy dictates the omission of a number of interesting theoretical topics. Two of them have received so much attention in the literature that some justification seems necessary.

The first is the issue of the existence of a general-equilibrium solution in the presence of externalities; this is a subject that has given rise to a small, but very sophisticated, body of materials.[2] It is clear that, in an ultimate sense, the issue of existence is highly relevant. If no solution exists, theoretical discussion of policy is basically pointless. It is possible also that the necessary or sufficient conditions for existence will themselves turn out to have some direct policy implications. So far, however, no such connection seems to have emerged, and so we will do no more than acknowledge the issue and make sure to build at least some of our models so that they satisfy sufficient conditions for existence of an equilibrium.

3 Another omitted area: the small-numbers and voluntary solution case

We have also omitted (aside from a brief section in Chapter 3) a second noteworthy topic in externalities theory – the small-numbers case in which a very few decision makers are involved in the generation of an externality *and* few are affected by it. With all of the complexities that beset the

[2] See, for example, K. J. Arrow and F. H. Hahn, *General Competitive Analysis* (San Francisco: Holden-Day, 1971).

theory of oligopoly and other small-numbers models, this case has proved an irresistible subject for theoretical analysis. The result is an extensive literature focusing on the small-number situation, a literature which, we are convinced, is disproportionate to its importance for policy.

Many of these analyses reach the conclusion that, in the circumstances postulated, the affected parties, if left to themselves, will negotiate a voluntary set of payments to induce those who generate the social damage to adjust their behavior, perhaps even to optimal levels.[3] The farmer whose crops are damaged by runoff from a higher field will find it profitable to offer a side payment to the unwitting tormentor sufficient to induce him to reduce the runoff appropriately.[4] All this rests on the assumption that the number of parties to such a situation is sufficiently small to make negotiation possible. It is generally recognized that where the number of individuals concerned is large, the likelihood of voluntary negotiation becomes small, because the administrative costs of coordination become prohibitive and because "as the number of participants becomes critically large, the individual will more and more come to treat the behavior of 'all others' as beyond his own possible range of influence" (p. 116).[5]

The important point for us is that most of the major externalities problems that concern society so deeply today *are* large-number cases. *Even where the number of polluters in a particular neighborhood is small, so long as the number of persons affected significantly by the emissions is substantial, the process of direct negotiation and agreement will generally be unmanageable.*[6] The same point, obviously, applies to all other types of externality. It thus seems to us that the role of voluntary negotiation

[3] See Coase, "The Problem of Social Cost," *Journal of Law Economics;* J. M. Buchanan and W. C. Stubblebine, "Externality," *Economica* XXIX (November, 1962), 371–84; and Ralph Turvey, "On Divergences Between Social Cost and Private Cost," *Economica* XXX (August, 1963), 309–13.

[4] The argument does assume away the problems of oligopolistic indeterminancy. If both sides to such a negotiation try to outsmart one another by devious strategies, an optimal outcome is by no means certain.

[5] J. M. Buchanan, "Cooperation and Conflict in Public-Goods Interaction," *Western Economic Journal* V (March, 1967), 109–21.

[6] This does not mean to imply that the number of polluters makes no difference for policy. For example, Lerner observes that "...where the firm is large enough to be able to influence the price of pollution by varying its own output, we have a kind of monopolistic distortion 'in reverse'... As the additional pollution raised the price per unit...he would have to pay not only the higher price of the additional unit but the *price increase* on each unit he was previously producing...so that he would be producing *too little pollution.*" A. P. Lerner, "The 1971 Report of the President's Council of Economic Advisors; 'Priorities and Efficiency,'" *American Economic Review* LXI (September, 1971), 527–30. (Quote from 529–30.) This issue is discussed in detail in Chapter 6.

among individual decision makers is of limited applicability for environmental policy.[7]

Once asserted, the point is almost obvious. Yet it is important to nail it down, because it seems to get lost in so much of the discussion. For example, it is surprising how many casual readers of the literature one encounters who feel that Coase's shafts have dealt a fatal blow to the Pigouvian solution in practice because, if negotiation moves resource allocation toward the ideal, the imposition of the optimal Pigouvian taxes on top of this will prove too much of a good thing. The argument, so far as it goes, is valid. But if, in most important externalities problems, negotiation is impractical and virtually nonexistent, the damage to the Pigouvian position inflicted by this point can hardly be very serious.

We want to be clear on this assertion. No one can possibly sustain against Coase, Buchanan, or Turvey the accusation that he does not understand the significance of the large-numbers case. For example, the preceding quotation from Buchanan makes his grasp of the issue abundantly clear, and the same is true of Turvey.[8] Moreover, all three surely recognize its importance in practice. Indeed, the sentence immediately preceding our quotation from Buchanan asserts, "To be at all relevant for public-goods problems in the real world, the analysis must be extended from the small-number to the large-number case."[9] This does not mean that our discussion attacks a straw man. At the least, it indicates which portions of the recent theoretical literature are of central "relevance" for environmental policy. In addition, it deals with a misplaced emphasis (if not an error) that is widespread among those who have read the literature without sufficient care.

The point may be brought home most effectively by a simple listing of pervasive externalities problems that the majority of observers would consider to be among the most serious:

[7] An instructive exception is a case reported in the Swedish newspapers. On the outskirts of Göteborg in Sweden, an automobile plant is located next to an oil refinery. The automobile producer found that, when the refining of lower quality petroleum was underway and the wind was blowing in the direction of the automobile plant, there was a marked increase in corrosion of its metal inventory and the paint of recently produced vehicles. Negotiation between these two parties *did* take place. It was agreed to conduct the corrosive activities only when the wind was blowing in the other direction *toward the large number of nearby inhabitants who, naturally, took no part in negotiation.* See "BP och Volvo, jättarna som kom överens," *Medecinska Füreiningens Tidsskrift* (March, 1969), p. 114. We are grateful to Peter Bohm for this illustration.

[8] See, for example, Turvey's discussion of a large-numbers case in "Optimization in Fishery Regulation," *American Economic Review* LIV (March, 1964), 64–76.

[9] Buchanan, "Cooperation and Conflict in Public-Goods Interaction," *Western Economic Journal,* 116.

a. Disposal of toxic wastes,
b. Sulfur dioxide, particulates, and other contaminants of the atmosphere,
c. Various degradable and nondegradable wastes that pollute the world's waterways,
d. Pesticides, which, through various routes, become imbedded in food products,
e. Deterioration of neighborhoods into slums,
f. Congestion along urban highways,
g. High noise levels in metropolitan areas.

Other important illustrations will occur to the reader, but this list is representative. It should be clear that the number of individuals involved in each of these cases is typically very substantial. In considering the list, we want to stress again that negotiation is usually precluded by the presence of a large number of individuals *either* on the side that generates the externalities *or* on the side that suffers from them. That is, if pollution is emitted only by a small number of sources but affects a great many individuals, the small-numbers analysis simply does not apply.

To illustrate the issues raised by the concrete problems in the preceding list, we conclude by offering a few comments on one of them: the pesticides problem. Chemical insecticides have been used by millions of farmers in the United States alone. Certainly, their number is sufficiently large to make negotiation impractical. It may perhaps be surmised that the pesticide used by a farmer only affects persons living in his immediate neighborhood, and that therefore effective negotiations can be conducted by small groups of farmers and their neighbors. Unfortunately, this simply is not true. The mechanism whereby a pesticide is transported beyond its point of origin is fairly well-known. Agricultural runoff carries it into rivers from which it is borne by winds and by ocean currents and spread throughout the globe. When the pesticide is sprayed by airplanes, only a small portion (in one study, only 13 to 38 percent) ends up on the plants or in the local soil; a substantial proportion is transported enormous distances by air currents. That is how it gets into the organs of arctic animals, as the newspapers have reported. One striking observation illustrates the point: "Rain falling on the agriculturally remote Shetland Islands has been found to have about the same level of pesticide concentrations as is found in the San Joaquin River even where that river received drainage directly from irrigated fields."[10] Thus, the number of persons affected by a pesticide spraying (though each one will sustain a negligible amount of

[10] These and other interesting materials on the movements of pesticides can be found in Justin Frost, "Earth, Air, Water," *Environment* XI (July–August, 1969), 14–33.

damage from any one spraying) is likely to be enormous. Moreover, they are likely to be spread over huge distances with the sources of the spray affecting any particular individual difficult, if not impossible, to identify. It would seem clear that the pesticides are hardly promising subjects for control by spontaneous negotiation. It is equally hard to see much of a role for resolution through individual bargaining for any of the other environmental problems on our list.

CHAPTER 3

Externalities: definition, significant types, and optimal-pricing conditions

The externality is in some ways a straightforward concept: yet, in others, it is extraordinarily elusive. We know how to take it into account in our analysis, and we are aware of many of its implications, but, despite a number of illuminating attempts to define the notion,[1] one is left with the feeling that we still have not captured all its ramifications. Perhaps this does not matter greatly. The definitional issue does not seem to have limited seriously our ability to analyze the problem, and so it may not be worth a great deal of effort. Certainly, we do not delude ourselves that this discussion will be the last word on the subject.

consequences

The literature has also offered distinctions among a number of different classes of externalities. Some of these distinctions have been illuminating; others (including one proposed by the authors!) have been the source of some confusion. Consequently, it is useful to explore the different kinds of externalities and their implications for Pareto-optimal pricing. In particular, we shall examine with some care Viner's distinction between technological and pecuniary externalities; although economists have generally accepted Viner's distinction and its implications, propositions that overlook this point still appear periodically and yield misleading conclusions. We will encounter such a case later in this chapter.

We shall also examine the distinction between public-goods and private-goods externalities, which has its source in the seminal work of Bator and Head.[2] Most externalities of relevance for public policy, as we shall see, are of the public-goods variety. There are instances, however, in which externalities of policy significance can possess the property of privateness. As Freeman has shown recently, this distinction, though perhaps of

[1] See, for example, F. M. Bator, "The Anatomy of Market Failure," *Quarterly Journal of Economics* LXXII (August, 1958), 351–79; J. M. Buchanan and W. C. Stubblebine, "Externality," *Economica,* as well as the classic discussion by James E. Meade in his "External Economies and Diseconomies in a Competitive Situation," *Economic Journal* LXII (March, 1952), 54–67; and in his book, *The Theory of Economic Externalities* (Geneva: Institut Universitaire de Hautes Études, 1973), especially Chapters 1 and 2.

[2] Bator, "The Anatomy of Market Failure," *Quarterly Journal of Economics;* and J. G. Head, "Public Goods and Public Policy," *Public Finance* XVII (No. 3, 1962), 197–219.

some interest in itself, does not have any fundamental implications for the pricing of externalities.[3] We shall find that the optimal pricing of externalities, be they of the public-goods or private-goods types, calls for a pricing vector that exhibits a fundamental asymmetry: It requires one level of price for the consumers (victims) of the externality and a different level of price for its producer or source. No normal market price can fulfill this asymmetry requirement, since if the buyer of a product pays p dollars for it, the seller must, by the reciprocal nature of a market transaction, receive p dollars for it. Viewed in this way, it is necessary to qualify the widespread attribution of the misallocations that stem from externalities to the failure to charge a price for the resource or service in question. What is needed is not an ordinary price but a fiscal instrument with the basic asymmetry property possessed, as we shall see, by a Pigouvian tax or subsidy.[4]

The analysis will require us to explore in some depth the treatment of the recipients or "victims" of an externality. Some authors have argued for the compensation of victims for the damages that they absorb; others have contended that in some circumstances victims must be taxed in order to induce optimal behavior.[5] We shall find that neither of these policies is, in general, compatible with economic efficiency. For the basic case, we show that victims should neither be compensated nor taxed if Pareto optimality is the objective. The level of damages itself provides precisely the correct inducement for victims to adopt the efficient levels of "defensive" activities. Any payments to, or taxation of, victims will, in general, lead to inefficient responses by the individuals affected by the externality. Where numbers are large, this proposition is valid except for the instance where the victim is in a position to transfer or "shift" the externality to some other victim. In this special case, the victim must be subject to a tax on any such shifting activities.

In this chapter, we will present and discuss these propositions rather heuristically; we postpone more rigorous derivations to the following chapter where they easily fall out of the analysis of the formal models.

1 Definition: externality

Ultimately, definitions are a matter of taste and convenience. Bator, who makes no attempt to define the externalities concept very formally, never-

[3] A. Myrick Freeman III, "Depletable Externalities and Pigouvian Taxation," *Journal of Environmental Economics and Management* XI (June, 1984), 173–9.

[4] As we shall discuss later in this chapter, under an appropriate (and feasible) definition of property rights, market transactions can provide an alternative to the Pigouvian measures.

[5] For a noted example of the latter position, see R. H. Coase, "The Problem of Social Cost," *Journal of Law and Economics* III (October, 1960), 1–44.

theless proposes to interpret the concept so broadly that it includes most major sources of what he calls "market failure."[6] He even includes in this category cases of increasing returns to scale in which "natural monopoly" may be the most efficient market form and in which marginal-cost pricing does not permit the firm to cover its costs. One can only object that this broad connotation is not what most writers have in mind when they discuss externalities. The analysis of the increasing-returns problem is ultimately quite different from that of the more conventional externalities[7] that constitute the primary threat to the environment and to the quality of life more generally. It therefore seems preferable to hold to a narrower, more conventional interpretation of the term.

Buchanan and Stubblebine do just that, though, as has been suggested elsewhere, the concept they call the "Pareto-relevant externality" corresponds to what is meant in most of the literature when the term *externality* is used without modifiers.[8] Their approach is, in general, unobjectionable as an operational concept. By and large, they define externalities not in terms of what they are but what they do. That is, they assert, in effect, that a (Pareto-relevant) externality is present when, in competitive

[6] Bator, "Anatomy of Market Failure," *Quarterly Journal of Economics.*

[7] For an alternative and illuminating approach to the concept of externalities that also distinguishes them from increasing returns, see K. J. Arrow, "The Organization of Economic Activity: Issues Pertinent to the Choice of Market Versus Nonmarket Allocation," in Congress of the United States, Joint Economic Committee, *The Analysis and Evaluation of Public Expenditures: The PPB System,* 1 (Washington, D.C.: Government Printing Office, 1969), 47–64. Arrow associates externalities with the absence of some markets for the trading of items affecting the welfare of economic agents. Thus, the absence of a market for the right to emit smoke is taken, quite correctly, as a central condition leading to a socially excessive level of smoke emissions.

Increasing returns were, at one point, considered to be an externalities problem in the conventional sense, because *A*'s purchase of such an item may make it cheaper for *B* to obtain. This led to a long and confusing controversy that was only settled when J. Viner, in his "Cost Curves and Supply Curves," *Zeitschrift für Nationalökonomie,* 111 (1931-1), 23–46, showed that what was involved was just a pecuniary externality. For a review of the literature see H. S. Ellis and W. Fellner, "External Economies and Diseconomies," *American Economic Review,* XXXIII (September, 1943), 493–511. Of course, increasing returns do give rise to a number of analytic and policy problems: the unsustainability of competition (if the increasing returns are not produced by external economies), the losses resulting from marginal cost pricing in these circumstances, and the danger of breakdown of the second-order maximum conditions. None of these is, however, an externalities problem in the conventional sense, and each has given rise to a distinct body of literature. For a review of the discussion of increasing returns and monopoly, see Alfred E. Kahn, *The Economics of Regulation* (Wiley: New York, 1970), especially Volume II, Chapter 4. On the literature on marginal cost pricing and decreasing costs, see W. Baumol and D. Bradford, "Optimal Departures from Marginal Cost Pricing," *American Economic Review,* LX (June, 1970), 265–83.

[8] "Externality," *Economica.*

equilibrium, the (marginal) conditions of optimal resource allocation are violated. Perhaps this is all that need be said. However, it is not fully satisfying. One is tempted to look for a definition that starts earlier in the process, one that identifies the economic phenomenon leading to the postulated violation of the optimality conditions. Somehow, one is happier if the violation of these requirements can be *deduced* from the economic conditions that one takes as a definition, rather than just assuming that the violation occurs in some unspecified way.

Let us then attempt to provide an alternative definition of our own.[9]

Condition 1. An externality is present whenever some individual's (say *A*'s) *utility* or *production* relationships include real (that is, nonmonetary) variables, whose values are chosen by others (persons, corporations, governments) without particular attention to the effects on *A*'s welfare.[10]

This definition should not be misunderstood to be a simple equation of externalities with economic interdependence. When I rely on farmers for my food, no externality need be involved, for they do not decide for me how many zucchini I will consume, nor does my consumption enter directly into their utility functions.[11] Note also that the definition rules out cases in which someone *deliberately* does something to affect *A*'s welfare, a requirement Mishan has emphasized.[12] If I purposely maneuver my car to splatter mud on a pedestrian whom I happen to dislike, he is given no choice in the amount of mud he "consumes," but one would not normally regard this as an externality.

It has also been suggested that for a relationship to qualify as an externality it must satisfy a second requirement:

Condition 2. The decision maker, whose activity affects others' utility levels or enters their production functions, does not receive (pay) in

[9] This definition is, of course, very similar in spirit to many others found in the literature. See, for example, E. J. Mishan, "The Postwar Literature on Externalities, An Interpretive Essay," *Journal of Economic Literature,* IX (March, 1971), 2–3.

[10] The reason the definition has been confined to effects operating through utility or production functions will become clear in a later section. We should also append to this definition the condition that the relationship holds in the absence of regulatory pressures for the control of the activity. One might argue that the threat or presence of government intervention can force the polluter to concern himself with the effects of his emissions on those whom he harms, but we would not want to say that his newly awakened concerns disqualify his emissions as an externality.

[11] Of course, my *payment* to him does affect his utility. This already brings in the distinction between pecuniary and technological externalities that will be discussed later in this chapter.

[12] E. J. Mishan, pp. 342–3 of his "The Relationship between Joint Products, Collective Goods and External Effects," *Journal of Political Economy* LXXVII (May/June, 1969), 329–48.

compensation for this activity an amount equal in value to the resulting benefits (or costs) to others.

This second proviso is required if the externality is to have all of the unpleasant consequences, including inefficiencies and resource misallocation, that are associated with the concept. It has long been recognized that, at least in some cases, proper pricing or tax-subsidy arrangements will eliminate the misallocations, though, as we will see later in this chapter, matters here are not as simple as has sometimes been supposed.[13]

Nevertheless, as was suggested to us by Professor Dorfman, one may prefer to define an externality to be present whenever condition 1 holds, whether or not such payments occur. If optimal taxes are levied, smoke generation by factories will no doubt be reduced, but it will not be reduced to zero. In that case, it seems more natural to say that the externality has been reduced to an appropriate level, rather than asserting that it has been eliminated altogether. Perhaps more important, the use of condition 1 alone as our definition has the advantage that, instead of postulating in advance the pricing arrangements that yield efficiency and Pareto optimality,[14] we can *deduce* from it what prices and taxes are compatible with these goals and which are not. These calculations will, as a matter of fact, be carried out in this and the following chapters. At any rate, we will say that an externality is present if the activity satisfies condition 1.

2 Public versus private externalities

In his classic paper, "The Anatomy of Market Failure," Bator pointed out that many externalities partake of the character of public goods. If the air in a city is polluted, it deteriorates simultaneously for every resident of the area, not just for any one individual. An increase in the number of people in the area will not reduce the level of atmospheric pollution. Air pollution, then, is clearly a public "bad." Similarly, landscaping of a garden that can be seen by all those passing by is a public good; it

share / contribute

[13] Thus, condition 1 may be taken to correspond roughly to what Buchanan and Stubblebine, in "Externality," *Economica,* have called *an externality* and conditions 1 and 2 together constitute what they call "a Pareto-relevant externality" (that is, an externality that prevents the necessary conditions for Pareto optimality from being satisfied). On the role of condition 2 in previous discussions of the definition of *externality,* see Mishan, "Relationship between Joint Products, Collective Goods and External Effects," *Journal of Political Economy,* p. 342.

[14] In this volume, we will define a vector of outputs to be *efficient* if it involves the largest *output* of some arbitrarily chosen good that can be attained without reducing the output of any other good. A vector of output values, *and its distribution among consumers,* is as usual, defined to be *Pareto-optimal* if it yields the largest value of some one consumer's *utility* that can be obtained without a reduction in the utility of any other consumer.

yields an externality which (at least up to some number of beneficiaries sufficiently large to cause congestion) confers benefits on all viewers of the garden. It is now commonplace that where a public good (or bad) is involved, the ordinary price system is unable to provide an efficient outcome. The basic source of the problem is (as we called it in the first edition of this book) the "undepletable" nature of public goods: the fact that an increase in the consumption of the good by one individual does not reduce its availability to others.[15] My breathing of polluted city air, for example, does not alter the quality of air inhaled by others. Likewise, my viewing of a local garden does not (if there is no congestion) detract from the pleasure to other onlookers.

As is well known, it is inefficient to charge for the consumption of such public goods, because the consumption of the good by one individual does not influence the level of satisfaction of anyone else. A positive price may inhibit an individual's consumption, thereby reducing his or her satisfaction without increasing that of other persons.[16]

[15] In his classic discussion of public goods, Head ("Public Goods and Public Policy," *Public Finance*) lists *two* attributes of such goods: "jointness of supply" and the inability to exclude potential consumers. Here, we concern ourselves with the first of these attributes, jointness of supply, for which we use the term "undepletability." An undepletable externality is thus one for which consumption by one individual does not reduce the consumption of anyone else. As Head shows, the two properties of public goods need not accompany one another (although they may). Exclusion may be possible even though the good is undepletable (e.g., a fence with a gate may exclude potential viewers of a garden). Similarly, depletion does not imply exclusion. The standard case here is one in which several petroleum suppliers have wells that draw on the same oil field; no supplier is excluded from the field, yet every barrel of oil removed by one supplier is no longer available to the others. We prefer to use the adjective "undepletable" rather than "public" because it focuses attention on the attribute that is pertinent here.

[16] This result, however, assumes the absence of a budget-balancing condition for the financing of the public goods. As Baumol and Ordover show, where a public good has to be financed by taxation (and where the amount in question is sufficiently large to distort decisions and cannot be raised by lump-sum measures), optimality requires *all* prices, P_i, in the economy to depart from marginal cost, MC_i, in accord with the well-known Ramsey formula, $P_i - MC_i = k(MR_i - MC_i)$, where MR_i is the marginal revenue of good i, and k is a constant that is identical for all goods, individuals, and firms in the economy. Thus, every commodity in the economy, and not just public goods, would have to experience a divergence between price and marginal cost, all thereby contributing to the financing of our public good j. However, since additional consumption of j adds nothing to social cost by its undepletability property, for that good the Ramsey rule simplifies to $P_j = k(MR_j)$. We note also that where the economy's production function is characterized by locally constant returns to scale at the equilibrium point, $k = 0$ so that the standard public good price $P_j = 0$ is then also the Ramsey price. See W. J. Baumol and J. A. Ordover, "On the Optimality of Public Goods Pricing with Exclusion Devices," *Kyklos* XXX (Fasc. 1, 1977), 5–21. All this is related to the issues raised by Common, to which we shall return in Chapter 4.

It is easy to think of many examples of environmental externalities that exhibit the property of undepletability: polluted air and water, noise, neighborhood slums, etc. We refer the reader to the list of externalities problems at the end of Chapter 2.

We turn now to the private (or as we will call it) the "depletable" case. For reasons that will soon become apparent, it is not so easy to provide a convincing example of a depletable externality. To get a clear illustration that may also begin to suggest the nature of the difficulty, we go back into economic history. Following World War II, there was a severe shortage of fuel, and it was reported that in several areas in Europe many people spent a good part of their time walking along railroad tracks looking for coal that had been dropped by passing trains. It is clear that this is a depletable externality, because for every additional bit of coal found by one gatherer, that much less was available to others.

The reason that the coal was left along the tracks was undoubtedly that the railroad companies did not find it profitable to gather the loose coal and then sell it. In principle, if there were enough money to be made, the railroad might even have hired the self-employed gatherers and put them to work collecting the coal for sale. We know very well that business firms are prepared to spend significant amounts on the accumulation of bits of material when they are precious enough (for example, in the working of gold and platinum). In such cases, then, either the externality must be insignificant or the cost of collecting an appropriate fee must be very high. Otherwise, private enterprise will find it profitable to take the measures necessary to eliminate the externality. Thus, it is hardly an accident that Bator found few depletable externalities that constitute important policy issues.

To take another example, consider the case of trash disposal by individual *A*. If *A* dumps trash on *B*'s (unguarded) property, then this trash is not available to be deposited on *C*'s land. In this instance, we have an external *bad*. But note that the externality is, in this case, divisible among the victims: Whatever trash is dumped on one victim's property cannot become a source of disutility for someone else. (Trash dumped on streets or in other public areas is obviously another matter.) Unlike the case of polluted air, our trash example involves a depletable externality in that it is divisible among the victims (i.e., one victim's consumption of the externality reduces that of others). The important allocative issue here is for the trash to be disposed of in the least costly way to society.

In summary, externalities can take either of two forms: a public (undepletable) form or a private (depletable) form. The issue of primary interest is how to adapt the set of incentives facing the parties to an externality so as to induce socially optimal behavior. We turn next to this important

matter. We will find in this regard that the basic policy prescription is the same for the undepletable and depletable cases. However, as we will discuss in a later section, there is a subclass of depletable externalities for which some supplementary measures may be needed.

3 Pareto-optimal pricing of externalities

In the first edition of this book, we contended that the distinction between depletable and undepletable externalities was of fundamental importance, because the appropriate policy measure for correcting the resulting allocative distortion differed in the two cases. However, as Freeman showed subsequently ("Depletable Externalities and Pigouvian Taxation"), this is not correct. Aside from the special case to be discussed later, the basic policy prescription is the same for both the depletable and undepletable cases. It is instructive, we believe, to explore this matter in more detail.

Let us consider first the undepletable case, which is, from all evidence, the more important one for environmental policy. We return, for purposes of illustration, to the familiar case of the smoky factory that pollutes the atmosphere over an entire area. All residents of the area suffer from the pollution; moreover, one individual's consumption of smoky air does not reduce that of any other. The allocative problem here involves two decisions: the adoption of the efficient level of smoke emissions by the factory, and the choice of the efficient level of "defensive" activities by the victims. The first of these decisions is self-explanatory: the factory owners must select the proper level of abatement measures to reduce emissions to their efficient levels. The response of victims is a bit more subtle. Victims may have available to them a range of activities through which they can protect themselves from the detrimental effects of the externality. In our case of the smoky factory, for example, nearby residents may invest in air-cleansing devices, or, alternatively, may choose to move to a new location more distant from the factory. Such responses we shall call "defensive activities." Note that such defensive activities have no effects on the consumption of smoke by any other victims; they are *purely private* in nature. (This is important, as we shall see shortly.)

Our problem is thus to find a set of conditions that characterize behavior consistent with a social optimum on the part of factory owners and victims and to determine a set of incentives that will induce profit-maximizing firms and utility-maximizing individuals to satisfy these conditions. We will undertake this exercise formally in the next chapter. The formal analysis confirms that in a competitive setting the solution to our problem requires only a single policy measure: a Pigouvian tax (or effluent fee) on emitters equal to marginal social damage. More precisely, the environmental authority should levy a fee per unit of smoke emissions equal to the marginal damages accruing to all victims (residents and other firms).

As is generally recognized, the Pigouvian tax serves to internalize the external costs that the emitting factory imposes on others. Consequently, the factory owners will take into consideration not only their usual costs of production but also the other forms of social cost that their activities entail. In contrast, there is no need for any supplementary incentives for victims. As we shall demonstrate in Chapter 4, the damages that victims suffer from the detrimental externality provide precisely the correct incentives to induce them to undertake the efficient levels of defensive activities.

Let us next consider the case of a depletable externality. Instead of smoke, suppose that the local factory emits a depletable waste (like trash). There are two subcases of interest here. First, assume that the factory has no control over where the wastes are deposited. For technical reasons (e.g., geography or weather), the wastes always end up in a particular place irrespective of any disposal actions by the factory. The victim in this case is the individual who occupies the disposal site. A little reflection suggests that this case is, in principle, little different in its essentials from the public or undepletable case. The only difference is that we have but one victim. Hence, the marginal social damages are equal to the marginal damages to that individual alone. But the policy prescription remains the same as that in the undepletable case: a Pigouvian tax on the source of the externality and no supplementary incentives for the victim.[17]

Suppose, however, that the factory owners have some choice as to where they dump their wastes. An important aspect of the allocative problem now becomes the choice of the most efficient disposal site. For this case, the factory owners must face a schedule of fees that reflects the varying damages associated with the dumping of the trash at alternative sites. Confronted by such a schedule of fees, a profit-maximizing firm can be counted on to choose the site that minimizes the damages. So, once again, we find that a Pigouvian charge equal to marginal social damage leads

[17] In the previous edition of this book, we claimed, mistakenly, that the depletable case has fundamentally different implications for optimal pricing than does the undepletable case. As we indicated earlier, our error was first discovered and corrected by Freeman, to whom we are grateful. The effects of the depletable externality discussed in the text need not, of course, be limited to a single victim. In our trash example, the disposal operation can result in a division of the trash among several sites with a consequent multiplicity of victims. Since the externality is depletable, it would remain true by definition that whatever trash is deposited on one site cannot be deposited elsewhere. In this instance, the generator of the externality should pay a Pigouvian unit tax equal to the sum of the marginal damages over the various sites.

to an efficient result. Moreover, as before, victims, responding solely to the damages, can be expected to select the efficient levels of defensive activities.

In sum, irrespective of whether the externality is of the depletable or undepletable variety, the proper corrective device is a Pigouvian tax equal to marginal social damage levied on the generator of the externality with no supplementary incentives for victims. The latter part of this prescription needs some further discussion, to which we turn next.

4 Should the victims of externalities be taxed or compensated?

The efficient treatment of victims of externalities has been the source of varied prescriptions and considerable confusion in the literature. Some have argued that victims should be compensated for the damages they suffer, and others (like Coase) have argued that in some circumstances, victims should be taxed. As we indicated in the preceding section and will show formally in the next chapter, *so long as the number of victims is large,* the efficient treatment of victims prohibits compensation – whether the externality is of the depletable or undepletable variety. Moreover, taxation of victims is equally inappropriate (except for a special case whose rationale is somewhat different from that proposed by Coase).[18]

The discussion in the preceding section indicates that the victim of a detrimental externality should face a zero charge: The victim should neither be taxed nor compensated for the damages absorbed. Thus, in our case of the smoky factory, the discussion suggests that residents in the neighborhood of the factory should not receive compensation for smoke damages from the owners of the factory. What sort of allocative distortion would result were such compensation to be paid to nearby residents? Professor Coase has provided the basis on which this question can be answered. In this case, the socially optimal solution is likely to involve some degree of spatial separation between the factory and local residences. But if all the neighbors of factories were paid amounts sufficient to compensate them fully for all damages, including increased laundry bills, injuries to health, aesthetic insults, etc., obviously no one would have any motivation to locate away from the factory. Too many people would choose to live in smoky conditions, for they would, in effect, have been offered an economic incentive to accept the ill effects of the smoke

[18] This, of course, is not to deny that it is desirable to pass on to someone the real resources corresponding to the taxes collected from the generators of externalities. However, in the absence of any lump-sum subsidy mechanism, this should, in principle, be done through Ramsey reductions in all prices as described in note 16 – not through compensation to the victims of the externality based on the amount of damage they sustain.

with no offsetting benefits to anyone. The resulting inefficiency should be clear enough.

The point here is that victims typically have available to them a variety of responses to reduce the damages they suffer. For example, a victim can install insulation to reduce the amount of noise experienced from a nearby construction activity, or, as mentioned earlier, move farther away from the smoky factory. And, as we have just seen, compensation of victims is not economically efficient because it weakens or destroys entirely the incentive to engage in the appropriate levels of such defensive activities. As Olson and Zeckhauser have put it, "...the commonplace suggestion that those who generate external diseconomies ought to have to compensate their victims for any losses they suffer, can work against Pareto optimality. When such a suggestion is adopted, those injured by the diseconomy have no incentive to protect themselves from it, even if this should be more economical than requiring adjustment on the part of those who generate the diseconomy."[19]

In addition to the moral hazard problem, compensation of victims leads to other economic inefficiencies. As we shall see in the next chapter, it tends to produce excessive entry into the "victim activity" - too many laundries will open for business in the vicinity of the smoky electricity plant. Moreover, since compensation is a form of subsidy payment to the victim, it will serve to reduce the price of the victim's product and lead to socially excessive levels of its consumption. Because purchasers of laundry services do not pay the full marginal social cost of these services (since the laundry is compensated for the costs attributable to pollution), a socially excessive amount of laundry activity will be elicited by consumer demand.

Coase, however, has pushed this point harder. He argues that not only should we avoid compensation of victims, but we should tax them for the

[19] M. Olson, Jr. and R. Zeckhauser, "The Efficient Production of External Economies," *American Economic Review* LX (June, 1970), 512–17. The allocative problems that can be produced by full compensation are well known in other contexts. Full payment by an insurance company for all losses from theft removes any incentive for precautions against robbery; it makes for an inadequate allocation of resources to burglary prevention devices. Or to bring the matter out more sharply with the aid of a rather grizzly example, suppose workers, *on the average,* were known to feel fully compensated for the loss of a finger by the payment of one million dollars. Imagine the horror that might result if industrial insurance were to offer this compensation to anyone suffering from such a loss! In each of these cases, the *absence* of full coverage is essential for the prevention of what may conservatively be described as great economic waste.

Of course, it may nevertheless be decided to undertake some compensation of victims on grounds of fairness. But then there must be a trade-off between fairness and efficiency. On this, see W. J. Baumol, *Superfairness: Applications and Theory* (Cambridge, Mass.: M.I.T. Press, 1986), Chapter 5.

costs that their decisions impose on the factory owners. Coase's contention is that when residents select a home in the vicinity of the factory, they impose an "external" cost on the generator of the externality, the owners of the factory. This cost takes the form of a higher Pigouvian fee to the owners reflecting the increase in damages from the factory's smoke emissions associated with the rise in the number of victims. This argument, however, is incorrect (for the case where the number of victims is large - the case that is *not* the subject of Coase's analysis). As we shall see later, the increase in the effluent fee to the firm is not a true externality in the sense that we have defined the term. To provide the proper incentives to victims for defensive activities, neither compensation nor a tax is appropriate.

5 A qualification: the special case of shiftable externalities

As we have seen, the general Pigouvian prescription entails no supplementary incentives, either compensation or taxation, for victims of detrimental externalities. However, as Bird has pointed out recently, there exists a special set of circumstances in which it may be necessary to subject victims to taxation.[20] We will treat this special case as a qualification to the general rule for the treatment of victims, but, as will become clear, this case really does not constitute an exception to the Pigouvian results. Rather, it entails an extension of the Pigouvian measure to encompass external effects associated with responses by victims. It is clearly Pigouvian in spirit.

This case involves what we shall call a "shiftable externality." In such instances, the victim has the opportunity to "shift" the externality to a third party.[21] Returning to our trash example, the victim may respond to the dumping of the rubbish on his or her own property by removal and dumping of the wastes onto someone else's land. In short, the victim avoids the detrimental effects of the externality by shifting it to another party. For such cases, we obviously need some sort of incentive

[20] Peter J. W. N. Bird, "The Transferability and Depletability of Externalities," *Journal of Environmental Economics and Management* XIV (March, 1987), 54–57.

[21] We choose the term *shiftable* here because of the close analogy with its use in the field of taxation. In particular, a tax is said to be shifted when the entity on which the tax is levied is able to alter its behavior in such a way as to place the burden of the tax on others. Similarly, we will call an externality shiftable if the recipient has the ability (as in our trash example) to push the externality along to other parties. We note that shiftable externalities are a subclass of depletable externalities. If the externality is undepletable, it must by definition be unshiftable, since one person's consumption of the externality leaves others unaffected. The property of depletability is a necessary, but not a sufficient, condition for an externality to be shiftable.

to induce efficient behavior by victims as well as by the generator of the externality.

The required incentive in this instance takes the form of a tax on the victim applicable to any shifting activities. More precisely, victims must be subject to a unit tax equal to the marginal social damage accruing to the parties to whom the victim shifts the externality. In our trash example, the initial victim should face a schedule of Pigouvian taxes equal to the marginal social damages corresponding to the various shifting alternatives available to him. It is easy to see why this leads to an efficient outcome. The socially optimal result involves the depositing of the wastes where they do the least net damage (net of shifting costs). Suppose that an initial victim finds that the tax he must pay to place the trash elsewhere exceeds the value of the damages he absorbs if he simply serves as the trash receptor. In this case, he will choose not to shift the externality, and this is obviously the optimal social outcome, since it is clear that the damage to the initial victim is less than that to any alternative victim. In contrast, if the initial victim finds an alternative victim that is willing to absorb the wastes for less than the former is willing to pay, then shifting will occur and will obviously be socially efficient.

In sum, in the special case of a shiftable externality, victims must themselves be subject to a tax equal to the marginal social damages caused by their shifting activities. As should be clear, such a tax is Pigouvian in spirit – it represents an extension of the Pigouvian prescription to encompass any externality-generating activities which are undertaken by victims in the course of protecting themselves from other externalities. The basic principle remains unmodified – all generators of externalities, whatever other roles they may play, must be charged for the (marginal) damage that they impose on others. But in the role of victim *per se*, efficiency requires that no one either be taxed or compensated. Only if one person happens to be both victim and generator of externalities simultaneously should he be subject to a tax, but only for assuming the latter role.

6 Externalities and property rights

The source of an externality is typically to be found in the absence of fully defined property rights.[22] And this implies that in some instances

[22] There is now a large literature on the relationship between externalities and property rights. The seminal piece is the Coase paper that we have so often cited. Among the paper's many insights is the now famous "theorem" that where there is costless bargaining between the generator and the victim of an externality, the optimal outcome will emerge so long as *either* party holds the pertinent property right – it does not matter which one. For other important contributions, see Harold Demsetz, "The Exchange and

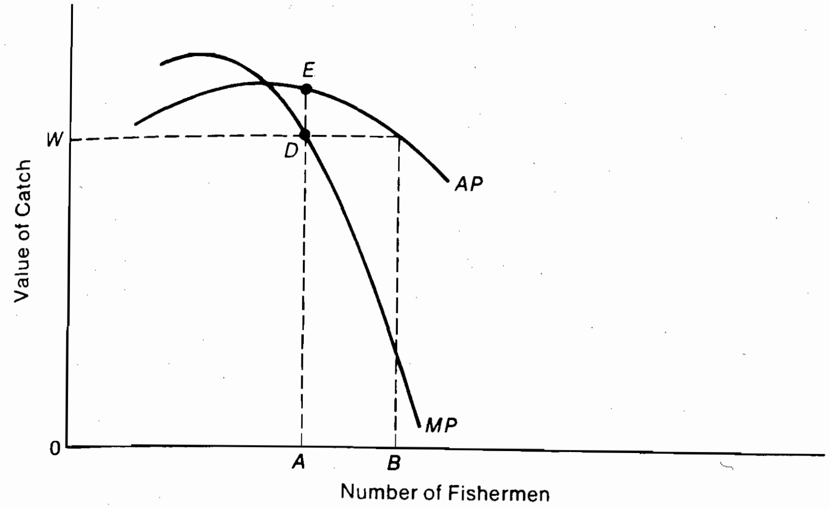


Figure 3.1

the distortions resulting from an externality can be eliminated through an appropriate redefinition of such rights of ownership. Once again, the general point is best made clear through an example. Consider a lake to which all fishermen have free access. The haul of one fisherman reduces the expected catch of the others, so a detrimental externality is present. The result of individual maximizing behavior in this setting will be an excessive level of fishing activity. This is easily seen with the aid of Figure 3.1. If W in the figure represents the wage (and marginal product) in alternative employments, the number of fishermen in equilibrium will be OB, where the average product (in money terms) of a fisherman equals the wage that he can obtain elsewhere. This is obviously too large a number of fishermen, because an individual's fishing activity imposes costs on others and thereby generates a marginal social yield lower than the value of marginal product in other activities. Following the discussion in the preceding sections, one can correct this distortion by introducing an appropriate charge for admission to the lake, a charge that effectively internalizes the external costs that a fisherman imposes on his compatriots. In Figure 3.1, such a charge is equal to DE; this effectively reduces the

Enforcement of Property Rights," *Journal of Law and Economics* VII (October, 1964), 11–26; and J. H. Dales, *Pollution, Property, and Prices* (Toronto: University of Toronto Press, 1968).

net return to the marginal fisherman to equality with his marginal social product and leads to a reduction in the number of fishermen to the efficient level, *OA*.

There is, however, another approach to the correction of the distortion associated with this free-access equilibrium. Suppose that, instead of introducing an entry fee, the lake were transferred from public to private ownership, perhaps through some sort of auction. Suppose, moreover, that the new owner seeks to maximize profits from fishing activities on the newly acquired lake. He thus hires fishermen to whom he pays a wage of *W* and from whom he receives the catch in return. Note that the profit-maximizing solution implies that the lake owner will hire *OA* fishermen; he will take on fishermen to the point at which the value of the marginal product equals the wage, *W*, that he must pay. Thus, the private-ownership outcome will be socially efficient.[23]

A redefinition of property rights may thus in some instances represent an alternative means (and sometimes even a preferable one) for dealing with an externality. By establishing ownership rights where none existed before, we may effectively eliminate the externality. However, this is not always easy to do. Establishing rights in "clean air," for example, is not a simple matter. There may, moreover, be other reasons for desiring free access to certain socially held resources. But, as we shall see in later chapters, there may be ways of establishing certain kinds of rights that can facilitate the regulation of various sorts of pollution. For now, we simply want to make clear the significant connection between externalities and property rights and the policy alternative that this relationship suggests.

[23] The inefficiencies associated with the free-access equilibrium have long been recognized. The issue is nicely described in a book that appeared early in the nineteenth century:

> Suppose that the earth yielded spontaneously all that is now produced by cultivation; still without the institution of property it could not be enjoyed; the fruit would be gathered before it was ripe, animals killed before they came to maturity; for who would protect what was not his own; or who would economize when all the stores of nature were open to him?...
>
> In this country, for instance, where the only common property consists in hedge-nuts and blackberries, how seldom are they allowed to ripen...

From Mrs. J. H. Marcet, *Conversations in Political Economy,* 3rd ed. (London, 1819), 60–1. This book, written by a friend of David Ricardo, was one of the first textbooks in economics. It takes the form of a dialogue between a Mrs. B and her young friend, Caroline, who quickly succumbs to her mentor's economic arguments. A more recent nontechnical and influential treatment of this issue is Garrett Hardin's "The Tragedy of the Commons," *Science* 162 (December 13, 1968), 1243–48. For a more rigorous analysis, see, for example, H. Scott Gordon, "The Economic Theory of a Common-Property Resource: The Fishery," *Journal of Political Economy* VXII (April, 1954), 124–42.

7 Summary: pricing and external effects

It has often been said that externalities introduce distortions in resource use because they are cases in which society fails to charge a price (positive or negative) for a good (or a bad). We see now that the issue is somewhat more complex. The real problem is that no normal price can do the job. The trouble in this case is that economic efficiency requires a pricing asymmetry: a nonzero price to the "supplier" of the externality (positive price for an external benefit and a negative price or tax for a detrimental externality), and a zero price for the consumption of the externality. However, an ordinary price is, by its nature, symmetrical between supplier and consumer; it cannot assume the asymmetrical form required to induce efficient behavior. But a Pigouvian tax (subsidy) can. The tax or subsidy provides the proper incentive for the supplier of the externality while leaving its consumer with a zero price, as efficiency dictates.

8 Technological and pecuniary externalities

In a paper that is now one of the classics of economic literature, Jacob Viner showed that not all relationships that appear to involve externalities will produce resource misallocation.[24] There is a category of pseudo-externalities, the *pecuniary externalities,* in which one individual's activity level affects the financial circumstances of another, but which need not produce a misallocation of resources in a world of pure competition. Viner brought the distinction to our attention to clear up an error in Pigou. The nature of the error is now largely a matter of doctrinal history and does not particularly concern us here. However (despite some recent assertions to the contrary), the distinction remains of great relevance for current discussions of externalities.

Pecuniary externalities result from a change in the prices of some inputs or outputs in the economy. An increase in the number of shoes demanded raises the price of leather and hence affects the welfare of the purchasers of handbags. But unlike a true externality (Viner called it a *technological externality*), it does not generate a *shift* in the handbag production function.

It should be emphasized that, whether an externality is pecuniary or technological, the ultimate comparative static effects are likely to involve changes both in prices *and* in the values of the relevant real variables. In the case of technological externalities (for example, the increased real

[24] Viner, "Cost Curves and Supply Curves," *Zeitschrift für Nationalökonomie.*

resource cost of laundry output resulting from an enlarged volume of smoke), prices will almost certainly be affected (laundry prices will rise) and even input prices may well be altered as their usage is changed. Similarly, in the pecuniary case, say in the case of a rise in the price of leather produced by an increased demand for shoes, the handbag manufacturers may well modify their manufacturing processes by, for example, the substitution of labor for leather through more careful cutting of the raw materials.

The essence of the distinction then is *not* that a pecuniary externality affects only the values of monetary, rather than real, variables. The point is that the introduction of a technological externality produces a *shift* in the functions relating quantities of resources as independent variables and output quantities or utility levels of consumers as dependent variables. Consequently, it means – comparing two otherwise identical states in which there is a technological externality in one, but not in the other – that a given vector of real inputs allocated identically in both cases will *not* leave all members of the economy indifferent between the two states. In contrast, the introduction of a pecuniary externality permits all members of the economy to remain at their initial utility levels *if all inputs are used as before* and if there is an appropriate redistribution of income to compensate for the income effects of the price changes that are the instrument of that externality.

The smoke that increases the soap and labor costs of the laundry means that, if one were to employ the same quantities of inputs as would be used in the absence of the externality, either fewer clothes must be laundered or the clothes cannot come out as clean. But with the enhanced demand for shoes, it need take no more leather than before to produce a handbag. The higher price of handbags represents, in effect, only a transfer of income from purchasers of handbags or from handbag manufacturers to the suppliers of leather, or perhaps, in the long-run competitive equilibrium, from handbag purchasers to the owners of land for cattle grazing. But the initial collection of inputs will still be capable of producing the initial bundle of outputs and, hence, of leaving everyone as well off as he would have been in the absence of the increased demand for shoes.

This immediately indicates why pecuniary externalities need produce no resource misallocation under conditions of pure competition. For they do not constitute any change in the real efficiency of the productive process viewed as a means to transform inputs into utility levels of the members of the economy. Indeed, the price effects that constitute the pecuniary externalities are merely the normal competitive mechanism for the reallocation of resources in response to changes in demands or factor supplies.

Viewed another way, our increased demand for shoes, for example, may well induce a rise in the production (and in the relative cost) of shoes compared to pencils. However, this takes the form of a movement along the production-possibility frontier; it does not shift the frontier itself, as would a change in the output of smoke by our illustrative factory, that is, it causes no divergence between the slope (social marginal rate of transformation) and the private *MRT* at any point on this frontier. Similarly, because a pecuniary externality enters no utility function, it will produce no divergence between any social and private *MRS*.

This suggests the irrelevance of pecuniary externalities for the optimality of the market equilibrium of the competitive system. Equilibrium conditions for the competitive system consist (where the relevant functions are twice differentiable) of a set of equalities and inequalities involving only *private* marginal rates of substitution and transformation (that is, those of the decision maker to whose decision variables the marginal rates apply). Optimality of resource allocation, however, requires the satisfaction of precisely the same equalities and inequalities but this time involving the *social* marginal rates of substitution and transformation. Because pecuniary externalities produce no divergences between private and social marginal rates of substitution and transformation, they do not create any differences between the optimality conditions and those characterizing a competitive equilibrium. Consequently, despite the presence of pecuniary externalities, the competitive equilibrium will produce an optimal allocation of resources, provided, of course, that all of the other necessary conditions (existence, the appropriate convexity-concavity requirements, and so on) are fulfilled.

9 Variations in Pigouvian taxes as pecuniary externalities

The analysis of the preceding section can shed some light on the optimality of the Pigouvian tax measures. It has been argued recently that the imposition of such a tax can itself introduce a set of externalities, for those who are protected by the tax can, by their own decisions, affect the magnitude of the payment. If a household moves near a smoke-generating factory or undertakes to do more laundry in its vicinity, the social damage caused by the smoke will be increased and this, in turn, will lead to an increase in the tax rate that will harm the factory owner; this rise in tax rate constitutes an externality caused by the decision of the household just as surely as the smoke produced by the factory. In the words of Professor Coase,

> An increase in the number of people living or of business operating in the vicinity of the smoke-emitting factory will increase the amount of harm produced

by a given emission of smoke. The tax that would be imposed would therefore increase with an increase in the number of those in the vicinity. This will tend to lead to a decrease in the value of production of the factors employed by the factory, either because a reduction in production due to the tax will result in factors being used elsewhere in ways which are less valuable, or because factors will be diverted to produce means for reducing the amount of smoke emitted. But people deciding to establish themselves in the vicinity of the factory will not take into account this fall in the value of production which results from their presence. This failure to take into account costs imposed on others is comparable to the action of a factory-owner in not taking into account the harm resulting from his emission of smoke.[25]

This rising tax relationship that Professor Coase described is equivalent, analytically, to a *pecuniary,* not a *technological,* externality. In the case where the number of victims is large (the case with which Coase was *not* dealing), it will produce no misallocation of resources. Again, this is not difficult to show. The generation of smoke increases the real resource cost of laundry production and perhaps influences the marginal utility of various types of consumption as well. However, the increase in the tax has no such effects. It merely changes the marginal *pecuniary* return to the activities of the factory. An increase in laundry activity that increases the tax rate is precisely analogous to an increase in shoe production that increases the cost of leather to handbag manufacturers. In each case, a resource (in one case, leather, in the other, clean air) has become more valuable and the price of the resource has increased commensurately, as proper resource allocation requires.

It is true that the rise in tax rates has some real effects and not just pecuniary consequences: it leads "...to a decrease in the value of production of the factors employed by the factory," but exactly the same is true in the handbag example. People formerly employed in handbag production may, because of higher leather prices, find themselves "being used elsewhere in ways which are [or, rather, formerly were] less valuable." But this is, of course, a common property of pecuniary externalities, one that has already been emphasized. Price changes do have real effects on the equilibrium values of various economic variables but need not result in resource misallocation.

10 A note on the small-numbers case

As we stressed in Chapter 2, our emphasis in this volume is on the large-numbers case, which we consider the more important case for purposes

[25] R. H. Coase, "Problem of Social Cost," *Journal of Law and Economics,* Section IX, p. 42.

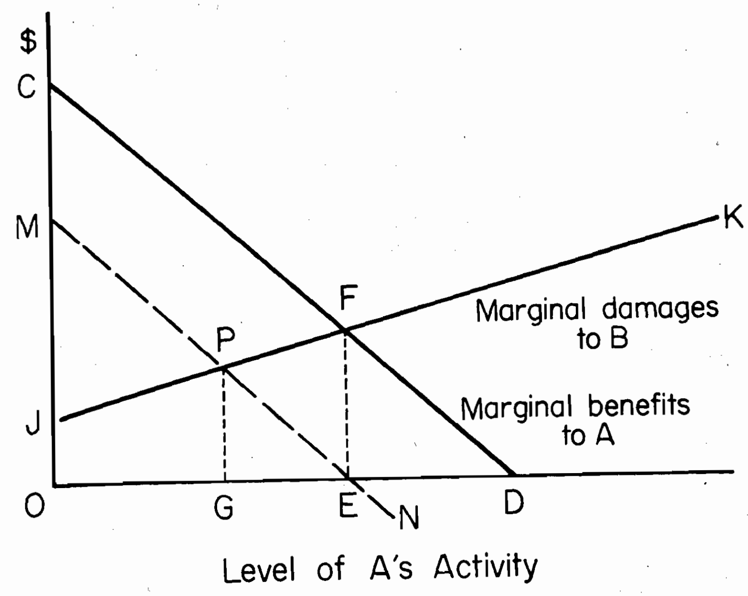


Figure 3.2

of environmental policy. However, there are a few points that are worth noting here. Coase has shown that where voluntary bargains that exhaust the potential gains from trade are struck among the parties to an externality, an efficient outcome will be reached.[26] The setting for such bargaining requires, in general, a small number of participants on both sides of the activity: one or few generators and one or few victims. In such a setting, Coasian behavior may indeed eliminate any distortions in resource use. Obviously, there would be no need for a Pigouvian tax or subsidy under such circumstances. In fact, as Coase argued and Turvey later emphasized, a Pigouvian tax in the Coase setting will itself become a source of misallocation of resources. This is easily seen in terms of an adaptation of a useful diagram introduced by Turvey.[27]

In Figure 3.2, the horizontal axis depicts the level of some activity by individual A that has associated with it external damages to some other party, B. The curve CD indicates the marginal benefits to A from this activity, and the curve JK reflects the marginal damages that B absorbs

[26] R. H. Coase, "The Problem of Social Cost," *Journal of Law and Economics.*

[27] Ralph Turvey, "On Divergences between Social Cost and Private Cost," *Economica* XXX (August, 1963), 309–13.

as an external cost of A's doings. In the absence of any extraordinary incentives, utility-maximizing behavior by A will lead to a level of the activity, OD, at which point marginal benefits become zero. Marginal benefits to society, however, become zero at OE, the point at which the marginal benefits to A are precisely offset by the marginal damages to B. Hence, OE is the Pareto-optimal outcome. Note that in a Coasian world of bargaining, individual B would be prepared to pay A to cut back on the activity to OE. For any unit of the activity to the right of OE, the marginal damages to B exceed the marginal gains to A; there are thus potential gains from trade to be realized. The Coasian equilibrium is OE, the socially correct outcome.

Suppose, however, that a public agency, behaving like a good Pigouvian, levies a tax on A equal to marginal social damage at the efficient level of output OE. The tax would be a levy of EF per unit of the activity. The effec of this tax would be to shift A's marginal benefit curve down to the dashed line MN; MN depicts the marginal gains to A net of the tax. In the absence of any bargaining, this would clearly lead A to the socially efficient outcome OE. But suppose that Coasian bargaining takes place in the presence of the tax. Realization of the gains from trade will now lead the parties to point P and the associated level of activity OG. A's activity will now be below the efficient level. We thus find that in a Coasian world, Pigouvian taxes are not just superfluous; they themselves become the source of distortions in resource allocation.

The small-numbers case can undermine the optimality of the Pigouvian solution in yet another way. A tax (positive or negative) upon generators of an externality always invites strategic behavior by victims that is deliberately designed to change the magnitude of the tax in a way that benefits the victims at the expense of society. Victims of detrimental externalities will aim for further (and socially excessive) restriction of the quantity of externality generated, whereas those who enjoy the consequences of beneficial externalities will seek to elicit socially excessive externality outputs. An example will make the mechanism clear. Imagine a laundry with two plants: plant A located near a smoky electricity-generating station, and plant B, located farther away. Suppose also that plant B is free of smoke damage but that its operation incurs heavy transport cost. Then the laundry firm may find it profitable to assign more of its operation to plant A than it would have otherwise, because the greater the level of activity at plant A, the larger the marginal damage of a puff of smoke and, hence, the larger the tax upon the electricity generator will be. The net effect will then clearly be an inappropriately low level of electricity output from the viewpoint of social welfare. The laundry will benefit by reduced transport costs and reduced pollution damage at plant A through

socially excessive use of that plant. Of course, none of this can happen if every victim is too small to be able to affect significantly the magnitude of the tax upon the polluter.

This discussion also helps to explain why Coase suggests that a tax on victims may be necessary for optimality, along with the Pigouvian tax on the generator of the externality. For if the victim's strategy involves deliberate and excessive self-subjection to damage from the externality in order to raise the tax on the generator, then a tax on the victim will be needed to discourage such antisocial strategic behavior. Thus, in the small-numbers case where there are incentives for strategic behavior, a tax on victims that accompanies a Pigouvian tax on generators may, indeed, make sense, at least in theory.

Perhaps more to the point, where both the number of generators and victims are small, the Pigouvian tax approach may well be impractical (imagine a tax rule devised for just a handful of people!). For such a case the Coasian property-rights approach may well be the most sensible way to control the externality.

The moral of the story is clear. In a small-numbers setting where Coasian bargains are likely, we should be wary of the introduction of Pigouvian measures. At the same time, we must reiterate our contention in Chapter 2 that the most widespread and serious of our environmental problems involve the large-number case for which Coasian sorts of negotiations are not to be expected. Moreover, even in the small-numbers case, there may be serious impediments to efficient bargains in the form of strategic behavior by the parties.[28]

[28] In fact, under certain forms of strategic behavior, Pigouvian taxes can yield optimal outcomes, even in the small-numbers case. On this, see Donald Wittman, "Pigovian Taxes Which Work in the Small-Number Case," *Journal of Environmental Economics and Management* XII (June, 1985), 144–54.

CHAPTER 4

Externalities: formal analysis

In this chapter, we construct a model of externalities that can then be used to derive formally the results discussed in the preceding chapter. This model and the associated analysis will serve as the basis for much of the treatment in later chapters.

Throughout the book we will utilize general equilibrium models almost exclusively. In welfare economics, perhaps as much as in any branch of our subject, there is real danger in partial analysis. When we consider expanding one sector of the economy, say, because of the net social benefits that it generates, it is essential that we take into account where the necessary resources will come from and what the consequences in other sectors will be. Interdependence among location decisions, levels of polluting outputs, and the use of pollution-suppressing devices are all at the heart of the problem. Indeed, the very concept of externalities implies a degree of interdependence sufficient to cast doubt upon the reliability of the partial analysis that, curiously, has often characterized writings in this area.

1 Pareto optimality in the basic externalities model

In this section, we first describe the structure of the basic model and then derive the necessary conditions for Pareto optimality. With this done, we can determine fairly easily in the two subsequent sections what prices and taxes are necessary to induce firms and individuals to behave in a manner compatible with the requirements for Pareto optimality.

Assume we have a perfectly competitive economy.[1] Let the productive activities of the firms generate an externality (for concreteness, it will be

[1] The reader is reminded that, in accord with the Pigouvian tradition, our pure competition assumption is taken to involve both a "large number" of producers and a "large number" of consumers of the externality, in the sense that each one of them takes the magnitudes of the pertinent prices and taxes as given and beyond his influence. Thus, everyone in the economy is assumed to be a "price taker" in this extended sense. Without this premise, one gets into problems of monopolistic strategies designed to affect the levels of taxes and prices to be used to control externalities. This case is discussed briefly in Chapter 6.

referred to as *smoke*) that increases the cost of (at least some) other production processes and constitutes a disutility to consumers. The choice of activity levels, including levels of outputs and input usage, are taken to influence the firm's output of smoke either directly or indirectly through the use of less polluting technological processes. Similarly, by the choice *both* of activity levels and of location, individuals and firms determine their vulnerability to smoke damage.

We use the following notation:

x_{ij} = the amount of good (resource) i consumed by individual j $(i=1,\dots,n)$ $(j=1,\dots,m)$[2]

y_{ik} = the amount of good (resource) i produced (used) by firm k $(i=1,\dots,n)$ $(k=1,\dots,h)$

r_i = the total quantity of resource i available to the community

s_k = the emission of externality (smoke) by firm k

$z=\sum s_k$ = total emissions in the community

$u^j(x_{1j},\dots,x_{nj},z)$ = individual j's utility function

and

$$f^k(y_{1k},\dots,y_{nk},s_k,z)\le 0 = \text{firm } k\text{'s production set.}$$

Here the variable z in each utility and production function represents the possibility that the utility (production) of the corresponding individual (firm) is affected by the output of the externality in the community. This clearly represents the undepletable externalities case in which any emission can enter into every utility and production function (that is, in which the amount of the externality consumed by one individual does not reduce the amount available to any other person or firm).

We assume that the feasible set of consumption complexes for each consumer is convex, closed, bounded from below in the x's, and contains the null vector, that the utility function that represents each person's preferences is twice differentiable, quasi-concave, and increasing in the x's, and that the feasible production set for each firm is defined by a set of technical constraints that are twice differentiable and define a convex production possibility set. Under these circumstances, as is well-known, the solution to the maximization problem that is about to be described exists and is unique.

[2] We do not distinguish here between manufactured goods and resources, such as land or labor. In the short run, even the consumption of a manufactured good can be constrained by the quantity of that item inherited from the past.

To find a Pareto optimum, we maximize the utility of any arbitrarily chosen individual, say individual 1, subject to the requirements that there be no consequent loss to any other individual, and that the constraints constituted by the production functions and the availability of resources are satisfied. Our problem, then, is to

maximize

$$u^1(x_{11}, \dots, x_{n1}, z) \tag{1}$$

subject to

$$\left.\begin{array}{ll} u^j(x_{1j}, \dots, x_{nj}, z) \geqq u^{*j} & (j=2, \dots, m) \\ f^k(y_{1k}, \dots, y_{nk}, s_k, z) \leqq 0 & (k=1, \dots, h) \\ \sum_{j=1}^{m} x_{ij} - \sum_{k=1}^{h} y_{ik} \leq r_i & (i=1, \dots, n) \\ \text{all } x_{ij} \geq 0,\ s_k \geq 0,\ z \geq 0. & \end{array}\right\} \tag{2}$$

Note that we do *not* require all $y_{ik} \geq 0$, for some firms may use the outputs of other firms as inputs (intermediate goods), and this is described by treating y_{ik} as a negative output when it is employed as an input.[3]

Because of our concavity-convexity assumptions we can use the Kuhn-Tucker theorem to characterize the desired maximum. We obtain the Lagrangian[4]

$$L = \sum \lambda_j [u^j(\cdot) - u^{*j}] - \sum \mu_k f^k(\cdot) + \sum_i \omega_i \left(r_i - \sum_j x_{ij} + \sum_k y_{ik} \right)$$

where the Greek letters all represent Lagrange multipliers. Differentiating in turn with respect to the x_{ij}, y_{ik}, and s_k we obtain the Kuhn-Tucker conditions given in the second column of Table 4.1. Here we use the notation $u_i^j = \partial u^j / \partial x_{ij}$, $f_i^k = \partial f^k / \partial y_{ik}$, and so on. It will be recalled also from

[3] Because y_{ik} is unrestricted in sign, as is well-known, the corresponding partial derivative of the Lagrangian will be set equal to zero, not less than or equal to zero as in the Kuhn-Tucker condition corresponding to a variable that is restricted to take only nonnegative values.

This assumption that y_{ik} is unrestricted in sign for all i is of course not always valid, for although every output can serve as an input in the form of inventory, the reverse is not true of inputs, such as "the original and indestructible powers of the soil" (land) that cannot be manufactured by firms. That is, the corresponding variable cannot take a positive value. The discussion would be complicated needlessly by taking this into account throughout and we provide the appropriate amendments in footnotes.

[4] Here we may, if we prefer, take $\lambda_1 = 1$ and $u^{*1} = 0$, so that the first term in L becomes $\sum_{j=1}^{m} \lambda_j [u^j(\cdot) - u^{*j}] = u^1 + \sum_{j=2}^{m} \lambda_j [u^j(\cdot) - u^{*j}]$, the latter, of course, being the form more usually encountered in the literature. With our concavity-convexity assumptions, the two forms are equivalent.

$t^j = f(x_{ij}, z)$.

Table 4.1. *Kuhn–Tucker conditions for optimality with externalities*

Variable		Pareto optimality		Market equilibrium	Prices
x_{ij}	(3°)	$\lambda_j u_i^j - \omega_i \leq 0$	(3ᶜ)	$p_i - \alpha_j u_i^j + t_i^j \geq 0$	$p_i = \omega_i$
		$x_{ij}(\lambda_j u_i^j - \omega_i) = 0$		$x_{ij}(p_i - \alpha_j u_i^j + t_i^j) = 0$	$t_i^j = t_i^*$
		(all i, j)		(all i, j)	
y_{ik}	(4°)[a]	$-\mu_k f_i^k + \omega_i = 0$	(4ᶜ)[a]	$p_i - \beta_k f_i^k - t_i^k = 0$	$p_i = \omega_i$
		(all i, k)		(all i, k)	$t_i^k = t_i^*$
$s_{\bar{k}}$	(5°)[b]	$\underbrace{-\mu_{\bar{k}} f_s^{\bar{k}}}_{\text{Particular}} + \sum_j \lambda_j u_z^j - \sum_k \mu_k f_z^k \leq 0$	(5ᶜ)[b]	$-t_s - \beta_{\bar{k}} f_s^{\bar{k}} \leq 0$	$t_s = -\sum \lambda_j u_z^j$
		$s_{\bar{k}}\left(-\mu_{\bar{k}} f_s^{\bar{k}} + \sum_j \lambda_j u_z^j - \sum_k \mu_k f_z^k\right) = 0$		$s_{\bar{k}}(-t_s - \beta_{\bar{k}} f_s^{\bar{k}}) = 0$	$+\sum \mu_k f_z^k$
		(all $\bar{k}$)		(all $\bar{k}$)	

[a] For inputs that cannot be manufactured by the firm, (4°) and (4ᶜ) must be replaced by the *pairs* of Kuhn-Tucker conditions similar to those in (3°) and (3ᶜ).

[b] Here it is necessary to distinguish between the firm $\bar{k}$ that generates the externality, and the other firms k that are affected by it. The bar is omitted where this distinction is not pertinent.

an earlier footnote that there is only a single equality condition corresponding to the variable y_{ik}, because that variable is unrestricted in sign.

Conditions (3°)–(5°), together with the constraints[5] (2) and the concavity-convexity conditions described earlier, are necessary conditions for *any* Pareto optimum. That is, *no* candidate solution that violates *any* of these conditions can be a Pareto optimum.

2 Market equilibrium

We will return presently to an economic interpretation of the Kuhn-Tucker conditions for a Pareto optimum, (3°)–(5°). However, it is more convenient to consider first the corresponding market equilibrium requirements. Specifically, our objective is to determine the characteristics of the prices and taxes (compensations), assuming that they exist,[6] that will induce the behavior patterns necessary (and sufficient) for the satisfaction of our Pareto-optimality conditions, and whether that set of prices and taxes is unique.

It is helpful to employ an admittedly artificial distinction between prices and compensatory taxes or subsidies. A *price,* in our competitive model, is a pecuniary quantity charged on each unit of some activity, whose magnitude is the same for all buyers and sellers. If a pair of gloves of some specification sells for $5.80, then anyone can by it for exactly that price, and, similarly, each seller will also receive $5.80 per pair.

A compensatory tax or a subsidy rate, however, will presumably depend on the smoke damage *to* the individual or firm and hence will differ from person to person and from firm to firm. If the optimal value of that tax turns out to be negative, it will represent a compensation payment to the victim. On the other hand, if it is positive, à la Coase, it will presumably

[5] Associated with the inequality constraints we also have the corresponding complementary slackness conditions

$$\lambda_j[u^j(\cdot)-u^{*j}]=0,\quad \mu_k f^k(\cdot)=0,\quad \text{and}$$

$$\omega_i\left(r_i-\sum_j x_{ij}+\sum_k y_{ik}\right)=0.$$

[6] As was noted in Chapter 1, we will not concern ourselves with the issue of the existence of a competitive solution that is consistent with any particular Pareto optimum. This subject has, of course, been explored in an extensive literature following Kenneth J. Arrow's classic paper. Our object here is to *describe* the prices and taxes that are part of such an equilibrium, on the premise that the existence issue has been settled. Of course, this is not meant to imply that the existence literature is either trivial or uninteresting, but only that it has not yielded any clear implications for policy, which are the primary concern of this volume. A noteworthy exception arises out of the relationship of externalities and violation of the convexity conditions, a subject that is examined in detail in Chapter 8.

represent an inducement to the victim to take measures to protect himself from the damage (for example, by moving away from the source of emissions).[7] We then assign to each consumer and firm a tax (compensation) payment for smoke damage he or it suffers, where we use t^j and t^k to designate the tax rate for individual j and firm k, respectively, the objective being to determine Pareto-optimal values for the t^j and the t^k.

The magnitudes of these tax-compensation rates must obviously depend on the victim's activity levels. If an exogenous shift in laundry demand leads to an increase in output, the damage caused the laundry by the polluter's smoke will necessarily increase. Hence, compensation payments to the laundry must rise correspondingly. Thus t^j and t^k cannot be treated as constants but must be considered functions of j's and k's respective decision variables. $t^j = f((x_{ij}), z_k)$

We also impose on the emission of smoke a tax rate, t_s, per unit of emission whose optimal value is to be determined.

We can now proceed directly to examine the equilibrium of the consumer and of the firm. The consumer is taken to *minimize* the expenditure necessary to achieve any given level of utility,[8] u^{*j}, so that in Lagrangian form the problem is to find the saddle value of

$$L_j=\sum p_i x_{ij}+t^j+\alpha_j[u^{*j}-u^j(\cdot)] \tag{6}$$

(all $x_{ij}\geq 0$, where α_j is a Lagrange multiplier). We immediately obtain the Kuhn-Tucker conditions (3^c) in Table 4.1.

Similarly, the objective of our (competitive) firm is taken to be maximization of profits after taxes subject to the constraint given by its production relation, $f^k\leq 0$. Its Lagrangian problem is to find the saddle value of

[7] In our model, the victim can, indeed, take such protective action. For example, if item i' is land in a smoky area and item i'' is land in an unpolluted neighborhood, a laundry (firm k) can reduce its vulnerability to smoke damage by increasing its use of i'' relative to i' (that is, by increasing the absolute value of $y_{i''k}$ and decreasing that of $y_{i'k}$). So long as these protective activities do not shift the damage to others, they are consistent with the model under discussion. For a more extended treatment of defensive activities and the compensation issue, see W. Oates, "The Regulation of Externalities: Efficient Behavior by Sources and Victims," *Public Finance* XXXVIII (No. 3, 1983), 362–75; and H. Shibata and J. S. Winrich, "Control of Pollution When the Offended Defend Themselves," *Economica* L (November, 1983), 425–37.

[8] We proceed in this manner rather than following the usual premise that the consumer maximizes the utility he derives from his income because our approach simplifies matters somewhat. First, it produces results more immediately comparable with (3°) and in (3^c). Moreover, our procedure evades the determination of the consumer's income which is clearly affected by the prices of the resources he holds. In any event, though the two approaches are *not* quite equivalent, clearly either is valid for our purposes.

constant

$$L_k = \sum p_i y_{ik} - t^k - t_s s_k - \beta_k f^k(\cdot)$$

$$s_k \geq 0, \quad y_{ik} \text{ unrestricted,} \tag{7}$$

whose Kuhn-Tucker conditions are (4^c) and (5^c), in Table 4.1.[9]

3 The price-tax solution

Our objective now is to determine what values of emission taxes and damage-compensations (taxes) will induce consumers and firms to select Pareto-optimal activity levels. That is, we want to know what tax structure can sustain a competitive equilibrium that is Pareto-optimal. We will prove first that this *can* be achieved by setting

$$t_s = -\sum \lambda_j u_z^j + \sum \mu_k f_z^k, \quad \text{all } t_i^j = t_i^k = 0. \tag{8a}$$

Note that (8a) calls for a zero derivative both of t^j with respect to any x_{ij} and of t^k with respect to y_{ik}. That is, even if damage from the externality varies with the victim's activity levels, it requires compensation payments to be completely unaffected by those activity levels (contrary to the concept of a compensation payment that we have just formulated).

To show that conditions (8a) are sufficient to induce the market to satisfy the Pareto-optimality requirements, note that competitive equilibrium is characterized by conditions (3^c)–(5^c) together with constraints (2) (including among them the market-clearance condition $\sum x_{ij} - \sum y_{ik} \leq r_i$) and the complementary slackness conditions corresponding to (2). Substituting the values of t_s, t_i^j and, t_i^k from (8a) into (3^c)–(5^c), we see that the system of inequalities and equations determining the competitive equilibrium (i.e., those determining the values of the variables x_{ij}^c, y_{ik}^c, s_k^c, α_j, β_k, and p_i) becomes identical with the system of inequalities and equations (2), (3^o)–(5^o) and the complementary slackness conditions for (2) that determine a Pareto-optimal solution: x_{ij}^o, y_{ik}^o, s_k^o, λ_j, μ_k, and ω_i. Thus, these systems will have the same solutions, so that if they are unique[10]

[9] The y_{ik} are unrestricted with the exceptions noted earlier in footnote three in this chapter. We also point out that, for purposes of simplification, we have omitted from the Kuhn-Tucker conditions (5c) a term, $-\beta_k f_z^k$. This term reflects the indirect effect on its *own* output of a firm's emissions (at the margin) operating through z (the aggregate level of pollution). Such an effect will typically be minuscule, and since it complicates the analysis considerably, we have chosen to ignore it.

[10] It will be noted that even if the solution is otherwise unique, one can multiply all of the p_i, t_s, t^j, and t^k and all the Lagrange multipliers in any solution by the same constant without violating (3)–(5), the only relationships in which these variables appear. This gives us our one degree of freedom in the choice of absolute prices and taxes. Even if the solutions to the market equilibrium and optimality requirements were not otherwise unique, of course (8b) would still hold for *corresponding* solutions to the two systems.

$$p_i = \omega_i, \quad \lambda_j = \alpha_j, \quad \mu_k = \beta_k \quad (\text{all } i, j, k). \tag{8b}$$

We have

Proposition One. Conditions (8a) are sufficient to render identical the competitive equilibrium and the Pareto-optimality conditions. That is, given the assumed convexity conditions, market behavior subject to this set of taxes will yield an optimal allocation of resources.

By (8a) and (8b) we have, in fact, proven that neither any tax nor any compensation of the victims of externalities is *necessary* to sustain *any* Pareto optimum, for $t^j \equiv 0$ and $t^k \equiv 0$ will obviously satisfy (8a) if t_s, the tax on the generation of the externality, is set appropriately. It may, however, be asked whether compensation or taxation of the victims is even possible without preventing the attainment of a Pareto optimum; that is, we may ask whether conditions (8a) are absolutely required for an optimum. The answer is that they are if we accept one plausible premise: that there exists one item, some of which is consumed by every individual.[11]

To deal with this issue, the uniqueness of the tax-compensation solution (8a), we must assume that there is a set of taxes and prices which yield equality between the market and Pareto-optimal activity levels [i.e., that there exist $x_{ij}^c = x_{ij}^o$, $y_{ik}^c = y_{ik}^o$, and $s_k^c = s_k^o$, which satisfy both (3^c)–(5^c) and (3^o)–(5^o)]. We then ask what values of the p_i, t_s, t^j, and t^k are consistent with these relationships.

For this purpose we can take leisure (labor) to be the item which is used by every individual (no one works 24 hours per day).

Let i^* represent leisure-labor. Because of our premise all $x_{i^*j} > 0$, the corresponding conditions (3^o) and (3^c) become equalities.[12] Taking i^* as our standard of value, we set arbitrarily[13]

$$\omega_{i^*} = p_{i^*}. \tag{9}$$

We then obtain from (3^o) and (3^c), both of which are now assumed to be satisfied,

$$\lambda_j = \omega_{i^*}/u_{i^*}^j = p_{i^*}/u_{i^*}^j = \alpha_j \quad (\text{for every } j) \tag{10}$$

[11] We also require the absence of discontinuities in derivatives. For, at such a kinked point, the slope of the budget line is not generally fixed and hence the corresponding taxes are not unique.

[12] With each firm using labor, the corresponding conditions (4^o) and (4^c) remain equalities even though y_{i^*k} is not unrestricted in sign because the firm cannot manufacture labor.

[13] This is where we use up our factor of proportionality. The reader will verify that if we had instead set $p_{i^*} = a\omega_{i^*}$, all other prices and taxes in (8) would simply be multiplied by a.

and[14]

$$\mu_k = \omega_{i^*}/f_{i^*}^k = p_{i^*}/f_{i^*}^k = \beta_k \quad \text{(for every } k). \tag{11}$$

That is, each $\lambda_j = \alpha_j$ and each $\mu_k = \beta_k$.

Then by (3°) and (3^c), we must have, for any one item, i', if it is consumed by individual j' and consumed or produced by firm k',

$$\omega_{i'} = p_{i'} + t_{i'}^{j'} = p_{i'} - t_{i'}^{k'}. \tag{12}$$

It follows immediately, because $\omega_{i'} - p_{i'}$ takes the same value for every individual and every firm (that is, it is independent of j' and k'), that we must have

$$\text{for all } x_{i'j'} > 0 \text{ and all } y_{i'k'}, \quad t_{i'}^{j'} = -t_{i'}^{k'} = \omega_{i'} - p_{i'}, \tag{13}$$

which is independent of j' and k'. That is, Pareto optimality requires the amount of tax paid or compensation received by any individual or firm subjected to an externality to vary by exactly the same amount in response to a given change in the level of any of the activities in which he or it is engaged, that is,

$$t_i^j \equiv \frac{\partial t^j}{\partial x_{ij}} = -\frac{\partial t^k}{\partial y_{ik}} \equiv -t_i^k, \quad \text{for all } x_{ij} > 0 \text{ and all } y_{ik}.$$

Writing $t_i^* = t_i^j = -t_i^k$ and

$$p_i^* = p_i + t_i^j = p_i - t_i^k = p_i + t_i^* = \omega_i, \tag{14}$$

we see that the $p_i + t_i^j$ and $p_i - t_i^k$ are merely disguised forms of the ordinary prices, given by (8b). Consequently,

Proposition Two. Aside from a lump-sum subsidy or tax, the Pareto-optimal solution [as described by (1) and (2)] can be sustained only by a financial arrangement that does not differ from a set of prices p_i^* for all activity levels and a set of zero (incremental) tax or compensation levels.

From (5°) and (5^c) we deduce immediately[15] the remainder of the price-tax solution (8), that is, we deduce the postulated pollution tax rate, t_s. Thus we conclude

Proposition Three. Aside from a factor of proportionality and for all $x_{ij} > 0$, conditions (8) are necessary for achievement of a Pareto-optimal equilibrium through a system of prices and taxes under a regime of pure competition.

[14] To derive $\beta_k = \mu_k$, we do not have to find any item used or produced by every firm. We merely need some item that is *potentially* either an output or an input for every firm so that the corresponding variable is unrestricted in sign and the corresponding conditions (4°) and (4^c) are equations.

[15] We assume that t^k does not vary with s_k, the firm's own emissions. Otherwise, we must repeat the preceding argument to show that t^k must be identical for all firms and is therefore simply a camouflaged component of t_s.

4 Interpretation of the results and the Kuhn-Tucker conditions

We can characterize the preceding results succinctly:

Proposition Four. The price-tax conditions (8) necessary to sustain the Pareto optimality of a competitive market solution under the assumed convexity conditions are tantamount to the standard Pigouvian rules, with neither taxes imposed upon, nor compensation paid to,[16] the victims of externalities (except possibly for lump-sum taxes or subsidies).

This is obviously true of the prices in (8). The only thing that remains to be shown is that the tax rate, t_s, per unit of smoke emissions is indeed equal to the marginal social damage of smoke. For that purpose we again use leisure-labor, i^*, as the standard of evaluation. Assume now that every firm uses *some* labor and that every individual consumes some leisure so that all $x_{i^*j} > 0$ and all $y_{i^*k} > 0$. Then the corresponding inequalities (3°) and (4°) must be equations. We may then write

$$\lambda_j = \omega_{i^*}/u_{i^*}^j, \qquad \mu_k = \omega_{i^*}/f_{i^*}^k. \tag{15}$$

Substituting these into the tax relationship in (8) we obtain[17]

[16] The fact that these will be zero only for $x_{ij} > 0$ does not restrict the generality of these conclusions, because for any variable that is zero, the marginal payment must clearly be zero.

The reason tax and compensation payments must be zero for Pareto optimality should be clear. If these payments really are to correspond to the magnitude of the damage they *must* vary with the values of the victim's decision variables. The laundry whose output increases in response to an autonomous shift in demand suffers more damage as a result. Hence, a true compensation payment to the laundry *must* vary with the laundry's output level. But that will serve as an inducement to the laundry to increase its output on its own volition and, consequently, will produce a violation of the requirements of Pareto optimality.

If all that is at issue is a single state equilibrium it must be admitted that compensation can indeed be arranged without precluding a Pareto optimum. For this purpose one need only (!) calculate the damage that would be sustained by each victim if the Pareto optimum were somehow to be attained. The victim can then be given in compensation a payment that exactly offsets that Pareto-optimal damage level, a lump-sum payment absolutely immune to change by an act of the victim. However, that payment would at once become inappropriate if there were any autonomous change in tastes, technology, etc., which would change the nature of the Pareto optimum and the corresponding damage levels. As usual, lump-sum taxes have little relevance for policy – even for the *theory* of policy.

[17] Note the similarity of the RHS of (16) to the well-known Samuelson condition for optimality in the output of a public good in which the *sum* of its marginal rates of substitution with respect to a private good is the relevant datum. The reason for this similarity is obvious: we are dealing here with an externality that is, essentially, a public good.

$$t_s = \sum -\lambda_j u_z^j + \sum \mu_k f_z^k = \omega_{i^*}\left[-\sum_j (u_z^j/u_{i^*}^j) + \sum_k (f_z^k/f_{i^*}^k)\right]. \tag{16}$$

But keeping output and utility levels fixed we have[18]

$$u_z^j/u_{i^*}^j = -\partial x_{i^*j}/\partial z, \qquad f_z^k/f_{i^*}^k = \partial \bar{y}_{i^*k}/\partial z, \tag{17}$$

[writing $\bar{y}_{i^*k}$ for the absolute value of the (negative) input y_{i^*k}]. These expressions represent the increase in quantity of labor needed to keep utilities or outputs and use of other inputs constant when there is a unit increase in smoke output in the community. Hence substituting from (17) into (16), t_s becomes

$$t_s = \omega_{i^*}\left[\sum_j (\partial x_{i^*j}/\partial z) + \sum_k (\partial \bar{y}_{i^*k}/\partial z)\right]. \tag{18}$$

Interpreting the dual variable ω_{i^*} in the usual manner as the shadow price of labor,[19] we see that (18) is indeed the marginal smoke damage, measured in terms of the *value* of the labor needed to offset the various types of damage.

Having thus shown the economic implications of our solution, we may return briefly to the Kuhn-Tucker conditions (3)–(4). Their interpretation is now straightforward. Using ω_{i^*} as the shadow price of labor, we find from (15) that (3°) and (3^c) call for prices to be proportionate to marginal utilities; similarly, (4°) and (4^c) indicate that these same prices should be proportionate to the ratios of marginal costs (products), all measured in terms of labor if we wish.

Note also that (8) calls for a tax on smoke *emissions,* not on either inputs or outputs directly. Inputs and outputs that generate smoke are, of course, subject to tax, but only in proportion to the smoke they produce. Common sense confirms the logic of this rule. After all, one wants to motivate the firm to reduce the emissions it generates when it produces a given output or uses a given quantity of an input, and a tax on outputs or inputs that is independent of the pollution generated by them is certainly not the way to go about this.[20]

Observe, finally, that from standard Kuhn-Tucker theory we know that

$$\omega_i\left(r_i - \sum_j x_{ij} + \sum_k y_{ik}\right) = 0 \quad (i = 1, \ldots, n).$$

[18] Thus, for example, holding all other variables constant, to keep j's utility constant we must have $0 = du^j = u_z^j dz + u_{i^*}^j dx_{i^*j}$ from which the result (17) follows directly.

[19] Specifically, if the derivative exists, we have $\omega_{i^*} = \partial u^1/\partial r_{i^*}$, the marginal utility of individual 1 (the person whose utility is being maximized) of a unit increase in the quantity of labor available.

[20] Compare Charles R. Plott, "Externalities and Corrective Taxes," *Economica* N.S. XXXIII (February, 1966), 84–7.

Consequently, because by (8) our solution calls for $p_i = \omega_i$, we have

Proposition Five. The prices p_i that can sustain a Pareto optimum will be nonzero only for items used up completely in the corresponding optimal solution, that is,

$$p_{i'} > 0 \quad \text{implies} \quad \sum_j x_{i'j} = r_{i'} + \sum_k y_{i'k}.$$

Looked at the other way, any item not utilized fully in an optimal solution must be assigned a zero price:

$$\sum_j x_{i''j} < r_{i''} + \sum_k y_{i''k} \quad \text{implies} \quad p_{i''} = 0.$$

5 Extensions of the basic model: some remarks

Our basic model, we believe, captures the essentials of the externalities problem. However, our particular construct is not of the most general form. It involves (at least) two major simplifications that require further discussion. First, as we noted earlier, the model deals only with externalities of the pure public goods or undepletable variety. We assumed that the same externality variable, z, the aggregate level of smoke emissions in the community, enters into every agent's utility or production function. One agent's consumption of the externality does not, in this formulation, reduce the consumption of the externality by anyone else. Second, we assumed that units of emissions from the different sources are perfect substitutes for one another; a unit of smoke emissions from source i is thus posited to have the same effects on air quality as a unit of smoke emissions from source j. This is the "perfect mixing" assumption; it is the aggregate of emissions, not their composition, that matters.

Each of these simplifications requires some further comment. Let us turn first to our assumption that the externalities are undepletable. As we discussed in Chapter 3, some externalities are, in fact, depletable. Freeman illustrates this phenomenon with the case of acid rain.[21] In this instance, the sulfur emissions from a particular source are distributed in the form of acid-rain among a set of locations with the distribution depending on prevailing weather conditions. The point is that "each pound of sulfur emitted to the atmosphere must land somewhere, and if the quantity falling on A's land increases, there is less to fall elsewhere."[22] For this case, we must amend our model to take account of the distribution of the externality among the various victims; no longer do all victims

[21] A. Myrick Freeman III, "Depletable Externalities and Pigouvian Taxation," *Journal of Environmental Economics and Management* XI (June, 1984), 173–9.

[22] Freeman, p. 175.

consume all the units of the externality – each victim is now assigned a certain number of units, and the sum of these units consumed over all victims equals the aggregate of the wastes emitted. Freeman has analyzed this case formally and demonstrates (contrary to what was said in the first edition of this book) that the relevant modification to the model has absolutely no substantive effects on the results. It remains true that the modified model calls for a Pigouvian levy on the generator of the externality equal to marginal social damage and no compensation or taxes on the victims. It thus makes no difference for our results whether the externality is of the undepletable or depletable variety (provided that the victims cannot affect the consumption of the externality by other victims, as we will see shortly).

We turn next to the assumption of perfect mixing. It is certainly true for some pollutants that the location and other characteristics (e.g., height and velocity of emissions) of the source differentiate the effects of its discharges from those of other sources. The effects, for example, on various victims of carbon-monoxide emissions depend to a significant degree on just where the discharges take place. For such cases, we obviously must distinguish among the different sources. It is a straightforward matter to carry out the required extension of our model. Instead of making a victim's consumption of the externality simply equal to the aggregate of the emissions, we now make each victim's utility depend on the composition of the waste discharges. Rather than including the same variable, z, in every individual's utility function, we now introduce the variable $Z^j(s_1, \dots, s_n)$ for victim j (that differs from one victim to another and that depends in a more complicated way on the levels of discharges, s_i, of the various sources). Such a substitution in our model produces one modification of the results, which follows directly from the same sort of formal argument as before. Since the effects of the emissions of the various sources will now differ, Pareto optimality requires the Pigouvian tax or effluent fee to be tailored individually to each source. The unit tax on the emissions of each generator of the externality must still equal marginal social damage, but since the marginal damages will now vary from source to source, different tax rates are called for.[23] So in place of a uniform fee on all sources (as under perfect mixing), we now have a set of Pigouvian taxes that correspond to the marginal damages of the emissions of each source.

We return next to the issue of shiftable externalities that we raised in Chapter 3. We recall that for a shiftable externality, victims can undertake activities that pass the externality along to other victims (e.g., they can transfer trash initially dumped on their property onto sites owned by others). To treat this case, we must amend the equation that deals with the amount of the externality consumed by a particular victim to include the consequences of the shifting activities. More specifically, the amount of the externality consumed by the ith victim will now be equal to the amount initially "deposited" upon i by the sources of the externality, plus any additional units shifted to the victim by other victims, and minus any units shifted by i to other victims. With this modification of the model (which we shall not work through formally here), we find that the policy prescription for the attainment of Pareto optimality must be extended in a straightforward way. In addition to the Pigouvian tax upon the generator of the externality, the environmental authority must also confront victims with a unit tax on their shifting activities equal to the marginal social damage of transferring the externality to another victim. The reason for this tax is clear. The extension of the Pigouvian tax to shifting activities effectively internalizes the social costs that such activities entail. It makes victims incorporate into their decision calculus the social costs (benefits) inherent in shifting the externality to someone else. This set of taxes will ensure that the externality ends up among victims to whom it does the least damage. Alternatively, where the externality provides a benefit capable of being distributed among different individuals, such a set of subsidies is needed to ensure that the external benefits accrue to those to whom they do the most good.

There is a further modification of our model that may be of some interest. This is the proposal by Michael Common that a budget-balancing requirement be imposed upon the public sector so that any addition to its revenues from its Pigouvian taxes must be offset by an equal increase in its disbursements.[24] In an important sense, he is right. In real terms, welfare maximization requires this, for if the government were to collect real resources equivalent in value to the Pigouvian taxes and were to give nothing in return, then it would, indeed, be possible to make some persons better off without harming anyone.

Having said this, there is an obvious solution of our model when augmented by such a balanced-budget constraint for government. For what we have now is simply the Ramsey-Boiteux model with the addition of undepletable externalities. That is, we have a model involving Pareto optimization subject to a budget constraint. The solution is nowadays well known. All prices in the economy, including the Pigouvian tax (price) on pollution, *along with the (zero) price on consumption of externalities*

[23] Freeman, p. 178.

[24] M. Common, "On the Concept of Externality and Pollution for Efficiency in Allocation," unpublished paper (October, 1985).

must be modified. Rather than all prices (including the Pigouvian taxes) being set equal to the true social marginal costs (SMC), they must deviate from these costs in the manner dictated by the formulas

$$(p_i + t_i - SMC_i) = k(MR_i - SMC_i) \quad \text{for all activities } i \tag{19}$$

$$\sum t_i y_i = 0 \tag{20}$$

where t_i is the tax rate (positive or negative) on activity i, y_i is the ith activity level, and MR_i is the marginal revenue from its sale.[25]

This and other standard properties of Ramsey pricing immediately yield the following conclusion:

Proposition Six. If a governmental balanced-budget constraint is added to the model of welfare maximization in the presence of undepletable externalities, then the price-tax results of Table 4.1 will remain completely unaffected when the economy's production frontier is locally linearly homogeneous in a neighborhood of the solution point. However, in the absence of linear homogeneity at that point, *all* prices and taxes in the economy will deviate from their values in Table 4.1 in accord with the requirements of (19) and (20).

Corollary. With the addition of the budget constraint of Proposition Six and in the absence of linear homogeneity, welfare maximization will require the victims of externalities to receive some payment, positive or negative, which can be regarded as receipt of some compensation or payment of some tax. However, the magnitudes of the amounts paid in "compensation" to the victims (along with everyone else in the economy) will bear no relationship to the damage they suffer.

Note that in a large economy this means that after the proceeds of a tax upon a particular externality are divided among all the members of the economy, the returns to any particular victim are likely to be very small and perhaps not even noticeable.[26]

[25] For a derivation of these results, see, for example, W. J. Baumol and D. F. Bradford, "Optimal Departures from Marginal Cost Pricing," *American Economic Review* LX (June, 1970), 265–83.

[26] Common contends that the introduction of the balanced-budget constraint implies that victims should be fully compensated for the damages they suffer. However, this result has its source in a condition that requires the disbursement of Pigouvian tax revenues solely to victims. Ramsey analysis shows that such a restriction can hardly be welfare maximizing. In addition, Common implicitly (and seemingly inadvertently) allows individual household victims (on page 12) to select the quantity of pollution, z_j, that they consume, despite the recognition that in the undepletable case households have no control over the amount of pollution from which they suffer. We note these matters in the interest of avoiding any misunderstandings associated with Common's important contribution in introducing the balanced-budget issue.

Taking another tack, David Newbery argues that compensation of victims may be a good political strategy. Although we certainly agree with his point, we would note that it has nothing to do with the conditions required for economic efficiency. See D. M. G. Newbery, "Externalities: The Theory of Environmental Policy," in G. A. Hughes and G. M. Heal, eds., *Public Policy and the Tax System* (London: Allen and Unwin, 1980), 106–149.

Finally, we note that both Common and Newbery appear to misinterpret us when they take us to believe that only decisions on location by victims will be distorted by compensation. As we have indicated in the text, compensation will also discourage other sorts of defensive activities such as insulation against noise, the use of air-cleansing devices, and other measures to reduce damages from pollution. It may result in additional distortions by inducing the entry of an excessive number of victim firms.

As a final extension of the basic model, we consider the case of pure crowding or congestion.[27] The distinguishing feature of this case is that the economic agents are themselves simultaneously both generators of the externality and victims. For example, on a crowded highway or beach, individual users simultaneously contribute to the severity of congestion and suffer from it. To incorporate congestion into the model, we must therefore introduce into the individual utility function two arguments: the individual's level of utilization of the congested facility and the aggregate level of usage. We thus rewrite individual j's utility function as $u^j(x_{1j}, x_{2j}, \ldots, x_{nj}, z_j, z)$, where $z = \sum z_j$ is the aggregate usage of the facility. In this formulation, we posit that the individual consumer receives positive marginal utility from the consumption of the collective good (so that $\partial u^j / \partial z_j$ is positive) but suffers from congestion of the good (so that $\partial u^j / \partial z$ is negative). The implications of this extension of the model are straightforward. As a generator of the externality, it follows from the earlier analysis that the individual should be subject to a Pigouvian tax (perhaps in the form of an entrance fee – a toll for use of the highway) equal to the marginal social damages associated with the increase in congestion attributable to usage by an additional person. But as a victim, the individual (as we have seen) should not receive compensation. Existing congestion (in conjunction with the Pigouvian fee) provides the required economic inducement for the individual to adjust his usage of the collective good to the efficient level. We note, incidentally, that in the basic model we have already effectively introduced this formulation for firms: They benefit from their smoke emissions, on the one hand, but suffer from the aggregate level of smoke discharges on the other. Firms are thus both generators and victims of the externality in the model used in this chapter. As we have discussed here, this

[27] We are grateful to Henry Peskin for his helpful comments on this matter.

formulation can easily be interpreted to encompass the phenomenon of congestion.[28]

6 A note on the entry-exit issue[29]

The interpretive discussion up to this point has focused entirely on the proper signals or incentives to polluting agents and victims for the choice of levels of polluting, defensive, and shifting activities. We have derived the first-order conditions and the associated policy implications for efficient choices in these activities. However, policy measures for the control of pollution can also have direct implications for another kind of economic choice critical for economic efficiency: the decision by an emitting or a victim firm to enter or leave the industry. The point is that the adoption of policy measures such as effluent fees or compensation of victims affects the firm's overall level of profits; such fees or other policy measures thus influence the attractiveness of the productive activities to which they apply. If they are to be consistent with optimality, pollution-control policies must not only lead to efficient levels of waste emissions and responses by victims; they must also be consistent with the optimal composition of final output, which depends on the number of sources as well as the output decision of each individual source.

The nature of the polluter's entry-exit problem is readily seen in terms of Figure 4.1. Suppose that we have an area in which there is a single polluter. The *MSD* curve depicts the marginal social damages associated with the polluting firm's waste emissions, and *DD'* is the firm's demand curve for emissions.[30] The optimal level of emissions is E^*. Note that our Pigouvian prescription for regulation of the firm's waste emissions calls for an effluent fee per unit of emissions equal to *OB*; this will induce the

[28] The degree of congestion will, in general, depend on the size of the facility as well as on the level of usage. Where the size or capacity of the facility is itself a decision variable, it is necessary to introduce this explicitly into the analysis. The degree of congestion will then depend jointly upon the size of the facility and the number of users; more formally, we would introduce as an argument into the individual's utility function $c(z, f)$ to indicate that congestion depends on facility size, f, as well as on the level of usage, z. On this, see, for example, James Buchanan, "An Economic Theory of Clubs," *Economica* XXXII (February, 1965), 1–14. See also our treatment in the first edition of this book, pp. 49–51.

[29] For an excellent, comprehensive treatment of this issue, see Daniel F. Spulber, "Effluent Regulation and Long-Run Optimality," *Journal of Environmental Economics and Management* XII (June, 1985), 103–116.

[30] In the figure, we treat waste emissions, as was done earlier, as a factor input so that *DD'* depicts the value of the marginal product of emissions. Note that for any point on the horizontal axis, the vertical distance to *DD'* is also the firm's marginal abatement cost; it measures the cost of abatement in terms of the value of foregone output.

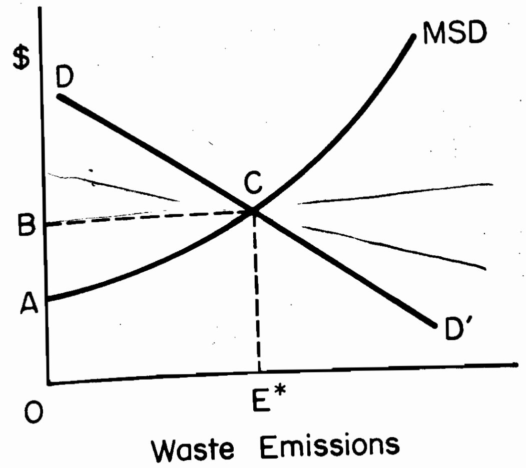


Figure 4.1

firm to emit the socially optimal quantity of wastes. This may not, however, be consistent with optimal industry size and output. The difficulty is that the firm's total tax bill, $OBCE^*$, will exceed the ~~total damages~~ that it imposes on society ($OACE^*$) by the amount *ABC*. The total levy is thus excessive and, in the long run, may induce the firm to leave the industry even though its output has a net positive value to society. In the case where the *MSD* curve is downward sloping, the opposite is obviously true: The firm's total tax bill will undervalue the damages of its emissions and therefore may induce entry (or discourage exit) where the firm's total costs to society exceed the value of its output.

In contrast, in the case where the *MSD* curve is perfectly horizontal, we see that the firm's tax bill will coincide with the total social damages from its emissions. For this particular case, the fee will induce both the proper amount of waste emission from the firm and provide the correct incentive for the long-run decision concerning entry or exit. This makes clear a further assumption that has been implicit in our analysis up to this point. Throughout we have assumed that the individual polluter is "small" in the sense that over the range of its emissions, marginal social damages are (approximately) constant. If this is true, then as Schulze and d'Arge and, more recently, Kohn and Spulber have shown, the Pigouvian tax will lead to the socially optimal number of firms in the emitting industry.[31] This,

[31] William Schulze and Ralph C. d'Arge, "The Coase Proposition, Information Constraints, and Long-Run Equilibrium," *American Economic Review* LXIV (September, 1974),

incidentally, is really a straightforward extension of the standard assumption of pure competition under which we posit that the individual firm is sufficiently small to have a negligible effect on the values of the "industry-level" variables. As is well known, where the firm's behavior influences these variables, distortions of various sorts result, and the policy implications differ from those of the purely competitive case.[32]

The entry-exit issue (this time for an industry composed of victims of the externality) is also relevant to our discussion of compensation of victims. As we noted in the preceding section, compensation can be inefficient because it provides a pecuniary incentive for a victim firm to stay in business even though its receipts do not cover its costs. Compensation is, therefore, a source of excessive size in an industry that suffers from a detrimental externality. The reason for this is straightforward. Under perfect competition, with product prices parametric with respect to the entry of a new (small) firm and cost equal to true opportunity cost, the welfare contribution, W, of the entry of an additional firm, all other things remaining equal, must be

$$W = \sum p_i y_i - C(y_1, y_2, \ldots, y_n)$$

where p_i is the market price of good i, y_i is the entrant's output of the good, and $C(\cdot)$ is the entrant's total cost function. Optimality then clearly requires entry to continue up to the point where W, the incremental yield of entry, reaches zero. But with a subsidy, further entry will obviously still be profitable when $W=0$, so that a socially excessive level of entry of victim firms will take place.

We shall return to entry-exit issues in Chapter 14 in our discussion of subsidies. For now, we simply make explicit our assumption of constant marginal damages over the range of emissions of an individual polluter. And we reiterate that economic efficiency requires the absence of compensation of victims of detrimental externalities (or of charges to the recipients of a beneficial externality) in the case where the affected entities are relatively small.

Footnote 31 *(cont.)*
763–72; Robert E. Kohn, "A General Equilibrium Analysis of the Optimal Number of Firms in a Polluting Industry," *Canadian Journal of Economics* XVIII (May, 1985), 347–54; and Daniel F. Spulber, "Effluent Regulation and Long-Run Optimality," *Journal of Environmental Economics and Management* 12 (June, 1985), 103–16.

[32] For the case in Figure 4.1, what is obviously needed is a schedule of fees under which the fee at any particular level of emissions equals marginal social damages. For a more general treatment of all this, including the case of a few "large" polluters, see Robert A. Collinge and Wallace E. Oates, "Efficiency in Pollution Control in the Short and Long Runs: A System of Rental Emission Permits," *Canadian Journal of Economics* XV (May, 1982), 346–54.

7 Summary: implications of the models[33]

We are now in a position to draw together a number of important conclusions about pricing and optimality in the presence of externalities:

a. Our optimality and market equilibrium analyses jointly call for a unique set of (relative) prices to consumers for each and every product and each and every resource. After normalization by (9), each price becomes equal to the value of the Lagrangian multiplier for the corresponding constraint [that is, the shadow price (marginal utility to individual 1) of the corresponding item] so that $p_i = \omega_i$. Consequently, prices to competitive suppliers of those goods that yield no externalities should equal their (private) marginal resources costs, with each resource, i evaluated at its shadow price, ω_i.

b. For a producer whose activities generate an externality, however, we see from (8) that net revenue per unit (price minus tax or plus subsidy) should *not* simply be equal to its marginal resources cost. Rather, (8) indicates that unit receipts should also reflect both the marginal (dis)utility of the externalities to consumers, $\sum \lambda_j (\partial u^j/\partial z)$, and the marginal resources cost (benefits) imposed on firms, $\sum \mu_k (\partial f^k/\partial z)$. It follows that the optimal unit revenues of the externality-generating output equals its private marginal cost plus (minus) the value of the benefits (damage) imposed by the externalities. This is, of course, the standard Pigouvian result. In a competitive economy, it calls for a tax (subsidy) per unit on the externality-generating activity equal to its marginal external damage (benefit).

c. We come next to results of this chapter that are less well known. The first relates to the issue of compensation to the victims (beneficiaries) of the externalities. As already noted, there is disagreement on this subject in the literature, with some writers calling for compensation and others actually seeming to propose a tax upon the victims, on the ground that this will be required for optimal resource allocation. But (8) is unambiguous on that point for the large-numbers case. It indicates that the price of any consumer good that generates no externality should equal its (private) marginal cost. For with $t^j = t^k = 0$ by (8) (except for lump sum payments) we have for i^*, any input (negative output) actually used in

[33] In concluding the formal analysis of our basic models, we should note that there are other ways to construct models of environmental externalities. One such approach recognizes that our environmental resources are assets that yield a stream of services and introduces explicit variables corresponding to the stocks of these resources. For examples of this approach, see H. Mohring and J. G. Boyd, "Analyzing Externalities: Direct Interaction vs. Asset Utilization Frameworks," *Economica*, N.S. XXXVIII (November, 1971), 347–61; and Henry Peskin, *National Accounting and the Environment* (forthcoming).

firm k, and i any output of firm k, $p_i = \beta_k f_i^k$, $p_{i^*} = \beta_k f_{i^*}^k$ [by (4^c)] so that eliminating β_k between these two equations we have at once [by the analog of (17)]

$$p_i = p_{i^*} f_i^k / f_{i^*}^k = p_{i^*} \partial \bar{y}_{i^*k} / \partial y_{ik} \quad \text{where } \bar{y}_{i^*k} = |y_{i^*k}|.$$

That is, the optimal price of i is the cost of the quantity of input i^* necessary to produce a unit addition in i, all other inputs and outputs held constant. In brief, it is the marginal *private* cost of i.[34] This means that if, for example, marginal smoke damage to the production of two firms of different types, k and k^*, is quite different (that is, if $\mu_k \partial f^k/\partial z \neq \mu_{k^*} \partial f^{k^*}/\partial z$), there will be no compensation to offset the differential effects on the optimal prices of the two outputs. Laundry and phonograph records will both sell at their private marginal costs though one cost is more heavily affected by smoke than the other. Thus, our results imply that, *in the presence of an externality, optimal resource allocation calls for pricing that involves zero taxation and zero compensation to those affected by the externalities* (but nonzero taxation of their generators). Laundry purchasers will then not be able to buy laundry at a price below the high marginal cost resulting from the presence of smoke, because there is no compensation.

d. Where the externality is shiftable, the result is a bit more complicated. It is still true that no compensation for the damage suffered should be paid to victims of the externality.[35] However, victims must now be subject to a tax on any shifting activities they choose to engage in. More specifically, they must pay a unit tax for shifting equal to the marginal social damage to the secondary victim. Such an extension of the Pigouvian tax will create the requisite incentives for an optimal allocation of the external product among victims.

[34] The reader may be disturbed at the notion of expressing marginal private cost in terms of the single input, i^*, rather than the full set of inputs used by the firm. However, in equilibrium the ratio of input price to marginal physical product will be the same for all of the firm's inputs. Hence, it will cost exactly the same whether the firm expands an output by a very small amount by using more of one input, i^*, or more of some other input, i^{**}, or *any* combination of these inputs.

[35] This result requires one important qualification. As Martin Bailey has shown recently, compensation need not result in any allocative distortions if such compensation is capitalized into property values. Such compensation payments become, in effect, an increment in rent (i.e., a lump-sum transfer). We explore Bailey's argument in Chapter 14 in conjunction with our treatment of subsidies for pollution abatement.

CHAPTER 5

Uncertainty and the choice of policy instruments: price or quantity controls?

In the preceding chapter, we focused our attention on a particular policy measure: Pigouvian taxes (or effluent charges) as a means to regulate pollution. In this chapter, we will expand the set of available policy instruments to encompass marketable emission permits. Until fairly recently, most microeconomists would have argued that the two were virtually equivalent – nearly so in practice and surely so in theory. But a series of papers published in the 1970s have forced a major revision in this view.[1] These papers demonstrated that in the presence of uncertainty, the expected value of social welfare can differ markedly under a system of Pigouvian fees from that under a regime of marketable emission permits. These two policy instruments remain equivalent in a setting of perfect certainty. But as we shall see in this chapter, under particular forms of uncertainty, these two approaches to environmental management will yield very different outcomes. Depending on the shapes of the marginal damage and marginal abatement cost functions, the environmental authority will be better advised under some circumstances to use one of them, and under other circumstances to employ the other.

Our objective in this chapter is to describe the logic underlying the choice between these two policy instruments. For this purpose, we shall rely primarily on a series of simple diagrams that depict the basic propositions.

1 Effluent charges, marketable permits, and direct controls

It is important at the outset to be clear as to the precise character of the alternative policy instruments. As we have seen in Chapter 4, the

[1] See Martin L. Weitzman, "Prices vs. Quantities," *The Review of Economic Studies* XLI (October, 1974), 477–49; Zvi Adar and James M. Griffin, "Uncertainty and the Choice of Pollution Control Instruments," *Journal of Environmental Economics and Management* III (October, 1976), 178–88; Gideon Fishelson, "Emission Control Policies under Uncertainty," *Journal of Environmental Economics and Management* III (October, 1976), 189–97; and Marc J. Roberts and Michael Spence, "Effluent Charges and Licenses under Uncertainty," *Journal of Public Economics* V (April/May, 1976), 193–208.

Pigouvian fee is a tax (or effluent charge) per unit of emissions set equal to marginal social damage. In contrast, a system of marketable (that is, transferable) emission permits is one in which the regulatory authority effectively determines the *aggregate* quantity of waste emissions but leaves the allocation of these emissions among sources to market forces. To implement such a system, the environmental authority would issue permits for waste discharges such that, in the aggregate, total discharges would be at the level that equates marginal abatement cost and marginal social damage. Trading of these permits among sources would then establish the market-clearing price.

We emphasize that such a permit system is very different from the "direct controls" approach to permits or licenses. Under a system of direct controls, the environmental authority specifies for *each* source an allowable level of emissions. The emissions quota assigned to a particular source is not tradable so that there is no market in emission permits. We will have more to say about such systems of direct controls in Part II of this book. Here we simply note that in this chapter we are not concerned with such systems; our interest here is in marketable permits.

2 The equivalence of marketable emission permits and charges under certainty

It is clear that when the relevant functions are known with certainty by a welfare-maximizing regulator, exactly the same result will be achieved by a market in permits and by a system of effluent charges. If the optimal number of permits is issued by the environmental control agency, their price will be bid up on the free market to precisely the level of the Pigouvian tax. At that point, it will make no difference to the polluter whether he pays t dollars in effluent charges per unit of his emissions and pays it directly to the authorities, or whether, instead, he pays that same t dollars per unit of authorized emissions for the purchase of a permit on the unregulated permit market. In both cases, the polluter will restrict emissions by exactly the same amount, so each polluter who continues in operation will react in exactly the same way to the one incentive as to the other. The increased cost of doing business may also induce some exit from the field, but since the cost of any type of operation will not differ from one approach to the other, exit decisions will also be unaffected either in terms of the number of existing firms or the identity of the units that find it rational to cease operation.

Figure 5.1, the type of diagram we will be using throughout the chapter, depicts this outcome (it is based on the diagrams in Adar and Griffin). The horizontal axis of the diagram indicates the amount by which total

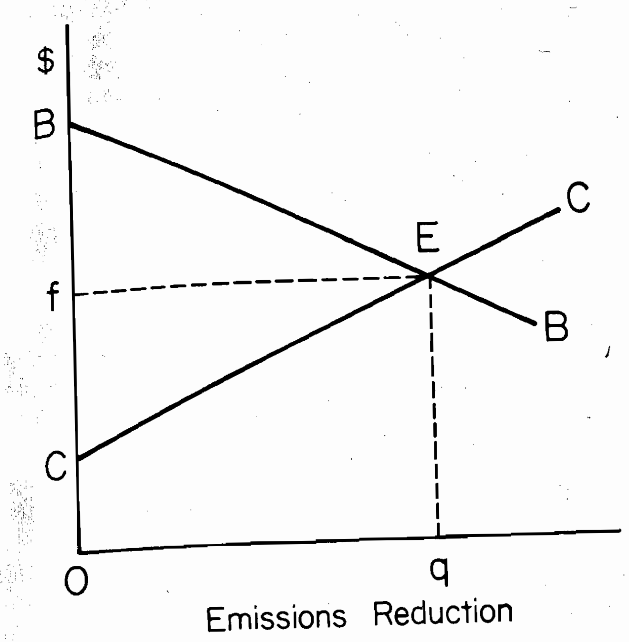


Figure 5.1

emissions are *reduced* below their uncontrolled level; the origin thus represents zero decrease in emissions below the level that would occur in the absence of an emissions-control policy. The curve *BB* represents the marginal social benefit of emissions reduction as a function of the quantity of emissions that has already been eliminated. In accord with the usual observations, it has a negative slope, indicating that the greater the degree of purity of air or water that has already been achieved, the less the marginal benefit of a further "unit" of purification. Similarly, *CC*, the curve of marginal control costs is increasing because of the rising cost of further abatement as the zero emissions point is approached. The optimal point is obviously E at which the marginal cost and benefit are equal. E can clearly be achieved by imposing a charge equal to f upon each unit of emissions; polluters would then find it more costly to pay the tax than to adopt measures that reduce their emissions up to the point where q units of emissions have been eliminated.

Similarly, the optimal solution can be attained if the environmental control agency issues a quantity of emissions permits just sufficient to lead to a q-unit reduction in discharges. If R is the amount that would be

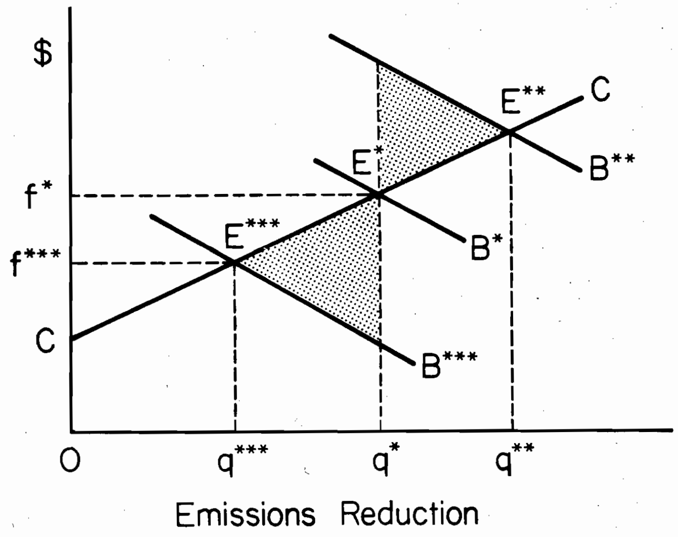


Figure 5.2

emitted in the absence of intervention by the public sector, the permits must allow, in total, $R-q$ units of emissions. Assuming that the market for permits is competitive, the price of a permit (allowing one unit of discharge) will be bid up exactly to f, that is, to the corresponding marginal cleanup cost.

Thus, both approaches will have the same result, reducing emissions to the optimal level and incurring the minimum cost for this level of control.

3 Regulatory uncertainty about the benefits function

Matters obviously become rather different when the regulator is unsure of the position of the pertinent curves and is therefore to be expected to make some error in calculating the optimal quantity of emissions reduction.

We will examine, in turn, the case of uncertainty about the benefits curve and uncertainty about the curve depicting marginal control costs. We will show in this section that when the regulator does not know the true position of the benefits curve, policy will, in general, not be optimal, which is to be expected. However, the resulting error and the corresponding social cost will be the same under effluent charges and marketable permits.

Figure 5.2 depicts this case. In the figure, the regulator has precise and correct information about the cost curve, CC. However, on the unfounded

belief that the benefit curve is B^*, the agency selects E^* as the optimal point, and so either introduces a fee, f^*, or issues the quantity of permits corresponding to q^*. Under either policy, the outcome will be the same if the market for permits is competitive. Emissions will be cut by q^* units and, if permits are issued, their price will rise to f^*.

If, however, the true benefit curve is B^{**} (rather than B^*) and the marginal benefits of abatement are thus greater than the regulator had thought, the q^*-unit reductions in emissions will be undesirably modest. In this instance, the optimal point is obviously E^{**} with a corresponding reduction in emissions of q^{**}. The social loss resulting from choosing q^* instead of q^{**} is equal to the shaded triangle to the right of and above point E^* (i.e., the excess of benefits over costs over the range from q^* to q^{**}). In contrast, were B^{***} the true benefits curve, then the choice of q^* would represent an excessive level of abatement activity. The social loss in this case would equal the shaded triangle to the left of and below E^*, which indicates the excess of control costs over benefits over the range q^{***} to q^*.

In short, an error in estimating the benefits curve necessarily has undesirable consequences, but those consequences and their undesirability will be exactly the same whether effluent charges or marketable permits are the regulator's chosen control instrument. It follows that uncertainty about the position of the benefits curve by itself offers no guidance on the choice between the two types of measures.

Why do the two approaches yield the same result when the cost curve is known? The answer is summed up in

Proposition One. Given any marginal control cost function $MC(q)$, then the regulator can be sure in a competitive market that emissions reduction q^* will emerge if price (the effluent fee) is set at $p^* = MC(q^*)$, and p^* will emerge as the equilibrium price of a unit emissions permit if a quantity of permits just sufficient to require emissions reduction of q^* is available. These prices and quantities depend exclusively on the cost function and are entirely independent of the shape or position of the benefit function.

This result follows because sources respond to the policy choice along the cost curve, CC. The authority can either set q^* directly through the issue of permits or, equivalently, can attain q^* indirectly by setting an effluent fee of f^*. The choice of a fee of f^* is identical in its effects to the issue of q^* of marketable permits.

4 Uncertainty about control costs

The key property of a system of marketable permits is that, if enforced, such a system guarantees a ceiling on emissions, *no matter how high or* *how low* the cost of keeping them to that level. Similarly, the choice of an effluent fee guarantees that if the polluters are minimizers of the cost of achieving a given vector of outputs (level of utility), the marginal cost of emissions control will be equated to the level of the effluent charge that has been selected, *no matter how large or small the resulting quantity of emissions.* Thus, a regulator who adopts a system of marketable permits will be able to achieve the amount of reduction in emissions that he had decided upon beforehand, but he may be greatly surprised at the associated costs. In contrast, the regulator who employs an effluent fee can be confident about the resulting marginal control cost, no matter how uncertain he is about the cost function, but he cannot rely on this means as a device to achieve a target level of emissions reduction.

However, this should not be taken as a claim that the regulator who uses marketable permits will be satisfied *ex post* with the quantity of emissions that emerges or that he will be content *ex post* with the level of marginal control cost if he uses an effluent charge. On the contrary, if his estimate of the cost function turns out to have been imperfect, his original estimate of the optimal level of emissions reduction and the associated level of marginal control cost will both prove to be erroneous; he will wish, in retrospect, that he had been less successful in attaining his original target of whichever of the two he turns out to achieve. More specifically, we have

Proposition Two. When the position of the marginal cost curve is lower than expected, the emissions reduction will generally be inadequate under a system of permits and excessive under an effluent charge if both are set at what appear to be their optimal levels *ex ante*; the reverse will be true if the actual cost curve is higher than the expected one.

Figure 5.3 confirms these results. In the figure, the marginal benefits curve, *BB*, is, by assumption, known with certainty. The cost curve, in contrast, is now subject to uncertainty. We see part of the *anticipated* cost curve, C_a, and the associated "optimal" point, E_a. Assuming the regulator selects either the corresponding effluent fee, f, or the corresponding volume of permits, leading to an emissions reduction, q_p, we can now see the consequences if the true curve of marginal control costs, C_t, lies below C_a. First, we see that with the marginal benefit curve having a negative slope, the true optimum, point E_t, must lie below and to the right of the anticipated optimum, E_a. The optimal reduction in emissions, q_o, will thus always be greater than q_p, the quantity selected by the regulator under his misapprehension about costs. We also see that q_f, the emissions reduction achieved by effluent fee f, will be greater than either q_p or q_o, so that we must have $q_p < q_o < q_f$. This must be so if the *BB* curve has a negative slope and if the *CC* curve has a positive slope.

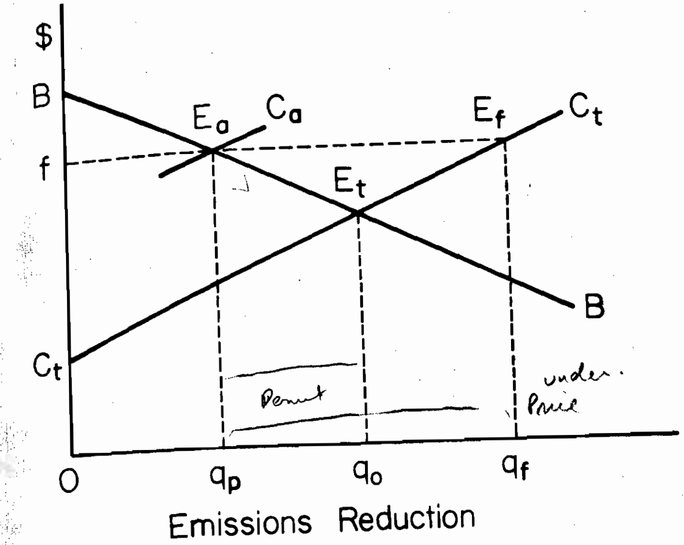
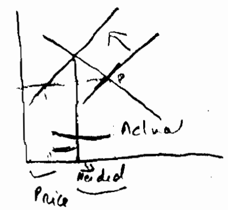


Figure 5.3



The intuitive explanation for the preceding result is straightforward. The emissions reduction q_p achieved under a system of marketable permits will be inadequate because it yields just the size of reduction the regulator initially thought to be optimal; the permit system offers no flexibility in adapting itself to the fact, which emerges subsequently, that additional emissions reductions are less costly than had been expected. The effluent fee, on the other hand, forces adoption of a level of q (denoted q_f) that incurs the same marginal cost as had initially been thought optimal; the fee approach does not adapt itself to the fact that at q_f the marginal benefit will have fallen below its level at q_o as a result of the diminishing marginal benefits to increased emissions reductions.

5 On the magnitudes of the relative distortions

Even though the true optimal value, q_o, lies between q_p and q_f, the emissions reductions achieved by marketable permits and effluent fees, respectively, do not lend any presumption that there will be anything close to equality either in the respective quantity distortions, $|q_p - q_o|$ and $|q_f - q_o|$ or in the resulting losses in consumers' and producers' surpluses. In both cases, the relative magnitudes or, rather, their expected values will depend on the shapes of the marginal cost and benefit curves and on the distribution of the random errors associated with the cost function.

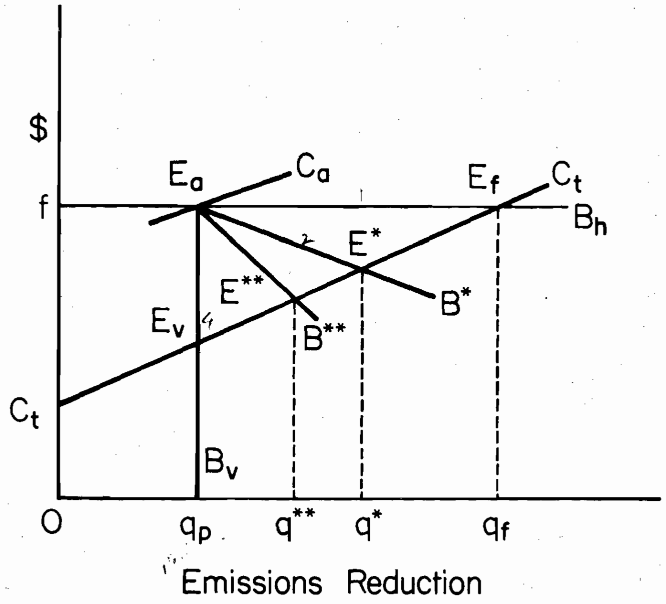


Figure 5.4

As an introduction to the relationship, we start with the quantity distortions and derive

Proposition Three. All other things being equal, the steeper the slope of the marginal benefits function, $MB(q)$ (i.e., the greater the absolute value of dMB/dq), the smaller will be the distortion $|q_p - q_o|$ resulting from regulatory error about the cost function under a system of marketable permits, and the greater will be the distortion $|q_f - q_o|$ yielded by an effluent fee.

This can once again be shown diagramatically. Figure 5.4 depicts four marginal benefit functions, ranging from the horizontal benefits curve, B_h, to the vertical benefits curve, B_v, with B^* and B^{**} being of intermediate steepness. All four curves must go through E_a since, by hypothesis, they were known correctly by the regulator and so went through his estimated optimal point, E_a. Based upon the anticipated cost curve, C_a, the regulator would thus select a fee level, f, under a system of effluent fees or, alternatively, a quantity of permits, q_p, under a system of marketable permits. We see immediately that if C_t turns out to be the true cost curve, the fee approach will result in emissions reductions of q_f. We can now

compare the distortions under the two systems. For the extreme case of a perfectly horizontal marginal benefits curve, B_h, we see that the fee instrument achieves the true optimal outcome, q_f; the distortion under the permit regime is, in contrast, relatively large, encompassing the entire range from q_p to q_f. In the other extreme case, a vertical marginal benefits curve, B_v, just the opposite is true; here, the permit approach produces the optimal outcome, and the fee system results in a large distortion $(q_f - q_p)$.

The intermediate cases show that, starting from E_f, as the benefit curve grows steeper, the optimal point must move leftward along the true marginal cost curve, from E_f to E^* to E^{**} to E_v; in short, it must move ever further from the effluent fee equilibrium, E_f, and ever closer to the permit equilibrium, E_v. Similarly, the optimal emissions reduction must move leftward, away from q_f and toward q_p.[2]

An identical argument shows that precisely the same relationships hold when the true marginal cost curve, C_t, lies above the estimated curve C_a. This completes the formal argument for Proposition Three.

Once again, an intuitive explanation is not difficult to provide. If the marginal benefits curve is declining very sharply, even a fairly severe fall in marginal costs will justify very little increase in the quantity of emissions eliminated since such an additional reduction will have little value to society. The same will obviously be true when the true marginal-cost curve turns out to be higher than the estimated cost curve (and the benefits curve is steep). In other words, in that case the quantity that was thought optimal in the erroneous *ex ante* calculation will still turn out to be very nearly correct, and so a system of marketable permits which enforces that quantity will turn out to produce a result very close to the true optimum.

On the other hand, when marginal benefits decline very little as q increases, then despite the error in the estimation of the cost function, the optimal value of the actual control cost will turn out to be very close to its estimated value *ex ante,* and the corresponding effluent fee will therefore come closer to yielding the desired results. Or, put slightly differently, if marginal benefits are relatively constant over the relevant range of waste emissions, then the fee, even though based on the anticipated function, will provide close to the right signal as a measure of external costs.

[2] A formal proof of the generality of the result is hardly necessary. C_t by assumption is a positively sloping curve that lies below and to the right of point E_a. Hence, if two negatively sloping curves emerge from E_a, and one uniformly has a greater absolute slope than the other, the former's intersection point with C_t must lie to the left of the latter's, and the result follows.

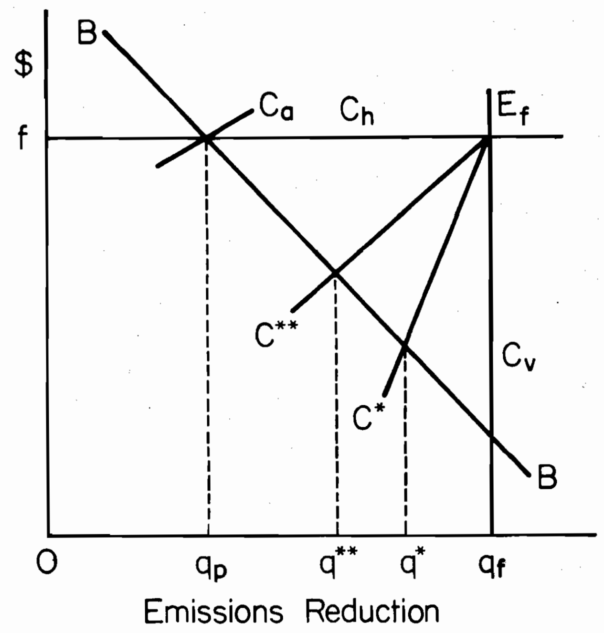


Figure 5.5

6 Effect of the slope of the cost function

In a similar manner we can derive

Proposition Four. All other things being equal, the steeper the curve of marginal control costs in the family of such curves meeting at q_f (the equilibrium value of the reduction in emissions under the effluent fee based on the erroneous cost estimate), the greater will be the distortion $|q_p - q_o|$ produced by a system of marketable permits and the smaller will be the distortion produced by the effluent fee.

The argument is indicated in Figure 5.5 and will only be sketched very briefly, since it is so similar to that of Proposition Three. In the figure, we see four cost curves through point E_f corresponding to effluent fee f and associated emissions reduction, q_f. As the true cost curve shifts from C_h to C^{**} to C^* to C_v (i.e., as it increases successively in steepness), the optimal value of q moves from q_p to q^{**} to q^* to q_f; that is, it moves steadily further from the quantity that will be achieved under a system of permits and toward the quantity that will result under an effluent fee. We

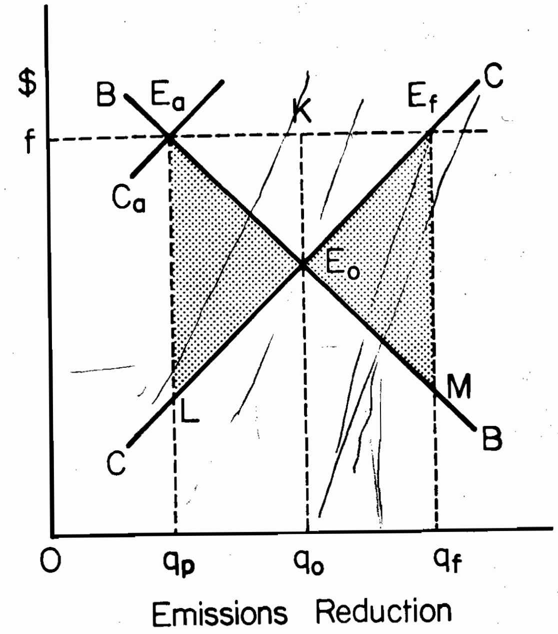


Figure 5.6

thus see that as the slope of the cost curve increases, the size of the distortion under the permit regime rises, whereas that under the fee system is diminished.

7 Relative slopes and the linear case

As a preliminary step toward a basic theorem first derived by Weitzman, we have

Proposition Five. When the marginal benefit and marginal cost curves are linear, marketable permits and effluent fees will produce the same absolute distortion when the regulator miscalculates marginal costs if the absolute values of the slopes of the two curves are equal. If the absolute value of the slope of the marginal cost curve is greater than that of the marginal benefit curve, effluent fees will lead to a smaller distortion, and *vice versa*.

The argument for Proposition Five is depicted in Figure 5.6, which shows the special case in which the slopes of CC and BB are equal in absolute value (but no assumption is made about the magnitude of that slope). E_a is again the regulator's (mistaken) *ex ante* estimate of the optimum so that he either adopts effluent fee f or imposes emissions reduction q_p via a set of permits. The true optimum is q_o, corresponding to the intersection of the (true) cost and benefit curves, and the emissions reduction under the effluent fee is q_f. To prove Proposition Five, we extend the vertical line segment q_oE_o to point K, where its height equals the value of the effluent fee. Then triangles E_aKE_o and E_fKE_o are congruent, since they are right triangles, share side E_oK and have another angle in common because of the assumed equality of slopes of E_aE_o and E_oE_f. Consequently, E_aK, the absolute distortion under permits, is equal to KE_f, the absolute distortion under the effluent fee.

This completes the proof for the case of equal slopes. The remainder of the result is an immediate corollary of what has just been shown and of Propositions Three and Four.

8 Relative slopes and consumers' and producers' surpluses

The true social damage from regulatory miscalculation is, of course, indicated by the consequent loss in consumers' and producers' surpluses, not by the distortion in emissions reductions with which we have been dealing so far. However, as we will see now, the analysis of the latter takes us a good part of the way toward analysis of the former. It is obvious that, in general, the permit approach will result in a loss of surpluses that differs, and can differ substantially, from the loss when the regulatory instrument is an effluent fee. This is illustrated in Figure 5.7. Here, q_p, q_o, and q_f indicate the reductions in emissions, respectively, under a system of permits, in an optimal solution, and under an effluent fee. The shaded areas represent the associated losses in consumers' and producers' surpluses. STE_a is the social loss under a system of permits and TUE_f is the loss under an effluent charge (both measured relative to the social optimum, q_o). In the diagram, the former loss is clearly greater than the latter, showing that the two need not be equal. Once again, their relative magnitude depends primarily on the slopes of the marginal benefit and marginal control cost curves. Indeed, here we have the fundamental theorem first derived by Weitzman:

Proposition Six. When the marginal benefit and marginal control cost curves are linear, where the former is known with certainty but an additive error term with zero expected value enters the equation for the latter (i.e., the cost curve), then a marketable permit system will produce the same expected welfare loss as an effluent fee regime if the slopes of the two marginal curves are equal. Otherwise, an effluent fee will be the preferable policy instrument to a risk-neutral regulator whose objective is welfare maximization if the marginal control cost curve is steeper than the marginal benefits curve, and vice versa. The choice is independent of the properties of the random element.

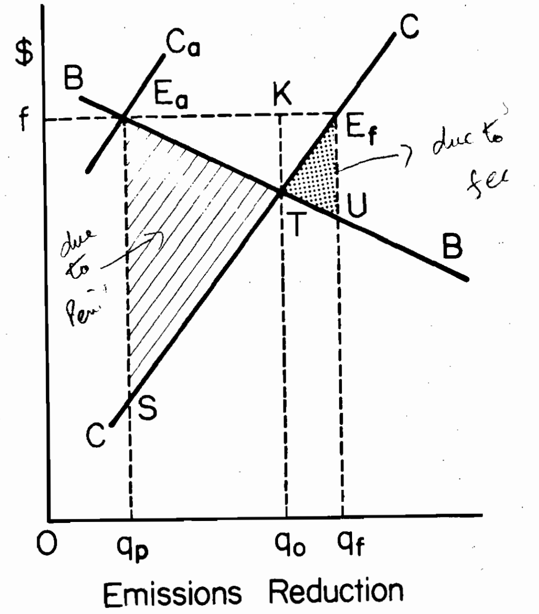


Figure 5.7

Note that this result is very similar to that in Proposition Five relating to the relative distortion of the value of q. As we will see in a moment, this is no accident. We shall provide a formal proof of this proposition shortly; however, a rough geometric argument leading to Proposition Six is now easily sketched.

We recall from Proposition Five that the absolute magnitude of the distortion under fees and under a permit system is the same if the slopes of the marginal benefit and cost curves are equal (in absolute value). In terms of Figure 5.6, we saw that this equality of slopes implied that $E_aK = KE_f$. But we can take this one step further. The equality in Figure 5.6 of E_aK and KE_f implies that the shaded triangles, E_aE_oL and E_fE_oM, have the same area.[3] But these areas, of course, represent the welfare losses, respectively, under systems of tradable permits and effluent fees. More

[3] This follows since the two triangles are necessarily similar and have the same height, $E_aK = KE_f$, measured from point K.

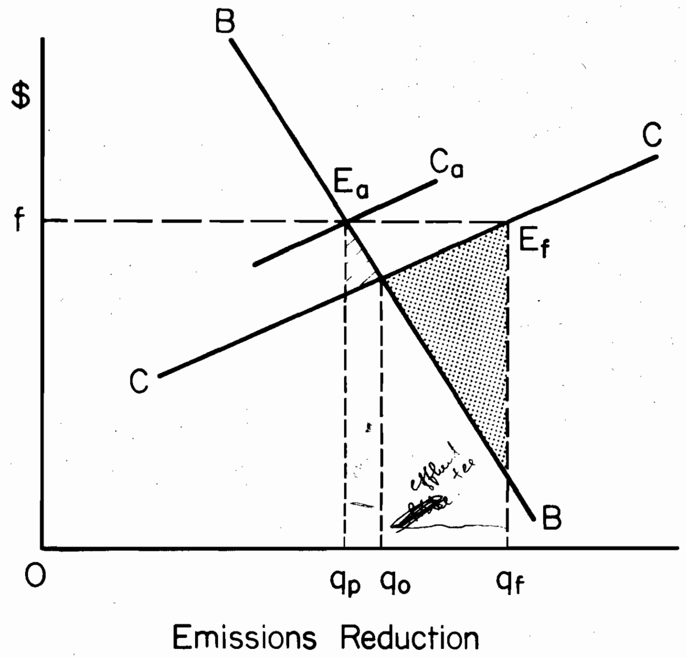


Figure 5.8

generally, as illustrated in Figure 5.7, the size of the distortion is related to the magnitude of the welfare loss as follows:

$$(E_aK)^2/(KE_f)^2 = (\text{Area } E_aST)/(\text{Area } TUE_f).$$

This is clear, because the two welfare loss triangles are necessarily similar and E_aK and KE_f are their respective heights measured from point K.

We thus see in Figure 5.7 that when the marginal control cost curve is steeper than the marginal benefits curve, the expected welfare loss under the fee approach is less than the expected loss under a permit system. Similarly, as depicted in Figure 5.8, where the marginal benefit function is the steeper of the two curves, the permit instrument is the preferred policy because it promises a smaller welfare loss than a fee regime.

9 A more formal proof of Proposition Six

The geometric approach used so far in dealing with the propositions of this chapter suffers from some limitations, most notably from its inability

to take account of the influence of the stochastic properties of the regulator's uncertainty about the pertinent functions. We therefore summarize a formal derivation of Proposition Six, mostly to illustrate the method of approach generally adopted in the literature.

Weitzman's proof deals with the *total* cost and *total* benefit functions and assumes that the random error is sufficiently small to justify quadratic approximations to those functions, that is, linear approximations to the marginal cost and benefit functions. Adar and Griffin simply *assume* such linearity and their exposition is, consequently, a bit easier to follow. We will, therefore, employ the general procedure of the latter. For our notation, let

q = quantity of emissions reduction
u = a random error, $E(u) = 0$
E = the expected value operator

$$MB = a - bq = \text{the marginal benefit of } q \tag{1}$$

$$MCC = w + vq + u = \text{the marginal control cost} \tag{2}$$

and * denotes optimal value.

Then the objective of the regulator is to select either a reduction in emissions, q^*, achieved by a set of marketable permits, or an effluent fee, f^*, which yields the expected reduction in emissions that maximizes the expected value:

$$W = E\int_0^Q [MB(q) - MCC(q,u)]\,dq. \tag{3}$$

Our procedure will be to calculate optimal values of q^* and f^* and then, by substituting these successively into (3), to obtain expressions for the respective welfare gains under permits and effluent charges. The difference between these two expressions will be used to measure the expected net benefit of the one policy over the other; this will yield Proposition Six (and a bit more).

To find f^*, the optimal fee, we first solve for q as a function of f by noting that profit maximization requires $f = MCC = w + vq + u$, or

$$q(f,u) = (f - w - u)/v. \tag{4}$$

Next, we note that optimality requires the derivative of the welfare gain (i.e., the derivative of expression (3) with respect to f) to be equal to zero after substitution of the linear expressions (1) and (2) for MB and MCC, respectively. Integrating, we obtain

$$\frac{dW}{df} = \left(\frac{dq}{df}\right)\frac{dE}{dq}\left[(a-w)q(f^*,u) - \frac{(b+v)q(f^*,u)^2}{2} - uq(f^*,u)\right] = 0. \tag{5}$$

check it

Because $E(u)=0$, we have, after differentiating with respect to q,

$$a-w-(b+v)E[q(f^*,u)]=0$$

or

$$E[q(f^*,u)]=(a-w)/(b+v). \tag{6}$$

From (4), we have

$$E[q(f^*,u)]=(f^*-w)/v. \tag{7}$$

Equation (6), incidentally, indicates that f^* should be chosen so that the marginal benefits from emissions reductions equal the *expected* marginal control costs.

Similarly, we obtain q^*, the optimal quantity of permits, by differentiating (3) with respect to q, yielding

$$q^*=(a-w)/(b+v)=E[q(f^*,u)]. \tag{8}$$

From Equations (8) and (6), we see that both policies will yield the same expected value of q. However, they will not promise the same expected level of social welfare. To see this, we first calculate the welfare gain $W(q^*)$ offered by q^*, the optimal quantity of permits. Substituting q^* into (3), the linear expressions for benefits and costs, we obtain, by integration,

$$W(q^*)=(a-w)q^*-[(b+v)/2]q^{*2}-E(q^*u) \tag{9}$$

with the last term equal to zero because $E(q^*u)=q^*E(u)=0$. To find $W(f^*)$, the welfare gain under an optimal effluent fee, we again integrate (3), obtaining the same expression as (9) but this time with (7) and (4) substituted for q^*, q^{*2}, and uq^*. We thus have

$$W(f^*)=(a-w)E[q(f^*,u)]-[(b+v)/2]E[q(f^*,u)^2]-E[uq(f^*,u)]. \tag{10}$$

Now, (4), (6), and (8) give us

$$q(f^*,u)=q^*-u/v$$

so with $E(u)=0$,

$$W(f^*)=(a-w)q^*-[(b+v)/2][q^{*2}+E(u/v)^2]+E(u)^2/v$$

or, by (9),

$$W(f^*)=W(q^*)-E[(b+v)u^2/2v^2]+E[u^2v/v^2]$$

or

$$W(f^*)-W(q^*)=E(u^2)(v-b)/2v^2. \tag{11}$$

Welfare
Difference

Equation (11) is the basic result given in Proposition Six. Since b and v are, respectively, the absolute slopes of the marginal benefit and the cost curves, (11) shows that where these slopes have the same absolute value, the expected welfare gains under the two policy regimes are equal. Where the slope of the marginal control cost curve, v, exceeds the absolute value, b, of the marginal benefits curve, the fee approach is to be preferred, and vice versa. Equation (11) also shows that $E(u^2)$, the variance of u, affects the magnitude of the difference between the welfare yields of the two policies, but it does not affect the choice of policy instrument.[4]

Of course, in the more general case, where the marginal cost and benefit functions are nonlinear, where the disturbance terms do not necessarily enter randomly, and where the regulator is not risk neutral, the results are less straightforward. The choice of instrument may now depend on the parameter values in the cost and benefit functions, the way in which the random variables enter the functions, and the frequency distributions of those variables. In such circumstances, qualitative generalizations are no longer easy to obtain.

Linear func.

10 On the choice between marketable permits and fees in practice

Proposition Six does not in itself establish any real presumption in favor of one of our policy instruments over the other. In particular cases, of course, where one has some empirical information about the shapes of the marginal cost and marginal benefit functions or even some *a priori* grounds on which to base an informed guess about their magnitudes, Proposition Six does provide some guidance to the regulator in choosing between them. But for the economy as a whole, we should not be surprised to find that each instrument will prove the better choice in some considerable number of cases.

Not everyone has drawn so noncommittal a conclusion. Weitzman, for example, expects that quantitative control instruments (such as marketable permits) will most frequently prove preferable. We quote his reasoning (which is obviously generalized well beyond the environmental issues that concern us here), leaving an evaluation to the judgment of the reader.

> There is, it seems to me, a rather fundamental reason to believe that quantities are better signals for situations demanding a high degree of coordination. A

[4] In Figure 5.7, $E(u^2)$ reflects the expected distance between C_u, the cost curve anticipated by the regulator, and CC, the true cost curve. The additivity of the error term implies that the two curves must be parallel, meaning that their distance from one another can be measured unambiguously.

classical example would be the short run production planning of intermediate industrial materials. Within a large production organization, be it the General Motors Corporation or the Soviet industrial sector as a whole, the need for balancing the output of any intermediate commodity whose production is relatively specialized to this organization and which cannot be effortlessly and instantaneously imported from or exported to a perfectly competitive outside world puts a kink in the benefit function. If it turns out that production of ball bearings of a certain specialized kind (plus reserves) falls short of anticipated internal consumption, far more than the value of the unproduced bearings can be lost. Factors of production and materials that were destined to be combined with the ball bearings and with commodities containing them in higher stages of production must stand idle and are prevented from adding value all along the line. If on the other hand more bearings are produced than were contemplated being consumed, the excess cannot be used immediately and will only go into storage to lose implicit interest over time. Such short run rigidity is essentially due to the limited substitutability, fixed coefficients nature of a technology based on machinery. Other things being equal, the asymmetry between the effects of overproducing and underproducing are more pronounced the further removed from final use is the commodity and the more difficult it is to substitute alternative slack resources or to quickly replenish supplies by emergency imports. The resulting strong curvature in benefits around the planned consumption levels of intermediate materials tends to create a very high comparative advantage for quantity instruments. If this is combined with a cost function that is nearly linear in the relevant range, the advantage of the quantity mode is doubly compounded (p. 487).

The Weitzman argument, however, does not seem applicable to many issues in the design of environmental policy. The case for the use of fees, in some instances, seems compelling. David Harrison, for example, in a study of the control of airport noise, finds that the marginal benefits from noise control are fairly constant over the relevant range.[5] On the basis of the results embodied in Proposition Six in this chapter, Harrison recommends the use of fees, rather than marketable permits, to regulate noise levels at local airports. Similarly, it has been argued that the use of quantity instruments (in this instance, direct controls) for the regulation of automotive exhausts in the face of rapidly rising marginal control costs has resulted in large welfare losses through excessive severity of controls and the associated high costs. A fee approach might, in this instance, have reduced social costs significantly.

On the other hand, where the marginal benefits function is quite steep, close control over quantity becomes important. For various hazardous wastes, for example, a permit system may well be preferable since it provides greater assurance against excessive, and possibly highly destructive, emissions of such pollutants. We shall return to these issues in a somewhat

[5] "The Regulation of Aircraft Noise," in Thomas C. Schelling, Ed., *Incentives for Environmental Protection* (Cambridge, Mass.: M.I.T. Press, 1983), pp. 41–144.

broader context in Part II when we consider the roles of various policy instruments in the arena of environmental decision-making.

11 Mixtures of instruments for pollution control

Up to this point, we have treated quantity and price instruments as alternative policy tools. However, Roberts and Spence have constructed an ingenious hybrid control instrument that employs marketable permits supplemented by an effluent fee and a subsidy. The fee serves as an escape mechanism to limit the detrimental consequences of extreme misjudgment of the optimal value of q and in the corresponding quantity of emissions permits issued. The system works as follows: the regulator issues a number of marketable emission permits, and on the market for those permits there emerges an equilibrium price per permit. Let us now use p to represent that price. At the same time, the regulator allows polluters to generate emissions without permits (or in excess of the quantity authorized by their permit holdings) but charges an effluent fee, f, per unit of such emissions. Finally, the regulator offers the polluter a subsidy, s, per unit for any unused permits, where $s \leq f$.

It is easy to show that in equilibrium we must have

$$s \leq p \leq f. \tag{12}$$

This is so because if p were greater than f, no one would purchase a permit but would pay the effluent charge instead, so p would have to fall. On the other hand, if s exceeded p, it would pay to purchase as many permits as were available and hold them unused at a profit of $s-p$ per unit; but obviously no one would be willing to sell a permit at that price.

It is also easy to see that by an appropriate choice of values of s and f, the mixed system can be transformed either into a pure permit scheme or a fee regime. It becomes a pure permit system if one sets $s=0$, $f=\infty$ so that both the subsidy and effluent charge elements are effectively eliminated. It becomes a pure effluent charge of any desired magnitude, k, if one sets $s=f=k$ so that by (12) the price of a permit is driven automatically to that level.

It follows at once that if the three regulator-controlled parameters in the system, s, f and the number of permits issued, l, are selected so as to maximize expected welfare, the result must be at least as desirable as either a pure permit regime or a pure effluent fee. For if it should transpire that either of the latter is optimal, then the maximization calculation will automatically select the corresponding parameter values that effectively eliminate the mixed system.

There are at least two other ways to describe the reason for the superiority of the mixed system. As we have seen, the use of a permit system limiting effluent quantity to q^* gives rise to two possible dangers: First, the regulator's estimate of cost on which his choice of q^* is based may turn out to be far too high, in which case the selected quantity of effluent reduction, q^*, could be far below the optimum. Second, the cost estimate might be far too low, in which case q^* will be correspondingly excessive. The mixed system induces polluters to avoid both errors when they are extreme. For example, if actual marginal cleanup cost turns out to be higher than f, it will pay polluters operating under the mixed arrangement to emit more than the permits allow and to pay the fee, f, on all emissions that exceed those justified by their permit holdings. Similarly, if cleanup costs turn out to be lower than s, it will pay polluters to continue to reduce their emissions and hold their excess licenses unused in return for the subsidy payment. Automatically, then, whenever the permit system would have performed very badly, it pays the polluters under the mixed scheme to act in a way that transforms it into a fee regime.

The reason a pure effluent fee is apt to perform badly when the regulator is uncertain about the cost function is that the fee is a fixed number, f, which corresponds to the marginal benefits of emissions reduction *only* at one value of q – the one the regulator considers, *ex ante*, to be optimal. Suppose, instead, it were somehow possible and feasible to institute a variable total effluent fee $F(q)$ that varied with q and whose marginal payment always equalled the marginal social benefit corresponding to that value of q, so that $dF(q)/dq = MB(q)$. Then in our diagrams, instead of corresponding to a horizontal line, the marginal effluent payment curve would coincide with the marginal benefit curve. In that case, at any value of q not equal to the optimal value, a polluter would find that the marginal cleanup cost was not equal to the marginal effluent charge; it would then pay the polluter to alter his emissions in the direction of the optimum. Note that to operate such a scheme, the regulator needs absolutely no information about marginal control costs, so his uncertainty on that subject becomes irrelevant. A penalty function that coincides with the damage function will yield the optimal outcome irrespective of the level of control costs.[6]

Now, the mixed system of Roberts and Spence represents a compromise between the horizontal effluent curve, f, and the pure variable payment $F(q)$. Instead, it is a step function which constitutes an approximation to the marginal benefit curve, as shown in Figure 5.9. We see there

[6] For another such scheme, see Robert A. Collinge and Wallace E. Oates, "Efficiency in Pollution Control in the Short and Long Runs: A System of Rental Emission Permits," *Canadian Journal of Economics* XV (May, 1982), 346–54.

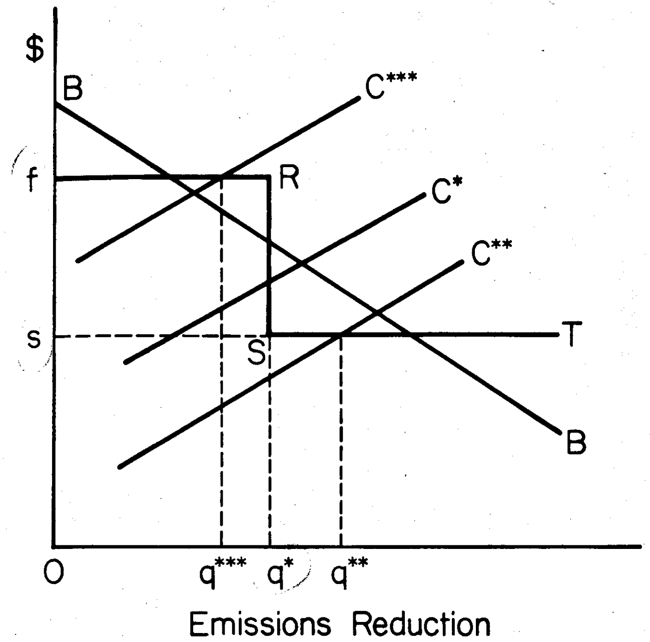


Figure 5.9

the three regulatory decision variables, q^*, f, and s. We also see that for an emissions reduction less than the prescribed quantity, q^*, there is an effluent fee, f, whereas for emissions reductions greater than q^*, incremental emissions have a low opportunity cost (equivalent to an effluent charge), s. Along the vertical segment SR, the effective fee is some value p, where $f \geq p \geq s$. It is clear that the implicit effluent locus $fRST$ is a better approximation to the marginal benefit curve, BB, than is any horizontal line. We also see how extreme errors in the regulator's estimate of marginal control costs (like curves C^{**} and C^{***}) can lead to adaptations in the value of q, unlike a pure permit system.

Roberts and Spence go on to show how one can design an effluent fee system whose graph constitutes a number of steps (unlike the one-step curve $fRST$ in Figure 5.9). With such a procedure, effluent payments can be made to approximate the marginal benefits curve, BB, even more closely, leading, in general, to an expected welfare level that is higher still. In the limit where the number of steps goes to infinity, we would, of course, have the variable fee system that we described earlier and which produces the optimal outcome.

12 A final note

In this chapter, we have found that in the presence of particular forms of uncertainty, fee and permit systems are unlikely to produce optimal outcomes and, moreover, may produce quite different results. We note in concluding this discussion that the analysis in this chapter has been wholly static in character. Moreover, we have considered only "once-and-for-all" choices of the policy variables. The results would be "softened" somewhat if we were to allow the environmental authority to amend policies that turn out, *ex post,* to involve significant welfare losses. Environmental regulators have, for example, revised environmental targets and rules for compliance. There are, of course, costs associated with changes in policies, and, in certain instances, policy decisions may be virtually irreversible in terms of their effects. However, for a wide range of environmental policy choices, there exists some opportunity for later corrections.

We raise this matter in anticipation of the analysis in Part II, where we will explore the design and implementation of environmental policy in a somewhat more realistic setting that incorporates a more diverse set of criteria for the selection of policy instruments. Expected welfare gains and losses in the standard static sense employed in this chapter will figure as an important consideration in the design of policy measures – but certainly not the only consideration.

CHAPTER 6

Market imperfections and the number of participants

In Chapter 4 we derived our results for optimal taxes and payments from a competitive model in which individuals and firms both behave as price-takers. In this framework, prices *and* our prescribed fees are parameters for individual decision-makers; they take them as given and simply respond so as to maximize utility or profit.

In this chapter, we consider some of the complications that market imperfections introduce into the analysis. More specifically, we will examine the implications of two sources of such imperfections. First, a firm that generates externalities (smoke emissions) may not sell its output in a competitive market. For example, we will consider how a profit-maximizing monopolist will respond to the Pigouvian taxes prescribed in Chapter 4. We will show that an emissions tax rate that is appropriate for the pure competitor will not, in general, induce behavior that is consistent with optimality in the second-best world inhabited by a monopolist.

We then consider a second source of imperfection: the presence of polluters who are not "fee-takers." There can be situations involving few polluters, the manipulation of whose activity levels can influence the *unit* tax paid on waste emissions. In such cases, we will see that producers (and perhaps also consumers) of externalities will have an incentive to adjust their behavior so as to influence not only their tax bills, but also the tax *rate* they pay per unit of pollution. As for the monopolist, this necessitates some modifications in the prescription for an optimal fee. In fact, we will find one case to which the Coase result calling for a tax on victims is applicable.

Finally, we offer a proposition that relates, not only to the number of producers of an externality, but also to the number of consumers or victims. This establishes a strong presumption that increasing marginal costs will characterize many sorts of externality-generating activities (particularly those involving congestion).

1 Externalities produced by a monopolist

We found in Chapter 4 that a unit fee on the polluting activities of competitive firms equal to the costs at the margin that they impose on other economic units is, in general, required to sustain a Pareto-optimal pattern of resource use. However, Buchanan has shown that the levying of such a fee on a monopolist will not usually lead to optimality, and, under certain circumstances, can even reduce the level of welfare.[1] The problem is that the Pigouvian tax on the output of the polluter may be too much of a good thing. Such a tax normally will reduce the outputs of the industry below their previous levels. However, a monopolist will already have restricted his outputs below their optimal levels, and the additional contraction in output induced by the tax may, on balance, be detrimental to society. The point is that a polluting monopolist subjects society to two sorts of costs: the external costs associated with the pollution and a cost resulting from the restriction of output. Our Pigouvian tax, while reducing the pollution costs, at the same time increases the welfare loss resulting from excessively low levels of production, so that the *net* effect on social welfare is uncertain.

2 A diagrammatic analysis

We can obtain some further insights into this problem with the aid of a simple diagram. In Figure 6.1, let DD' represent the industry demand curve confronting the monopolist, with DMR being the corresponding marginal-revenue curve. We assume that the monopolist can produce at constant cost (PMC = private marginal cost) but that his production activities impose costs on others. In particular, in the absence of any fees, the monopolist's (private) cost-minimizing technique of production generates pollution costs per unit equal to AB so that the SMC (social marginal cost) curve indicates the true cost to society of each unit of output. To maximize profits, the monopolist would produce OQ_m.

Suppose next that we subject the monopolist to a pollution tax, a fee per unit of waste emissions. This will provide an incentive to him to alter his production process in a way that yields lower emissions per unit of output. In Figure 6.1, this would have two effects: it would raise the PMC curve and, over some range, would tend to lower SMC.[2] This second effect results from the choice of what from *society's standpoint* is a lower-cost method of production (taking into account the costs of pollution). The minimum social cost of production will be reached when the pollution costs are wholly internalized so that $PMC_t = SMC_t$ (where the subscript t refers to costs in the presence of a Pigouvian tax). At this

[1] J. M. Buchanan, "External Diseconomies, Corrective Taxes, and Market Structure," *American Economic Review* LIX (March, 1969), 174–77.

[2] Buchanan's analysis assumes a fixed external cost per unit of output that is independent of the method of production.

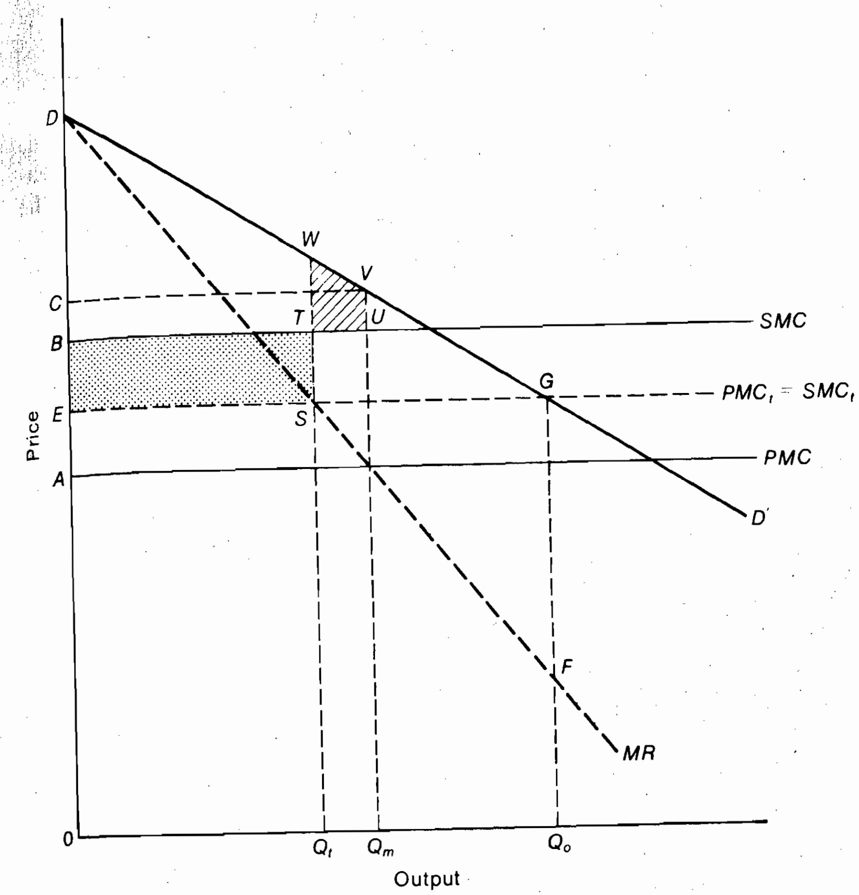


Figure 6.1

point, the firm's selection of a production process will be based upon a set of input prices (including a price of waste emissions) that reflect true social opportunity costs.

In Figure 6.1, we see that the optimal output is OQ_o, which is produced at the least social cost. To achieve this optimum, we would require *two* policy actions: a Pigouvian tax on waste emissions in order to reduce SMC to SMC_t *and* a subsidy per unit of output equal to GF (the difference between marginal cost and marginal revenue at the optimal level of output). Since we have two types of distortion, full correction generally requires two policy instruments.

3 Determination of the second-best fee

The environmental agency, however, will typically have neither the authority nor the inclination to offer subsidies to monopolists. Suppose, more realistically, that it is empowered only to tax waste emissions. The preceding discussion suggests that the agency should not impose the standard Pigouvian fee equal to marginal social damage, but should alter the fee to reflect the welfare losses associated with monopolistic restrictions in output. In the absence of the two policy instruments required for complete correction of the set of distortions, the agency should determine the second-best fee on waste emissions.

This is, in principle, a straightforward problem. Both Lee and Barnett have derived formulae for such a second-best fee.[3] Following Barnett's formulation, we note that maximization of social welfare requires that we maximize the difference between the value of the monopolist's output and the full social cost (including damages from pollution) of providing that output. We thus must maximize

$$W=\int_0^y f(y)\,dy-c(y,a)-D(s) \qquad s(y,a). \tag{1}$$

where y is the monopolist's level of output, $f(y)$ is society's willingness to pay for that output, $c(y,a)$ is the firm's cost of production and abatement (where a indicates the level of abatement activity), and $D(s)$ denotes the social damages associated with the level of waste emissions, s. Differentiating equation (1) with respect to t, the unit tax on waste emissions, yields the following first-order condition for the maximization of social welfare:

$$f(y)\frac{dy}{dt}-\frac{\partial c}{\partial y}\frac{dy}{dt}-\frac{\partial c}{\partial a}\frac{da}{dt}-\frac{dD}{ds}\left[\frac{\partial s}{\partial y}\frac{dy}{dt}+\frac{\partial s}{\partial a}\frac{da}{dt}\right]=0. \tag{2}$$

The monopolist's problem is to maximize profits:

$$\pi=f(y)y-c(y,a)-st. \tag{3}$$

Assuming for now that the monopolist takes t as given, profit-maximizing behavior implies the first-order conditions:

$$\frac{\partial\pi}{\partial y}=f(y)+y\frac{df}{dy}-\frac{\partial c}{\partial y}-t\frac{\partial s}{\partial y}=0 \tag{4}$$

[3] D. R. Lee, "Efficiency of Pollution Taxation and Market Structure," *Journal of Environmental Economics and Management* 2 (September, 1975), 69–72; A. H. Barnett, "The Pigouvian Tax Rule under Monopoly," *American Economic Review* LXX (December, 1980), 1037–41.

$$\frac{\partial\pi}{\partial a}=-\frac{\partial c}{\partial a}-t\frac{\partial s}{\partial a}=0. \tag{5}$$

Substituting (4) for $f(y)$ and (5) for $\partial c/\partial a$ into equation (2) and solving for t yield the solution for the welfare-maximizing tax (t^*):

$$t^*=\frac{dD}{ds}+\frac{y\dfrac{df}{dy}\dfrac{dy}{dt}}{\dfrac{\partial s}{\partial y}\dfrac{dy}{dt}+\dfrac{\partial s}{\partial a}\dfrac{da}{dt}}. \tag{6}$$

Letting η denote the price elasticity of demand, we can write equation (6) in the form

$$t^*=\frac{dD}{ds}+\frac{-\dfrac{f(y)}{|\eta|}\dfrac{dy}{dt}}{\dfrac{\partial s}{\partial y}\dfrac{dy}{dt}+\dfrac{\partial s}{\partial a}\dfrac{da}{dt}}. \tag{7}$$

$\frac{\partial P}{\partial q}\cdot\frac{q}{P}$ $\quad \boxed{\frac{1}{|\eta|}=\frac{dy}{df}\cdot\frac{f}{y}}$ $\quad \eta=\frac{df}{dy}\cdot\frac{y}{f}$

On examination of (7), we note that the first term on the right side is simply the marginal social damages associated with an additional unit of waste emissions; this is equal to our standard Pigouvian fee on a perfectly competitive firm (t_c). The second term should thus reflect the welfare losses associated with the reduced output of the monopolist. This is, indeed, the case. What equation (7) indicates is that[4]

$$t^*=t_c-\left|(P-MR)\frac{dy}{ds}\right| \tag{8}$$

$\frac{(P-MR)\frac{dy}{dt}}{\frac{\partial s}{\partial t}} = -|P-MR|$

where $P=f(y)$ is the price of output and $MR=f(y)+yf'(y)$ is marginal revenue. Since a profit-maximizing firm sets marginal revenue equal to marginal cost (MC), we have

$$t^*=t_c-\left|(P-MC)\frac{dy}{ds}\right|. \tag{9}$$

The second term on the right side of (9) is thus the welfare loss from reduced output expressed as the difference between the value of a marginal unit of output and its marginal cost times the reduction in output associated with a unit decrease in waste emissions.

The second-best fee for a polluting monopolist should thus be less than that for a perfect competitor. Moreover, as (7) makes clear, the fee will vary directly with the monopolist's price elasticity of demand. This is as

[4] To see this, note that the denominator of the last term in (7) can be interpreted as ds/dt. Moreover, by the standard formula, $MR=P(1-1/\eta)$, so $f(y)/\eta=P/\eta=P-MR$.

$MR = P - P/\eta \qquad P/\eta = P - MR$

it should be, for the more price elastic is the demand, the smaller is the divergence between price and marginal cost and hence the smaller the welfare loss associated with any reductions in output. In the limiting case of perfect competition where $\eta = \infty$, the second term on the right side becomes zero, and $t^* = t_c$.

The implication of the analysis is that in the presence of monopolistic sources of pollution, the environmental authority must, ideally, impose a differentiated set of effluent charges in which the fee for any given source will depend not only on the marginal social damage but also on the price elasticity of demand for the source's output and on its abatement cost function. This last form of information is needed to determine dy/ds in equation (9).

4 Pigouvian taxes on monopolists: some further thoughts

In principle, therefore, we can determine the optimal set of effluent fees on all polluters, be they competitive firms or monopolists. However, this is not, in fact, very comforting. First, such a determination would require an enormous amount of information encompassing both the price elasticities of demand *and* the abatement costs for each polluter. Second, even if the environmental authority were able to assemble all these data, it is difficult to envision a legal and political setting in which such a discriminatory set of fees would be acceptable. And, third, complex as all this would be, the rules for other market forms (oligopolists, monopolistic competitors) may be yet more complicated!

At the policy level, the real choice may well be that between a single fee applicable both to perfect and imperfect competitors or the abandonment of a system of fees for environmental protection. From this perspective, the important issue is the *extent* of the welfare loss associated with the pattern of reductions in output induced by the charge on waste emissions. There is a substantial empirical literature (with the seminal Harberger paper as its source) suggesting that the magnitude of the overall allocative losses in the economy attributable to monopolistic distortions is quite small.[5] Since the large estimated welfare gains offered by pollution abatement would seem to dwarf the apparently small welfare losses resulting from the effects on industry outputs, it is tempting to conclude that concern over monopolistic distortions represents, in this case, a theoretical nicety that we can safely ignore in the design of environmental policy.

[5] A. Harberger, "Monopoly and Resource Allocation," *American Economic Review, Papers and Proceedings* XLIV (May, 1954), 77–87.

This, however, will not quite do. The proper question is: *Given the existing pattern of monopolistic distortions* (i.e., divergences between price and marginal cost), do the *additional* reductions in monopoly output that would result from competitive Pigouvian charges generate efficiency losses of a substantial magnitude? Returning to Figure 6.1, we see that the standard Pigouvian fee would result in a reduction in output from OQ_m to OQ_t. At this output, the fee would generate a cost saving to society indicated by the shaded rectangle *EBTS*. At the same time, it would be accompanied by a welfare loss represented by the trapezoid *UVWT*; this is the loss in consumers' surplus resulting from the contraction in output to OQ_t.

The net effect of the fee on social welfare thus depends on the relative sizes of these two areas, and this is obviously an empirical matter. In one study, Oates and Strassmann have drawn on the empirical literature to obtain some representative values of the various parameters that determine the sizes of these areas.[6] Using these parameter values, their calculations indicate that the likely welfare gains from improved environmental quality (the rectangle *EBTS*) will typically be far larger (roughly by an order of magnitude) than the loss from reduced monopoly outputs (the trapezoid *UVWT*). If correct, their findings would suggest that, in view of the range of policy options available to the environmental authority, it is probably best to ignore the issue of incremental output distortions associated with a system of effluent fees. The case for Pigouvian taxation is, in all likelihood, not seriously undermined by the presence of monopoly producers.[7]

5 Monopolistic offsets to external effects

There is one line of argument that suggests that monopolization can sometimes reduce the need for tax measures in the control of externalities. Should a monopoly take over both the firms that generate some externalities and those that are affected by them, the externalities would be internalized and, therefore, what (in this respect) is good for society would then be good for the monopoly. For example, an electricity-laundry combine that took control of both these activities might soon enough recognize

[6] W. E. Oates and D. L. Strassmann, "Effluent Fees and Market Structure," *Journal of Public Economics* XXIV (June, 1984), 29–46.

[7] For more on this issue, see P. Asch and J. Seneca, "Monopoly and External Cost: An Application of Second Best Theory to the Automobile Industry," *Journal of Environmental Economics and Management* III (June, 1976), 69–79; W. S. Misiolek, "Effluent Taxation in Monopoly Markets," *Journal of Environmental Economics and Management* VII (June, 1980), 103–7; P. Burrows, "Controlling the Monopolistic Polluter: Nihilism or Eclecticism?," *Journal of Environmental Economics and Management* VIII (December, 1981), 372–80.

the costs to the laundry of the smoke generated by electricity production, and it would be motivated to deal with the smoke in the most economical manner available.

Although the argument is valid, it seems to us that its relevance is rather limited. Some of the most serious externalities that now beset society affect private individuals far more than they do firms. There is presumably no way in which we as individuals can merge with or be acquired by a monopoly firm, so that the health effects of the pollutants we breathe become a relevant entry in the account books of the polluting firm. Moreover, even where the polluter and his victim are both firms, their fields of operation are often so diverse that their merger is simply not practical. Conglomerates made up of oil refineries or electricity generating plants *and* laundries do not seem very common in practice.

6 Pollution by manipulators of the tax rate[8]

Even where a polluting activity is not carried out by a monopolist, the analysis may have to take account of a small-numbers problem if only one or a very few sources of substantial emissions are to be found in a particular geographic area. There are many communities whose air and water quality is effectively determined by the activities of one or several producers and smaller cities that are enveloped by the smoke emitted by one factory's chimneys.

Although voluntary negotiation is not more to be expected here than in the large-numbers case, another analytic complication for the Pigouvian approach does arise that our discussion up to this point has assumed away. The polluting firms may recognize that their behavior can affect the rate at which their emissions are taxed. Just as a monopolist or an oligopolist can profit by adjusting his output to obtain a more profitable price, he may be able to benefit by modifying his emissions to obtain a more favorable tax *rate*. And in both cases the result will generally violate the requirements for Pareto optimality unless special corrective measures are undertaken.

7 Preliminary: two interpretations of interim Pigouvian tax rates

Before getting down to a more formal discussion of the issue, we must note an ambiguity in the definition of the Pigouvian tax prescription for

[8] The discussion of the next three sections is based entirely on the analysis of Earl A. Thompson and Ronald Batchelder, "On Taxation and the Control of Externalities: Comment," *American Economic Review* LXIV (June, 1974), 467–71.

a situation that is, at least initially, *not* Pareto-optimal. Suppose that, in an optimal solution, five thousand gallons of a given effluent will be emitted into a stream and that the marginal damage at that point is five cents per gallon. Today, however, suppose four times that much is being poured into the waterway and that the corresponding marginal social damage is ten cents per gallon. What, then, is the appropriate Pigouvian tax rate on effluents for *today*: the optimal social damage level (that is, five cents), or the current marginal social damage (ten cents per gallon)? The literature is ambiguous on this point and, indeed, Coase and others have questioned whether the second of these two possibilities, a tax rate that varies over time with the current marginal damage rate, would actually converge to an optimum. Elsewhere, one of the authors of this book has argued that it would converge if the usual stability and convexity assumptions for a competitive equilibrium also hold in the presence of externalities.[9] It can, indeed, be argued that this is true by definition: if the market equilibrium is unique and (with the appropriate tax-subsidy rates) is also Pareto-optimal, then the assumption of stability means that the economy must approach the optimum, with current tax rates converging to optimal tax rates as marginal damages approach their optimal levels. After all, in this sense, the tax rates are perfectly analogous to competitive prices that converge along with marginal products and marginal rates of substitution to their optimal values.

The distinction between the two Pigouvian solutions is critical for the discussion of this section. If we define the Pigouvian prescription to call for the calculation and imposition of an optimal tax rate from the beginning, leaving it invariant come hell or high water, then it will obviously constitute no invitation to the isolated firm to modify its emissions in order to influence that tax rate. 1.

However, if the tax rate is adjusted (iteratively) to the magnitude of current marginal damage, the single polluter may find it in his interests to take into account the effects of his decisions on the tax rate he pays. He may find it profitable to emit more or less than he otherwise would in order to improve his tax position. 2.

Certainly, the analogy with flexibility of competitive pricing makes it worth considering the case of the current Pigouvian tax that is adjustable with current damage costs. We may remark, however, that there is little justification for the view that this iterative approach is somehow the more "practical" of the two (that is, that it is simpler to approach the optimal tax rates step by step rather than trying to construct a detailed model of

[9] See W. J. Baumol, "On Taxation and the Control of Externalities," *American Economic Review,* LXII (June, 1972), 307–22.

the entire economy and calculating the optimal tax rate from the start). In our view, as we will note again in a later chapter, neither of these procedures seems to lend itself well to implementation. The fixed tax rate does not, because we are still very far from being able to construct from empirical information the requisite general equilibrium model in the detail needed for numerical evaluations of all the many pertinent tax rates. 2. But the iterative method is hardly more promising, because the calculation of detailed and periodic revisions of estimates of marginal social damage for all significant externalities problems is an undertaking we do not know how to carry out.

8 A single-polluter model

To investigate the behavior of the polluter (or of his victim, if one or the other of them is a single-decision unit), we utilize the Kuhn-Tucker relationships corresponding to the emissions variable in our basic externalities model of Chapter 4. It will be recalled (Table 1 of Chapter 4) that relationship (5°) constitutes the relevant necessary condition for Pareto optimality. For $s_k > 0$ (that is, positive emissions by our one emitting firm), (5°) thus becomes, after some obvious modification of notation,

$$\underbrace{-\mu_k f_s^k}_{mc_k} - \sum \lambda_j \mu_z^j - \sum_{\bar{k} \neq k} \mu_{\bar{k}} f_z^{\bar{k}} \equiv -\mu_k f_s^k - D = 0. \tag{5°}$$

Here we take firm k to be the polluter, and all other firms $\bar{k} \neq k$ to suffer some pollution damage (that may, in some cases, be zero). Thus, the first term in (5°) represents the marginal cost to the emitting firm, k, of a reduction in emissions, and (after multiplication by -1) the other two terms, which we now write for simplicity as D, represent the marginal social damage to individuals, j, and to other firms, k^*, as was shown in Chapter 4. The optimal pricing policy in the large-numbers case, as described in (8) of Chapter 4, called for a tax rate on emissions equal to the marginal social damage. Specifically, we have

$$t = -\sum \lambda_j u_z^j + \sum \mu_{\bar{k}} f_z^{\bar{k}} = D. \tag{10}$$

Let us now examine the profit calculation of the emitting firm, k, when such a tax is imposed. Its Lagrangian profit function becomes (where y_{ik} is its quantity of output or input i) function of s_k.

$$L = \sum p_i y_{ik} - \beta_k f^k(y_{1k}, \ldots, y_{nk}, s_k) - s_k D$$

in which the last term represents the emissions tax payment. The first-order maximum condition corresponding to the variable s_k now becomes, writing D_s for $\partial D / \partial s_k$,

$$\frac{\partial L}{\partial s_k} = -\beta_k f_s^k - D - s_k D_s = 0. \tag{11}$$

Comparing the condition for profit maximization (11) with the corresponding optimality requirement (5°), we see that the two are no longer identical. Only if D_s is zero will the two equations be the same.[10] But if there is only a single emitter of smoke, we can no longer assume that this element will be zero, because the level of its emission can affect the marginal cost of smoke to others. Thus, suppose an increase in pollution leads others to move away from the vicinity of the source and thereby reduces the marginal damage of its emission. Then D_s will be negative, so that at the point at which $-\beta_k f_s^k - D = 0$, as Pareto-optimality condition (5°) requires, $\partial L / \partial s_k$ will still be positive, that is, the polluting firm will benefit by increasing its smoke emissions. The reason, of course, is that by doing so, it will drive some of those who suffer from the smoke away from the source and hence reduce the number of individuals subject to smoke damage, with the firm's tax rate declining correspondingly. In that event, optimality requires a tax higher than that given by the Pigouvian prescription. The additional tax is necessary to discourage the excess smoke emissions that would otherwise become profitable.

Thompson and Batchelder point out that this analysis is symmetrical in the sense that the Pigouvian rule works no better where there are many polluters but only a single victim, a case of some theoretical interest though it is probably of rather limited importance in practice. If the one victim is a firm, for example, it will benefit by transferring a proportion of its operations in excess of the optimum to the geographic area where there is pollution damage. The single laundry will move an excessive proportion of its activities near its plant that suffers from pollution, knowing that thereby the marginal smoke damage and, hence, the tax rate will be increased. It does this as a means to force an uneconomically large amount of investment in pollution control on the emitters.

In this case Coase does turn out to be right, after all. A tax on the victims is necessary to prevent resource misallocation. The tax must be sufficiently high to discourage excessive absorption of damage by the single victim, something he will undertake as a means to beat the tax game by forcing emitters to be cleaner than is socially desirable.

9 Why marginal congestion costs must generally be increasing

So far, we have considered almost exclusively the role of the number of generators of an externality. We come now to a significant policy issue in

[10] It will be remembered that, then, as was shown in Chapter 4, $\beta_k = \mu_k$. On this, see (8b) in Chapter 4.

which the number of persons consuming the externality also has an important bearing on the matter. It has been observed that the social costs of externalities seem to increase more rapidly than the density of the population involved. A case in point is that of congestion, where damage appears to rise disproportionately to the number of individuals causing the crowding. What has not generally been recognized is that the very logic of congestion costs makes it implausible that they will increase only linearly with the size of the relevant population.

Let

- n be the size of the population creating and consuming the congestion (for example, the number of cars on a stretch of highway);
- $c(n)$ be the congestion cost per capita of this population (for example, the number of minutes lost per vehicle in traversing the stretch of highway).

Evidence on congestion problems suggests that, after some point at which congestion begins to set in,

$$c'(n) > 0.$$

That is, per unit congestion costs will be increased by an increase in numbers. But *total* social cost to *all* persons affected must be

$$f(n) = nc(n).$$

The result follows immediately, for we must have

$$f'(n) = c(n) + nc'(n),$$

so the elasticity of congestion cost with respect to n is

$$\frac{n}{f(n)} f'(n) = \frac{nc(n)}{nc(n)} + \frac{n^2c'(n)}{nc(n)} = 1 + \frac{nc'(n)}{c(n)} > 1.$$

Hence, the social cost of congestion *must* increase more than proportionately with the number of individuals involved unless $c'(n) \leq 0$. In practice, of course, observation indicates that once congestion begins to set in, both $c'(n)$ and $c''(n)$ are positive and substantial in magnitude so that the preceding result will be strengthened correspondingly.[11]

Clearly, the preceding observation does not apply only to congestion problems. It is equally relevant to any case involving reciprocal externalities.

[11] Numerous studies of highway congestion indicate the striking rapidity with which traffic speed is reduced by additional vehicles once congestion has set in.

CHAPTER 7

Are competitive outputs with detrimental externalities necessarily excessive?

In this chapter we examine the direction of the bias produced by externalities. Is it true, as often asserted, that when an activity generates external benefits, its competitive equilibrium level will always be below its optimum, and that where an activity imposes external costs, its equilibrium level must be excessive?[1]

This is a proposition that underlies much of the policy advice given by economists on externalities issues: allocate more resources to goods that yield beneficial externalities and reduce their allocation to those that generate detrimental externalities. But suppose that advice is not always correct – what do such exceptions imply about the economist's advisory role?

As a matter of pure theory this problem is not as serious as the one discussed in the next chapter, for the difficulty we are considering here does not undermine the Pigouvian tax-subsidy solution. So long as the appropriate convexity conditions hold and the economy is competitive, one need merely impose the appropriate tax rates and the market equilibrium must occur at a Pareto optimum, wherever it may lie in relation to the equilibrium that would hold in the absence of Pigouvian taxes.

In practice, however, as will be emphasized in Part II, we do not know how to find or perhaps even to approximate optimal tax rates and so considerably coarser policy measures must be utilized. Usually these rely

[1] The literature on this issue includes J. M. Buchanan and M. Z. Kafoglis, "A Note on Public Goods Supply," *American Economic Review* LIII (June, 1963), 403–14; W. J. Baumol, "External Economies and Second-Order Optimality Conditions," *American Economic Review* LIV (June, 1964), 358–72; A. Williams, "The Optimal Provision of Public Goods in a System of Local Government," *Journal of Political Economy* LXXIV (February, 1966), 18–33; W. C. Brainard and F. T. Dolbear, Jr., "The Possibility of Oversupply of Local 'Public' Goods: A Critical Note," *Journal of Political Economy* LXXV (February, 1967), 86–90; A. Williams, "The Possibility of Oversupply of Public Goods: A Rejoinder," *Journal of Political Economy,* LXXV (February, 1967), 91–92; P. E. Vincent, "Reciprocal Externalities and Optimal Input and Output Levels," *American Economic Review* LIX (December, 1969), 976–84; M. Olson, Jr. and R. Zeckhauser, "The Efficient Production of External Economies," *American Economic Review* LX (June, 1970), 512–17; Peter A. Diamond and James A. Mirrlees, "Aggregate Production with Consumption Externalities," *Quarterly Journal of Economics* LXXXVII (February, 1973), 1–24.

heavily on the conventional wisdom that constitutes the subject of this chapter: the acceptance of the view that one should expand outputs that yield beneficial externalities, and conversely.

We will find that there can, indeed, be cases in which the equilibrium output of a competitive industry that yields external benefits exceeds its optimal level and the reverse may be true in the case of damaging externalities. But, contrary to what has been implied in a number of recent writings (including a note by one of the present authors),[2] we will show that this cannot occur where there is a single activity that generates one externality and the usual convexity premises hold. That is, if there is one externality-producing activity and if convexity holds throughout, the conventional wisdom on this subject is strictly accurate: the competitive output of a good that generates external benefits will always be less than any of its Pareto-optimal values, and that of an output that yields detrimental externalities must always exceed such an optimum.

This result is rather more surprising than it may at first appear, for the obvious implication of an externality about the direction of change that is socially desirable is only *local* (that is, it tells us only about the best direction for a *small* move from the competitive equilibrium). Yet comparison between the competitive equilibrium and a social optimum is a *global* issue. We will see that the assumptions that have just been listed are sufficient to permit us to leap from the local to the global conclusion.

Although this result seems to be comforting to those who use theory as a basis for advice to policy makers, it is a weak reed on which to rely in practice. For, as will be shown, the theorem can break down if *any one* of the following four conditions holds:

a. the initial position is not a point of perfect competitive equilibrium;
b. there is more than one activity in the economy that yields an externality, or where different activities yield different externalities;
c. there exists any activity such as recycling or purification that can abate the externality;
d. the standard concavity-convexity conditions are violated somewhere in the economy.

Because *none* of these conditions is in fact satisfied in reality, we end up with relatively little confidence in the applicability of the global proposition that was just described. Moreover, as we will show in the next chapter, the presence of externalities contributes to the likelihood that the concavity-convexity assumptions constituting the second-order optimality conditions will not be satisfied. To put the matter starkly but not inaccurately, the more significant an externality, the more likely it is that the convexity assumptions will break down, thereby reducing the confidence we can have in the rules about the relation between the competitive equilibrium and the social optima that are described in this chapter. Add to this the likelihood that violation of the convexity conditions will be accompanied by a multiplicity of local maxima, and it is clear that this can complicate enormously the problems of policy design; in particular, it can undermine a price-tax program designed to induce optimal resource usage.

[2] See Baumol, "External Economies and Second-Order Optimality Conditions," *American Economic Review.* Different errors in a recent attempt to prove my original contention were pointed out to me by Robert Dorfman and by members of my seminar at the Stockholm School of Economics in January, 1973. I am, of course, deeply grateful to them for keeping me from falling into traps of my own devising. W.J.B.

1 Marginal externalities and the direction of misallocation

Before turning to the relatively new materials beginning in Section 3 we must, as a basis for comparison, review what may be considered the fundamental policy proposition of the theory of externalities:

Proposition One. If $y_1^c = \Sigma\, y_{1k}^c$ is the competitive level of the only activity that generates externalities,[3] or if the activity levels of all other items that generate externalities are held constant, then

a. If y_1 generates social damage, a small decrease in y_1 from y_1^c (that is, a marginal transfer of resources from y_1 to other activities) will increase social welfare;
b. If y_1 yields marginal social *benefits,* a small transfer of resources from other activities to y_1 will increase social welfare.

The proposition may be considered self-evident. In competitive equilibrium, the marginal private benefit of an increase in any activity level is zero ($mpb_1 = mpb_2 = 0$). But for any other activity, 2, whose level is permitted to vary because it produces no externalities by hypotheses, we have $mpb_2 = msb_2$ (marginal social benefit of 2). For activity 1, say, in the detrimental externalities case, $msb_1 < mpb_1$. Hence, in competitive equilibrium we must have $msb_1 < msb_2$, and it follows that a transfer of resources from 1 to 2 will be socially beneficial. That is, essentially, all there is to the matter.

[3] Commodity 1 can, of course, be a composite of all externality-generating activities, some of which may be detrimental while others may be beneficial. A few moments consideration confirms that no change in argument is required by this generalization.

2 A more explicit analysis

A proof taking explicit cognizance of the pertinent general-equilibrium relationships is somewhat tedious and not really more rigorous. Nevertheless, we provide it now, first, because, so far as we are aware, it is not available elsewhere, and, second, because it is needed for our analysis at a critical point later in the chapter.

In deriving our result, we return to our basic externalities model of Chapter 4. We again use the notation

x_{ij} = the level of consumption of commodity i by individual j

y_{ik} = quantity of output (input equals negative output) i produced (used) by firm k

r_i = the available quantity of resource i

s_k = the output of pollutant by firm k

$z = \sum s_k$ = total pollution output

$u^j(x_{1j}, \ldots, x_{nj}, z)$ = individual j's utility function

$f^k(y_{1k}, \ldots, y_{nk}, z)$ = firm k's production relationship

$s_k = g^k(y_{1k}, \ldots, y_{wk})$ = firm k's emissions function,

where the $y_{1k}, \ldots, y_{wk}$ are those activities that either generate externalities or can be used to suppress them (for example, labor used in recycling). We will refer to $y_{1k}, \ldots, y_{wk}$ as the activities *directly affecting* the magnitude of the externality.

Then the production constraints for a Pareto-optimality calculation are:

$$\left.\begin{array}{ll} f^k(\cdot) \le 0 & (\text{all } k) \\ \sum_j x_{ij} \le r_i + \sum_k y_{ik} & (\text{all } i) \\ z = \sum g^k(\cdot) & \end{array}\right\} \qquad (1)$$

and the nonnegativity conditions listed in Chapter 4.

To derive Proposition One, we will posit a small change, dy_{1k}, in the activity levels y_{1k}, holding constant the levels of all other activities that affect externalities directly; that is, we set

$$dy_{2k} = \cdots = dy_{wk} = 0. \qquad (2)$$

We will then undertake an adjustment in all other activity levels that renders this change feasible (that is, we will find a set of dx_{ij}, dy_{ik}, dz values that, given the dy_{1k}, will satisfy our constraints). These adjustments in the values of the other variables that are required for feasibility will be obtained by total differentiation of our constraint relationships. We will then substitute these feasible changes in the values of the variables into an appropriate objective function to see whether its value increases or decreases. In this process we will also make use of the information derived from the assumption of competitive equilibrium to relate the state of affairs on the production side with that on the consumption side of the equilibrium. This, in outline, is the logic of the argument.

To derive our proposition, we must assume that our constraints (1) hold as equalities throughout or that the two sides of any such relationship differ by a constant that drops out in differentiation. This may seem to evade the issues that led to the utilization of inequalities in our model. However, in the analysis of Proposition One, this premise is required by the logic of the issue, because it is equivalent to the assertion that the level of employment and of direct waste of resources is held constant throughout. These *must* be held constant in this analysis, because we are concerned here with the effects of *reallocation* of resources as contrasted with changes in their level of employment.

To obtain values of the changes in activity levels consistent with the conditions our technological constraints impose on the reallocation (that is, requiring the postulated change in the externality-generating activity y_{1k} to be feasible), we differentiate each of the constraints (1) totally to obtain

$$df^k = \sum f_i^k \, dy_{ik} + f_z^k \, dz = 0 \quad \text{or} \quad \sum f_i^k \, dy_{ik} = -f_z^k \, dz \quad (\text{all } k) \qquad (3)$$

$$\sum_j dx_{ij} = \sum_k dy_{ik} \quad (\text{all } i) \qquad (4)$$

$$dz = \sum_k \sum_{i=1}^{w} g_i^k \, dy_{ik} = \sum_k g_1^k \, dy_{1k}, \qquad (5)$$

because by (2) we have assumed $dy_{ik} = 0$, $(i = 2, \ldots, w)$.

We now want to determine how much the resulting changes are worth to the individuals who compose the community. For this purpose we evaluate the effects on each individual, j, in terms of the amount of some numeraire commodity, call it item n. We take n to be something like labor (leisure) that is used by every individual and every firm. Thus, a change, dx_{ij}, in the quantity of item i in j's possession would be evaluated as $(u_i^j/u_n^j)\,dx_{ij}$, where the expression inside the parentheses is the marginal rate of substitution between i and n. Hence, the total value of the output changes we are considering to the community as a whole is

$$dv = \sum_i \sum_j (u_i^j/u_n^j)\, dx_{ij} + \sum_j (u_z^j/u_n^j)\, dz. \tag{6}$$

If $dv > 0$, we say that the change is a "*potential* Pareto improvement."[4]

We assume the system is in competitive equilibrium at prices p_i, with p_n, the price of the numerative commodity, equal to unity. Consequently, by the standard result [compare relations (3^c)–(5^c) of Chapter 4] we have for every individual and firm that uses (produces) some of i and n

$$p_i = u_i^j/u_n^j = f_i^k/f_n^k \quad (\text{all } i, j, k). \tag{7}$$

We obtain, through the following sequence of tedious but straightforward steps, a translation of dv into a form that is directly interpretable in terms of the externality. Using the simplified notation

$$T \equiv \sum_j (u_z^j/u_n^j)\, dz, \tag{8}$$

we have, substituting from (7) into (6)

$$\begin{aligned} dv &= \sum_i \sum_j p_i\, dx_{ij} + T \\ &= \sum_i p_i \sum_j dx_{ij} + T \\ &= \sum_i p_i \sum_k dy_{ik} + T \qquad [\text{by } (4)] \\ &= \sum_i \sum_k p_i\, dy_{ik} + T \\ &= \sum_i \sum_k (f_i^k/f_n^k)\, dy_{ik} + T \quad [\text{by } (7)], \end{aligned} \tag{9}$$

[4] This is tantamount to a use of the Hicks-Kaldor criterion because we are, in effect, asking whether the gainers from the change would be willing to compensate the losers. If that compensation is actually paid, the change is obviously a Pareto improvement because someone gains and no one loses. In (6), dv may be interpreted as the maximal payments that the gainers would be willing to make rather than forgo the change, minus the minimal amounts the losers must receive if they are not to suffer from the change. As is now generally recognized, the Hicks-Kaldor criterion evades the evaluation of income distribution by taking each individual's income and, hence, his ability to pay, as given. It should be recognized that, like the standard theorem on the gains from free trade, Proposition One need not hold if income redistributions are not ruled out and if arbitrary interpersonal evaluations are not prohibited. For if the elimination of an externality damages the well-being of even one individual and the welfare function weighs that individual's interests sufficiently, we are forced to reject the change, no matter how great the benefits it offers the remaining members of the community. See J. R. Hicks, "The Foundations of Welfare Economics," *Economic Journal* XLIX (December, 1939), 696–712; Nicholas Kaldor, "A Note on Tariffs and the Terms of Trade," *Economica*, New Series VII (November, 1940), 377–80; and for an evaluation, I. M. D. Little, *A Critique of Welfare Economics*, 2nd ed. (Oxford: Clarendon Press, 1957).

or recalling the expression (8) represented by T, then by (3)

$$dv = \left[-\sum_k (f_z^k/f_n^k) + \sum (u_z^j/u_n^j) \right] dz. \tag{10}$$

This states that the net effect of the changes in question is simply the sum of the value of the resulting external effects to each affected firm, k, and each affected individual, j, all measured in terms of the numeraire commodity.[5]

Our result now follows directly from (5), because by our assumption that the y_{1k} produce the externality, we have $g_1^k > 0$. It also follows immediately, by permitting the appropriate $dy_{ik} \neq 0$, $(i = 2, \ldots, w)$, that if one were to have simultaneous increases in several activities, all of which directly increase (or all of which decrease) the magnitude of an externality, then Proposition One applies, with the obvious modifications, to this reallocation of resources to a number of activities directly affecting the externality.

Finally, note that we have proved with (10), in addition to Proposition One,

Proposition Two. Starting from a position of competitive equilibrium, the net effects of a marginal increase in exactly one of the outputs that affect externality levels directly *and any adjustments in other activity levels* necessary to meet the requirements of productive feasibility, will be evaluated by the affected firms and individuals, in terms of a numeraire commodity, at the net value of the external effects alone.

Proposition Two consequently confirms that a competitive equilibrium involving an externality but no corrective taxes or subsidies can never be Pareto-optimal, and shows that a small increase in the level of an activity that yields external benefits can always be introduced in a way that constitutes a *Pareto improvement*,[6] and that the same is true for a marginal decrease in the level of an activity that yields a detrimental externality.

3 Which way toward the optimum? Inefficiency and resource reallocation

Having gone this far, one is immediately tempted to go one step further. The literature is full of assertions that at least suggest the following proposition:

[5] It will be recalled from the discussion of Section 4 of Chapter 4 that the expression inside the brackets in (10) is equivalent to the expression for the external damage $\sum_j \lambda_j u_z^j - \sum_k \mu_k f_z^k$ that is used in (5^o) of Chapter 4 and from which the Pigouvian tax rate is determined.

[6] That is, the changes will make some persons better off without harming anyone, *provided* the initial gainers compensate the losers. As usual, a Pareto improvement will occur if a change satisfies the Hicks-Kaldor criterion *and* compensation is paid.

Proposition Three. If output $y_1 = \sum y_{1k}$ is the only activity that generates net social benefits, then Pareto optimality[7] requires an output of y_1 larger than that which would occur in competitive equilibrium, and the reverse holds if y_1 generates social damage. That is, if $(y_1^c, \ldots, y_n^c)$ and $(y_1^o, \ldots, y_n^o)$ are competitive and Pareto-optimal output vectors, respectively, then $y_1^c < y_1^o$ if y_1 produces external benefits and $y_1^c > y_1^o$ if y_1 yields external damage.

The difference between this and the Proposition One is that the former deals with *marginal* changes from the competitive equilibrium that yield increases in welfare, but the present proposition makes a much stronger assertion about the direction of the (*possibly large*) change needed to attain optimality when *all* activity levels are changed to their optimal values. That is, Proposition One relates to *ceteris paribus*[8] marginal changes that yield (presumably small) Pareto improvements; Proposition Three refers to large changes in which society moves all the way to an optimum and in which *all* other variable values are adjusted appropriately. As already indicated, the proposition of the preceding section is true, but this one is not always valid. However, as we will show in the next two sections, Proposition Three *is* valid if the appropriate convexity conditions hold and there is only one externality-yielding activity.

Before attempting to show the validity of Proposition Three under the convexity assumption, we must comment on a significant matter of interpretation. Though Proposition Three refers to levels of the externality-generating activities themselves, it seems frequently to have been interpreted to refer to the allocation of society's *resources* among them. But, as we will now see, these two propositions are *not* equivalent to one another; the latter states that excessive quantities of resources will be allocated by the market to an activity that generates detrimental externalities, but our formal Proposition Three asserts that the level of such an activity will be excessive.[9] For if the efficiency conditions are not satisfied, an increase in the level of x_1 will not necessarily require an increase in the quantity of resources allocated to activity x_1.

[7] Strictly speaking, we may not include all Pareto-optimal points in our calculation, but only those that constitute *potential* Pareto improvements over the initial point, in the Hicks-Kaldor sense indicated by expression (6).

[8] That is, other activities that affect externalities directly are held constant in Proposition One, though, obviously, feasibility does require a change in some other activity levels from which the resources are transferred in order to make possible the postulated marginal change.

[9] Olsen and Zeckhauser, "Efficient Production of External Economies," *American Economic Review*, seem to have been the first to point out the difference between the two assertions, and to discuss the difference systematically.

Buchanan and Kafoglis[10] demonstrate that *if efficiency is not assumed*, the assertion that refers to resource allocation is clearly false. Unlike the activity-level analysis of the next few sections, no formal argument is needed to show this. Instead, we need only consider a simple counterexample. Imagine a community in which police protection against crime is not provided by the state; rather, it takes the form of the employment of private policemen by individuals and organizations who can afford it. Assume that each additional policeman hired reduces the overall crime rate and thus contributes an external benefit. In these circumstances, optimality may well require more police protection, but it need *not* call for the hiring of more policemen. For, if a centralized department of police can protect the general public more efficiently than an uncoordinated set of policemen, then optimality may require more protection but a smaller allocation of resources for the purpose.

It is easy to provide other examples of this phenomenon, some of them quite significant. Consider the possibility of the substitution of relatively inexpensive public health measures, such as the spraying of the breeding grounds of disease-carrying insects as a substitute for individual inoculation against a communicable disease. Whenever individualistic decision making leads to inefficiency in the supply of an external benefit, it is clear that, even if optimality calls for an increase in the supply of the benefit, it does not follow that an expansion in the quantities of resources devoted to its production need be required.[11] Interpreted in terms of resource use, where production is not efficient, the standard allegation about the direction of resource misallocation produced by externalities is obviously false: despite its external benefits, the competitive allocation of inputs to police protection may exceed the optimal level.

4 Direction toward the optimum in the convex case: graphic version of the argument

We will now provide a somewhat heuristic, graphic argument showing that under appropriate convexity assumptions, Proposition Three relating to the levels of externality-generating activities must be valid. A more formal analysis is offered in the following section.

In our graphic discussion, the variables have been aggregated highly so that we end up with the three variables, x_1, x_2 (representing the total

[10] "A Note on Public Goods Supply," *American Economic Review.*

[11] For more formal counterexamples, see Buchanan and Kafoglis. Careful analytic discussion of these examples can be found in Vincent, "Reciprocal Externalities and Optimal Input and Output Levels," *American Economic Review* and in Olsen and Zeckhauser, "Efficient Production of External Economies," *American Economic Review.*

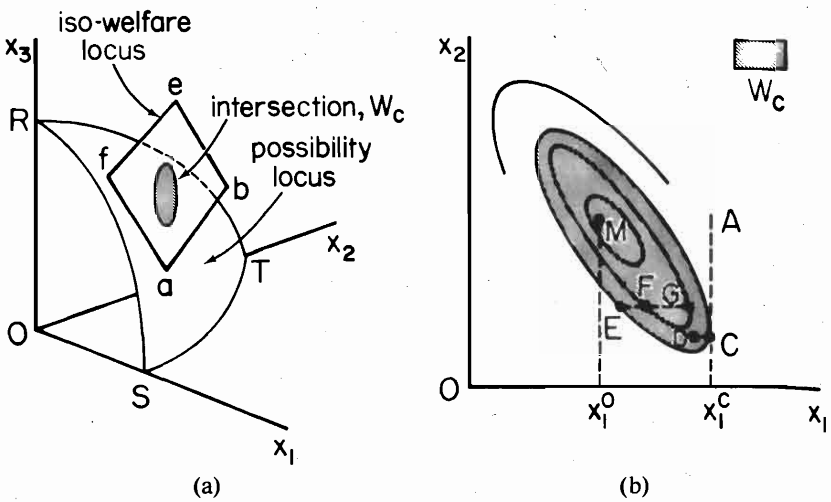


Figure 7.1

consumption of all other goods), and x_3 (representing the consumption of resources, say of labor, in the form of leisure). In Figure 7.1a, the three-dimensional region *ORST* represents our production-possibility set,[12] Y, corresponding to the constraints (2). The figure also depicts what we may refer to as an isowelfare locus given by setting $dv = 0$ (that is, $v =$ constant) in our social valuation relationship (6). The figure shows the intersection of the upper boundary of the production-possibility set with one of the family of isowelfare loci. The projection of several such intersection loci on the x_1x_2 plane is shown in Figure 7.1b. Such a locus plus its interior constitutes a set, W_c, (Figure 7.1a) of points socially preferable or indifferent to points on its boundary. Now, by assumption, neither x_2 nor x_3 generates any externalities. Hence, starting from a competitive equilibrium point, if we hold $x_1 = y_1$ constant but increase x_2 (with whatever change in x_3 is required), we will have $dz = 0$ (no change in the externality level) so that by (10), social welfare will neither rise nor fall. That is, the marginal shift in resources (say, to produce more x_2 and less leisure) will not cause any change in social utility because, in competitive equilibrium, the marginal private yields of resources in the two activities will be equal, and, for these two activities, marginal private and marginal social yields will also be equal.

[12] We assume in this section that every net output is consumed totally, so that for each i we have $x_i = y_i$.

Now, the increase in x_2 (holding x_1 constant) represents a vertical move in the x_1x_2 plane.[13] It follows that any competitive equilibrium must occur at a point on an isowelfare curve at which that curve is vertical (that is, a point such as C in Figure 7.1b). Thus, the curve must have a vertical tangent, x_1^cCA, at the competitive equilibrium point C. Because the shaded set of points, w_c, preferred to or indifferent to C is convex, it must lie entirely to the left of x_1^cCA or it must lie entirely to the right of that vertical line segment.

Our result now follows at once. For, say, if x_1 yields a detrimental externality, by Proposition One some small decrease in x_1, say the leftward move from C to D, must move us into the shaded region of points preferred to or indifferent to C. Hence, by the convexity property, *all* points in the shaded region must lie to the left of C. But the points in the shaded region represent all possible reallocations that are potential Pareto improvements over the competitive equilibrium point C. Hence, any point that represents a Pareto improvement over C must lie in this region, including the Pareto-optimal points, in which opportunities for Pareto improvement have been exhausted. In particular, if there is a point, M, that represents a maximal Pareto improvement over C [Δv, as indicated by (6), maximal], then M must lie in this shaded region.

5 Direction toward the optimum in activity space: convex case

We will not formalize the graphic argument of the preceding section, showing that Proposition Three, taken as a statement about the relation between competitive and optimal *output* levels, is valid if the appropriate convexity conditions hold.

Among the premises is the assumption that the production set, call it Y [that is, the set described by constraints (1)], is convex. We take this set to lie in the n-dimensional space of all possible levels of the n production activities. Assuming that the competitive process and the initial incomes yield a unique distribution of every output combination represented by a point in that space,[14] let us utilize the function v, defined implicitly by (6), to measure the improvement in social welfare. In particular, let $\Delta v(x, x^b)$ represent the sum of the maximal payments that the members of the economy who gain in the process are willing to offer rather than forgo the change from x^b (the vector representing the initial

[13] This is the point in the argument at which our premise that we begin from a competitive equilibrium plays its crucial role.

[14] That is, every point $y = (y_1, \ldots, y_n)$ in n-dimensional output space is associated with a unique point $x = (x_{11}, \ldots, x_{nm})$ in the $n \times m$ dimensional consumption space representing distributions of the n commodities among the m consumers.

or base position) to some other point, x, minus the minimal payments necessary to compensate those who lose from the change, all calculated in terms of a numeraire commodity.

Accordingly, we can use the

Definitions. x^a is potentially Pareto-preferred to x^b if

$$\Delta v(x^a, x^b) > 0, \tag{11a}$$

and x^a and x^b are potentially Pareto-indifferent if

$$\Delta v(x^a, x^b) = 0. \tag{11b}$$

Now let x represent the vector $(x_{11}, \ldots, x_{nm})$ and x^a and x^b be any two such vectors with some particular values of the x_{ij}. It seems natural to assume that the function v is strictly quasi-concave in x space in the sense that if x^a is potentially preferred to or indifferent to x^b [that is, if $\Delta v(x^a, x^b) \geq 0$], then for any intermediate point, $x^r = \alpha x^a + (1-\alpha)x^b$, where $0 < \alpha < 1$, we must have $\Delta v(x^r, x^b) > 0$.

Now, let c designate a competitive solution point, at which the variables take the values x_{ij}^c, and let v^c be the corresponding value of our social maximand, v. Define V_c to be the set of all values of x such that $\Delta v(x, x^c) \geq 0$, which may be described, somewhat inaccurately, as the set of all solutions socially preferred or indifferent to the competitive solution, x^c. Then the set $W_c = Y \cap V_c$ will also be convex, where W_c can be characterized as the set of all *feasible* solutions preferred to or indifferent to x^c. We assume that W_c is not empty and that it contains some interior points.[15]

We will now show that our equilibrium point, c, must lie in the set of the boundary points of the convex set, W_c. For, by our externalities assumption, the competitive equilibrium point, c, is not Pareto-optimal. Hence, with o designating a potentially-preferred point we must have $v^o > v^c$. Thus, if c were not on the boundary of W_c, then W_c must contain a line segment ock^* whose end points are o and k^*, with c an interior point of that line segment. Because k^* lies in W_c, we must by definition have $v^{k^*} \geq v^c$. But because c is in the interior of this line segment, the

[15] In fact, W_c need not inevitably have some interior points. If the production set, Y, includes only one process with absolutely fixed proportions it is represented by a ray with no interior points and so there must be no interior point in $W_b = Y \cap V_b$. However, as Figure 7.1a indicates, if the Y and V_c have the shapes usually assumed of them in neoclassical analysis, then interior points of W_c must exist. For the production possibility set is bounded from above by surface RST, which is concave to the origin, and V_c is bounded from below by the surface $abef$, which is convex to the origin. If the competitive solution is not optimal, as must be the case when externalities are present, then W_c, the shaded intersection of these two sets, will not be empty and will have an interior that is not empty.

strict quasi-concavity of v requires either $v^c > v^{k^*}$ or $v^c > v^o$, which produces a contradiction. We have proved:

Lemma. The competitive equilibrium point, c, must lie on the boundary of W_c.

Next, consider the hyperplane, call it $y_1 = y_1^c$, that is obtained by fixing y_1 at y_1^c, the competitive value of the externality-generating activity, leaving the values of all other variables unrestricted. We will show now that this is a supporting hyperplane of W_c. Obviously, it includes the boundary point c of W_c. Moreover, the hyperplane $y_1 = y_1^c$ can include no interior point of W_c, for suppose, on the contrary, that there is such a point, call it p. Then by the convexity of W_c, the line segment pc must lie entirely within W_c and within the hyperplane $y_1 = y_1^c$. Then, any point q on pc arbitrarily close to c must be potentially preferred to c by the strict quasi-concavity of the function v. But it is impossible for q to be potentially preferred to c because the move from c to q involves $\Delta y_1 = 0$ and so, presumably,[16] all $\Delta y_{1k} = 0$, so that in the limit, by (5), this move yields $dz = 0$ and hence, by (10), $dv = 0$. Thus, the assumption that the hyperplane $y_1 = y_1^c$ contains p, an interior point of W_c, leads to a contradiction.

In sum, because the hyperplane includes a boundary point, c, of W_c and none of the interior points of W_c (which we have assumed to exist), it must be a supporting hyperplane for the convex set W_c.

Proposition Three now follows at once from Proposition One. For W_c, the points socially preferred to or indifferent to c, have now all been shown to lie in one of the halfspaces bounded by the supporting hyperplane $y_1 = y_1^c$. Taking, for example, the beneficial externalities case, because a small increase in the value of y_1 must increase social welfare as measured by v, by Proposition One, it follows that *no* decrease in the value of y_1 can ever increase the value of v (that is, any Pareto-optimal point that is potentially superior to the competitive equilibrium must involve a $y_1^o > y_1^c$). Obviously, the corresponding argument holds for the detrimental externalities case.

6 Invalidity of Proposition Three where several activities yield externalities

It is trivial to show by simple counterexample that, if Proposition Three is amended to permit two activities to yield an externality (or to permit

[16] We require a zero change in *each* y_{1k} and not just in their sum, y_1, because otherwise a decrease in the activity level of a lightly polluting plant and an equal increase in that of a heavily polluting plant would raise emissions despite the absence of any change in *total* y_1. As will be proved in the next section, if we permit independent changes in the individual y_{1k}, Proposition Three can be violated.

two different types of externalities directly affected by several activity levels), then the resulting proposition is no longer valid. That is, we simply are not entitled to say in advance whether an optimal level of an activity that yields a detrimental externality is or is not smaller than its competitive value.[17] Moreover, we will show by concrete illustration (a) that the problem is a very real one, and not a mere theoretical curiosity, and (b) that the choice of those externality-yielding activities that should not be reduced is apt to be a complex matter requiring considerable information and the demanding calculations that are generally called for by interdependencies.

To prove that the theorem is invalid, we utilize a simple linear programming model in which the social welfare function is taken to be known and to be such that its components that are purely private benefits (ignoring externalities) are maximized in the competitive equilibrium.

Using the same notation as before, let there be two outputs, x_1 and x_2, each of which yields some of the externality, z, and one resource of which the available quantity is r. Then the social welfare function is

$$w = a_{01}x_1 + a_{02}x_2 - a_{03}z, \tag{12}$$

which is to be maximized subject to the two production conditions

$$a_{11}x_1 + a_{12}x_2 \le r \quad \text{(the resource constraint)} \tag{13}$$

and

$$a_{21}x_1 + a_{22}x_2 = z \quad \text{(the externality output function)} \tag{14}$$

where all parameter values, a_{ij}, are assumed positive and all values of the variables are nonnegative.

Under pure competition, we assume that (14) and the last term in (12) will play no role in the market equilibrium. Instead, the equilibrium will

$$\text{maximize } a_{01}x_1 + a_{02}x_2 \tag{15}$$

subject to (13), which has the solution

$$x_1^c = 0, \qquad x_2^c = r/a_{12} > 0 \tag{16}$$

if and only if

$$a_{01}/a_{11} < a_{02}/a_{12}. \tag{17}$$

[17] This suggests that one of the things that may go wrong in moving from the local Proposition One to its global counterpart, Proposition Three, is that, in the latter, other externality-generating activities cannot generally be held constant. Optimality may *require* all such activity levels to change and the resulting interaction can lead to consequences that follow no simple rule of thumb.

However, social optimality requires maximization of (12) subject to (13) and (14). Direct comparison with the previous solution is facilitated by the elimination of z between (14) and (12), yielding the maximand

$$w = (a_{01} - a_{03}a_{21})x_1 + (a_{02} - a_{03}a_{22})x_2. \tag{18}$$

This is again to be maximized subject to the constraint (13). Assuming the first expression in parentheses is positive, this will have the solution

$$x_1^o = r/a_{11} > 0 \qquad x_2^0 = 0 \tag{19}$$

if and only if

$$\frac{a_{01} - a_{03}a_{21}}{a_{11}} > \frac{a_{02} - a_{03}a_{22}}{a_{12}}. \tag{20}$$

For suitable values of the externality coefficients a_{03}, a_{21}, and a_{22}, (17) and (20) are clearly compatible. For example, setting $a_{01} = 1$, $a_{02} = 2.3$, $a_{03} = 0.2$, $a_{11} = 1$, $a_{12} = 1$, $a_{21} = 2$, $a_{22} = 10$ we have, in accord with (17),

$$1 = \frac{a_{01}}{a_{11}} < \frac{a_{02}}{a_{12}} = 2.3$$

but, as called for by (20),

$$0.6 = \frac{a_{01} - a_{03}a_{21}}{a_{11}} > \frac{a_{02} - a_{03}a_{22}}{a_{12}} = 0.3.$$

Thus, by (16) and (19), $x_1^c < x_1^o$, even though x_1 produces an externality, z, as shown by (14), and that externality is detrimental, as shown by (12), and even though all the convexity conditions required for maximization are satisfied, as is always true in a linear programming problem for which a solution exists.[18]

Thus we have proved that modified Proposition Three does not necessarily hold where more than one activity produces an externality, and the same sort of argument shows readily that the proposition breaks down where one activity produces an externality and another can be used to suppress it.

A simple illustration, transportation by railroad and private automobile, will show intuitively why this is so and will suggest that the problem is very real and significant. It is well known that emissions of pollutants per passenger mile by railroads are much smaller than those of autos. It is clear then that Pareto optimality may call for a decrease in the use of automobiles from the competitive level and some offsetting increase in

[18] It should be fairly clear that the linearity of this counterexample is in no way essential for the argument and that the only purpose of the linearity assumption is to provide a very simple case of the phenomenon.

the use of rails, despite the fact that railroad transportation is a polluting activity. The world of reality is full of such cases in which we cannot eliminate pollution but instead have to consider substituting more of a slightly polluting activity for another that is highly damaging.[19]

A similar problem arises where there are several different types of emissions. For example, automobiles give off carbon monoxide, particulates, lead aerosols, hydrocarbons, and a number of other deleterious pollutants. But devices for the suppression of some of these emissions characteristically contribute to others.[20] If these pollutants are not equally harmful and their suppression is not equally costly, it is obvious that a Pareto-optimal solution may actually call for an increase in the emission of some pollutants that are themselves undesirable, but are less damaging than others.

These illustrative cases suggest the subtle and complex character of comprehensive policy analysis. As a further example, consider two emissions, z_1 and z_2, each of which does damage that is measurable in money terms. Suppose a pound of z_1 does twice as much damage as a pound of z_2. It does not follow that z_2 should be increased and z_1 diminished. If suppression of z_2 is ten times as costly per unit as that of z_1, then the reverse is more plausible, and suppression of both of them at a much greater cost cannot be ruled out a priori. A reexamination of the issue indicates that selection of the activity to be increased requires a delicate balancing of their relative (marginal) valuation by consumers, the relative marginal damage resulting from the emissions they produce, the relative costs of the activities, of suppression of their emissions, and of substitute and complementary activities and emissions.

As has been recognized by designers of emission control programs, whether for waterways or for automobiles, the interdependencies involved in such calculations easily get beyond the powers of unaided intuition or the simple sort of advice that seems to follow from Proposition Three.

7 Violations of Proposition Three resulting from nonconvexity

Next, we turn briefly to the sort of case in which (a modified) Proposition Three may not hold even where only a single activity produces a single

[19] An example will also indicate why Proposition Three can be violated by an activity that abates the effects of an externality. It is conceivable that an optimal change in the competitive output of electricity requires both the production of more smoke suppression equipment *and* the generation of more electricity.

[20] For example, it is reported that a number of scientists have expressed concern over the sulphates and "sulphuric acid mists" yielded by the catalysts planned for installation on automobiles as a means to reduce the emissions of hydrocarbons and carbon monoxide. See V. K. McElheny, "Environmental Agency Is Divided over Car Pollution Control Issue," *The New York Times*, October 15, 1973, p. 40.

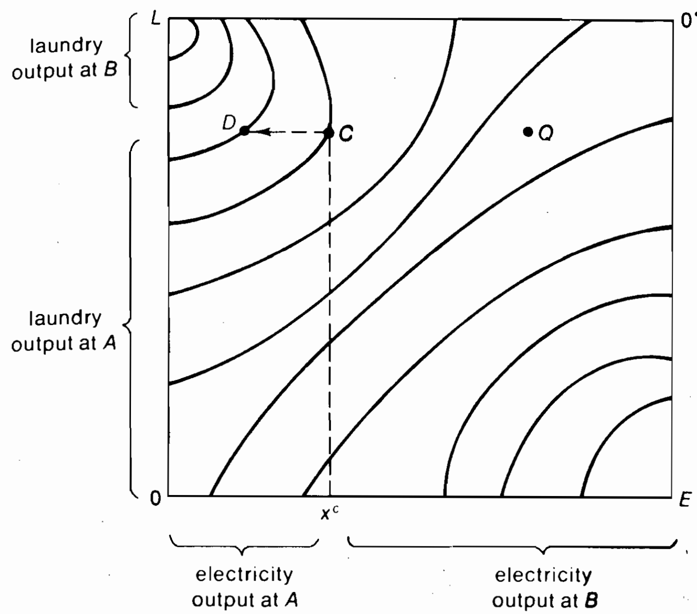


Figure 7.2

pollutant. It involves a situation that will be discussed more carefully in the next chapter: a case of multiple local maxima resulting from the violation of the usual convexity-concavity assumptions. The nature of the problem in this case is almost self-evident. Where there are several maxima, even if the rule proposed by Proposition Three can be relied upon to move the economy toward a local optimum, it may very well propel it away from the global optimum.

Leaving the details for the following chapter, the problem can be illustrated with the box diagram in Figure 7.2. The activity of an electricity producer generates smoke; it operates near a laundry industry and the results are economically inefficient. We assume that there are two possible locations, *A* and *B*, in which industry can operate, so that laundry and electricity output can be separated either by moving the former to *A* and the latter to *B* or vice versa. In our diagram, the abscissa and ordinate of any point, such as *C*, show the quantities of electricity and laundry produced at location *A*. Assuming that whatever is not processed here will be turned out at the other location, the outputs of electricity and laundry at *B* are indicated analogously, taking point O^* rather than 0 as our origin. If smoke damage is sufficiently costly, there will be (at least) two possible arrangements that are desirable and so constitute local optima: a) locating all (or most) of the laundries elsewhere without the electricity producers reducing their smoke output at A (point E in the diagram), or b) placing the electricity producers at B while the laundries remain in operation at A (point L). Accordingly, the isowelfare loci in the diagram are at their highest near points E and L, and are relatively low at points in the diagram, such as Q, representing simultaneous operation of both industries at A.

Suppose now that C is the competitive equilibrium point at which marginal private yields are zero. Then, as Proposition One tells us, and as we would expect, society will benefit from a *small* decrease in the output of the electricity industry at A, the generator of the external disservice; that is, the move from C toward D moves society to a higher indifference curve. We cannot tell from the diagram whether point E or L is the global maximum, but suppose it is point E. Then the optimal output of electricity produced at A will in fact be greater than the market equilibrium output, Ox^c. This is precisely what we wanted to show: where the social optimum is not unique and other things (the laundry output's location) are *not* held equal, the competitive equilibrium output of an item that generates an external disservice may, in fact, be less than its optimal level.

How such a case can arise is also easy to understand; it is a relative of Coase's well-known example in which society benefits if electricity output at A is curtailed, but, say, because cheap generating power is available at A and not at B, it benefits even more if electricity output at A is increased and laundry activity is simultaneously moved elsewhere.

8 Invalidity of Proposition Three if the initial point is noncompetitive

It is now easy to indicate intuitively why Proposition Three, suitably amended, does not hold for an initial point that is not a competitive equilibrium.

Returning to Figure 7.1b, if our initial point is not a competitive equilibrium, it need not correspond to a vertical point on an isowelfare boundary, such as point C. Suppose, then, we begin at point E from which a small rightward move is socially beneficial (presumably there is a local beneficial externality). The diagram shows how the optimal point, M, can nevertheless lie to the left of E. Moreover, without detailed knowledge of the social welfare function and the social production set, information which is not usually available, there is no way of realizing that a small increase in x_1, say from point E to F, is beneficial, but that once we get to G and beyond, things begin to get worse. There is no iterative process

whereby society can move in a sequence of steps always in a preferred direction.

For an illustration of this difficulty, we can simply recall a problem we posed in the preceding chapter. If we have a polluting monopolist, we cannot be sure whether social welfare will be increased or decreased by a reduction in his output below the profit-maximizing level. A fall in output will presumably reduce the social costs his waste emissions impose, but at the same time it will add to the welfare losses resulting from his failure to extend production to the point where marginal cost equals price. The net effect on social welfare depends upon the particular values of the variables in each case, and one simply cannot construct a dependable rule of thumb about the direction in which the firm should be induced to move to serve the interests of the community.

9 Conclusion: implications for policy recommendations

The upshot of all this seems fairly clear. Although the domain of validity of Proposition Three may be somewhat greater than some people had previously believed to be the case, it cannot be relied upon to hold in any class of cases that is really relevant for policy. That is, there seem to be few, if any, areas in which we can *depend* on the rule of thumb implied by that proposition. The world confronts us with many difficult and complex trade-off decisions, and there just seems to be no simple rule that permits us to cut through them.

CHAPTER 8

Detrimental externalities and nonconvexities in the production set

The preceding chapter showed that the conventional wisdom concerning the direction in which to modify output in the presence of externalities is likely, at least sometimes, to be misleading. The problem can arise whenever the relevant convexity conditions break down.

In this chapter, however, we will show that detrimental externalities of sufficient strength *will* produce a breakdown in the concavity-convexity conditions (the so-called second-order conditions) usually postulated for a social maximum, so that instead of a unique optimum, society may have the difficult task of choosing among a set, and, sometimes, a substantial set of discrete local maxima. Indeed, in a system otherwise characterized by constant returns everywhere (that is, a linear model), *any* detrimental externalities, however minor, can produce a nonconvexity. This problem is no mere theoretical curiosity. We will see that it produces some very real and difficult issues in the choice of policy.

Moreover, even in theory, prices and taxes cannot help with this matter. Prices and taxes (which, in general, influence the first-order maximum conditions) can affect the decisions of individuals and firms and thereby determine the location of the economy in relation to its production-possibility set. However, prices or taxes cannot change the shape of the possibility set itself to transform it from a nonconvex into a convex region, for that is essentially a technological matter. Moreover, as we will see later in this chapter, in the presence of nonconvexities, these prices may also give the wrong signals - directing the economy away from the social optimum.

It is not our objective here to review in any detail the difficulties caused by nonconvexity. Some of these consequences have long been recognized and are widely known.[1] However, until the recent appearance of papers by Starrett, Portes, Kolm, and Baumol,[2] it was apparently not recognized that externalities themselves are a source of nonconvexity. These more recent writings suggest more than one connection between the two phenomena. However, one particularly straightforward relationship seems to have received little or no attention. With sufficiently strong interactive effects, nonconvexity follows from the simple fact that if *either* of two activities, one of which interferes with the other, is operated at zero level, no hindrance is suffered.[3] The goal of this chapter is to explore this phenomenon and to show how it is that sufficiently severe detrimental externalities and nonconvexity necessarily go together.

In the first three sections we show, with the aid both of illustrative examples and more general analysis, that detrimental externalities of sufficient magnitude must always produce nonconvexity in the production possibility set for two activities: one generating the externality and one affected by it. In the fourth section we show that the problem is reduced, but not generally eliminated, by the possibility of spatial separation of offender and offended. However, achievement of the "right" spatial separation turns out not always to be a simple matter. Section 5 contains some speculations about the way in which the number of local peaks in the production-possibility function grows with the number of interacting activities. In Section 6, we discuss the possibility of using Pigouvian taxes to sustain desirable behavior and, in a concluding seventh section, we review briefly the problems for social policy inherent in the sort of nonconvexity we have been analyzing.

Our colleague, David F. Bradford, is a coauthor of this chapter, which draws heavily on W. Baumol and D. Bradford, "Detrimental Externalities and Non-Convexity of the Production Set," *Economica* XXXIX (May, 1972), 160–76.

[1] Pigou, for example, commented that "...if several arrangements are possible, all of which make the values of the marginal social net products equal, each of these arrangements does, indeed, imply what may be called a *relative maximum* for the [national] dividend; but only one of these maxima is the unequivocal, or absolute, maximum.... It is not necessary that all positions of relative maximum should represent larger dividends than all positions which are not maxima. On the contrary, a scheme of distribution approximating to that which yields the absolute maximum, but not itself fulfilling the condition of equal marginal yields, would probably imply a larger dividend than most of the schemes which do fulfill this condition and so constitute relative maxima of a minor character." *The Economics of Welfare,* London: Macmillan and Co., 1938 (4th ed.), p. 140.

[2] See D. A. Starrett, "Fundamental Nonconvexities in the Theory of Externalities," *Journal of Economic Theory* 4 (April, 1972), 180–99; R. D. Portes, "The Search for Efficiency in the Presence of Externalities," in *Unfashionable Economics: Essays in Honor of Lord Balogh,* ed. Paul Streeten (London, Weidenfeld and Nicolson, 1970), pp. 348–61; S. C. Kolm, "Les Non-Convexites d'Externalité," CRPREMAP Rapport No. 11, mimeograph, 1971; and Baumol, "External Economies and Second-Order Optimality Conditions," *American Economic Review.*

[3] Note that this observation does not hold for externalities that Davis and Whinston (page 244) have termed "separable." Here, if industry 1's output affects the costs of industry 2, the latter's cost function would be of the form $f(x_2)+g(x_1)$. This implies that $g(x_1)$, the ill effects of industry 1 upon industry 2, would remain unaffected even if 2 were to go out of operation altogether! There is obviously no contradiction in such a premise, but it would seem to cast doubt upon the widespread applicability of the separable-externalities concept. See O. A. Davis and Andrew Whinston, "Externalities, Welfare, and the Theory of Games," *Journal of Political Economy* LXX (June, 1962), 241–62.

An appendix contains a formal demonstration of the workability of Pigouvian taxes in this context. It is shown that, as long as individual production sets are convex, all socially efficient output vectors *can* be sustained as a sum of profit-maximizing output choices under taxes designed to equate marginal social and private costs.

1 A simple model

Consider a two-output, one-input economy in which each output is produced by a single industry. To avoid compounding problems we shall assume that each industry has a convex technology in terms of its own inputs and outputs.[4] However, the presence of detrimental externalities means that increases in the output of one of the industries raise the other's costs of production, which is to say, the amount of input required to produce any given output. What we wish to show is that, if this detrimental externality is strong enough, then the social production set must be nonconvex.[5]

For consistency with the general analysis in the appendix, let us begin by carrying through this example following the practice of measuring inputs as negative outputs. As in the previous chapter, we consider an economy having three or more outputs that, for concreteness, we take to be leisure, electricity, and laundry. The shaded region of Figure 8.1a shows the production set (the set of attainable net output vectors) for the electricity industry, bounded by the ray *OE*. Figure 8.1b displays the production set for the laundry industry under two alternative assumptions about output in the electricity industry. The detrimental externality generated by electricity means that, for a given input of labor to laundry, less laundering will be produced when electricity output is positive than when it is zero. Thus, in Figure 8.1b, *OM*, the ray serving as the laundry production frontier when some positive level of electricity is produced must lie below *OL*, the laundry frontier when no electricity is produced. To make things easy to follow, we have assumed constant returns to scale for each

[4] Thus, if r_k is the quantity of input to industry k and y_k is its output, and if (r_k^*, y_k^*) and (r_k^{**}, y_k^{**}) are two feasible input-output combinations (holding constant inputs and outputs in other sectors), then $0<\alpha<1$ implies that $[\alpha r_k^* + (1-\alpha) r_k^{**}, \alpha y_k^* + (1-\alpha) y_k^{**}]$ is also a feasible input-output combination. Convexity of a production set is sometimes referred to as *generalized nonincreasing returns,* which means that a convex technology cannot exhibit increasing returns to scale and that it obeys the laws of diminishing marginal rates of substitution among factors and among outputs, and diminishing marginal productivity of outputs by factors.

[5] In the notation of footnote 4, the social production set is the set of all vectors (r_1+r_2, y_1, y_2), such that (r_1, y_1) and (r_2, y_2) are *simultaneously* feasible for their respective industries.

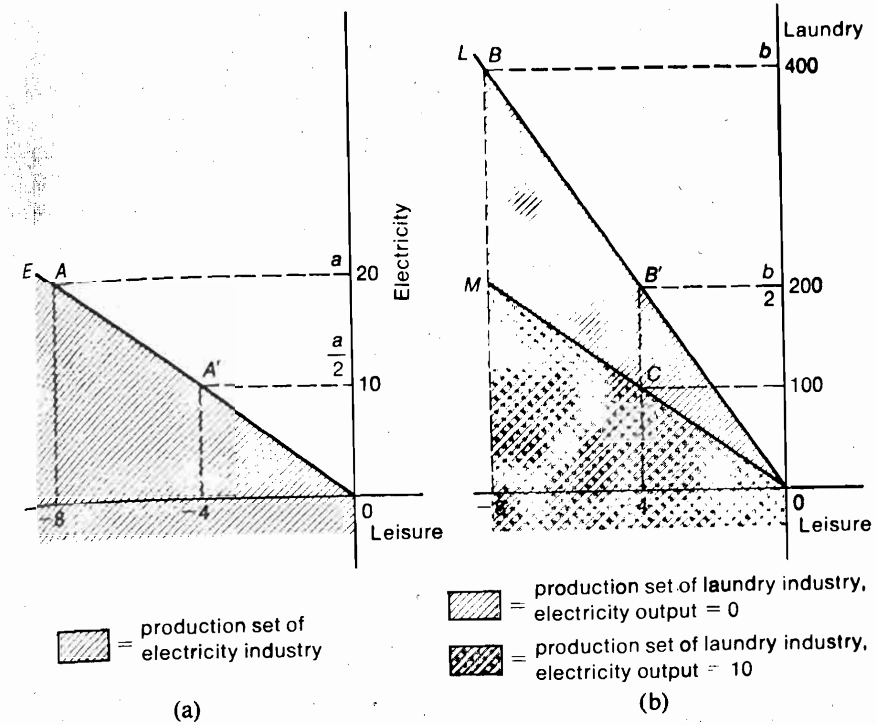


Figure 8.1

of the industries taken alone; hence the straight-line boundaries. We will now show that in this linear model any detrimental externality, however weak, can undermine the convexity conditions.

Consider two social production vectors on frontiers *OE* and *OL*, vector *A* on *OE* (-8 leisure, 20 electricity, 0 laundry) and vector *B* on *OL* (-8 leisure, 0 electricity, 400 laundry). Obviously both of these are technically feasible, as are (by constant returns to scale) the vectors A': $(-4, 10, 0)$ and B': $(-4, 0, 200)$, which are, respectively, halfway to the origin from *A* and *B*. However, the vector $V=(-8, 10, 200)$, which is a convex combination of *A* and *B* because $V=A'+B'=\frac{1}{2}A+\frac{1}{2}B$, is *not* feasible technically. If we wish to give up 8 units of leisure altogether and insist on 10 units of electricity, requiring four of these units of leisure, the most we can obtain is 100 units of laundry (point *C*). More generally, if *L* is the amount of leisure devoted to the two outputs and *a* and *b* represent the respective outputs of electricity and laundry, if *L* is devoted exclusively to the one or the other, then the assignment of $\frac{1}{2}L$ to each output must

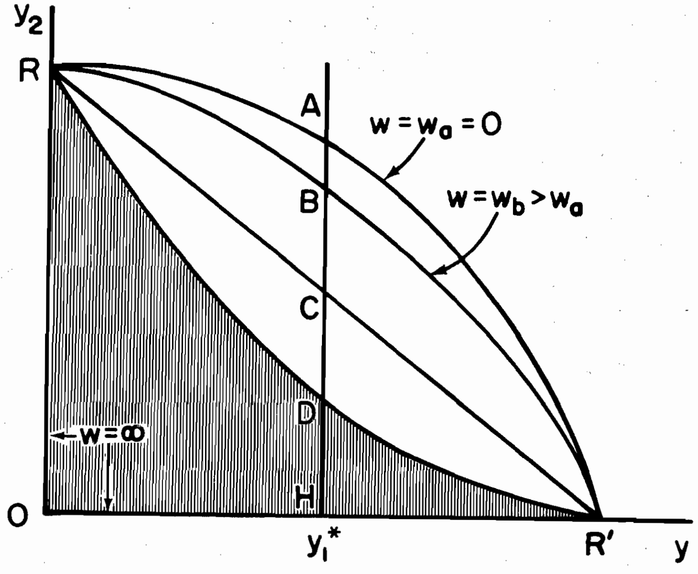


Figure 8.2

necessarily provide less than $b/2$ of laundry output if there is any detrimental externality present. Point B' is never attainable under these conditions and nonconvexity *must* follow. Thus we have

Proposition One. In a linear model, *any* detrimental externality that occurs only when there are nonzero levels of each of two activities must produce a nonconvexity in the social possibility set.

2 An alternative version of the nonconvexity argument

Another way of looking at the matter may be helpful to the intuition. Figure 8.2 depicts an ordinary production-possibility frontier RAR' in the absence of externalities. Dropping our earlier assumption of a constant marginal rate of transformation between outputs, we take this curve to bound the convex feasible region $ORAR'$. Let us, for expository convenience, introduce a parameter w measuring the strength of the externality. In terms of our example, w can be taken to measure the mean addition to the resources cost of cleaning a given batch of laundry that occurs when an added unit of electricity output causes smoke to increase. By definition, then, along RAR', which corresponds to the absence of external effects, the value of w (call it w_a) is zero.

Consider what happens to the production-possibility locus as the value of w is increased. We will show that the position of the end points R and R' will be totally unaffected, but all other points on the locus will be shifted downward. Point R, where electricity production is zero, will be unaffected by a rise in the value of w; whatever the social cost of smoke, at that point there will be no increase in damage because, by assumption, there is no smoke produced in the absence of any electricity output. Similarly, the location of R', where laundry output is zero, is invariant with w, because at that point no resources are devoted to laundry production, and hence there can be no increase in the resources cost of laundry output. There simply is no laundry to be damaged so that the electricity industry can smoke away without causing any harm to the only other output in our model.

However, consider some intermediate level of electricity output, say y_1^*. Here an increase in w means that with a given amount of electricity and a given quantity of resources, a smaller quantity of clean laundry can be produced than before. Consequently, point A must shift downward to some lower point, B, and the entire possibility locus becomes something like RBR'. With further increases in the value of w, point A will be shifted lower still. If, at some value of w, it is pulled below line segment RCR', the possibility set becomes a nonconvex region, such as shaded region $ORDR'$.

This must certainly happen if the individual industries exhibit constant returns to scale, as in our example of the previous section,[6] so that the production possibility frontier is a line segment like RCR'. For then *any* downward shift in point C, with points R and R' stationary, must yield a nonconvexity. Thus, in the nonlinear case, a detrimental externality will produce a nonconvexity if it is sufficiently strong to offset the influence of the diminishing marginal rate of transformation between the outputs in question.

Even in the nonlinear case, if the external damage is sufficiently serious[7] (that is, for sufficiently high values of w), A *must* lie below C. For if the marginal smoke output is so great and so noxious that no quantity of

[6] Figure 8.2 can be connected directly to the interrelated individual production sets of Figure 8.1a and 8.1b. Points R and R', respectively, represent the social output vectors $(-8, 0, 400)$, that is, point B in Figure 8.1a, and $(-8, 20, 0)$, that is, point A in Figure 8.1a. With constant returns to scale and a single input, the production frontier, in the absence of externalities, must be the line segment RCR'. However, with electricity output at $y_1^* = 10$ in Figure 8.2, the most laundry we can obtain in the presence of the externality is $HD = 100$, not $HC = 200$.

[7] Of course, even if A lies below C, the resulting nonconvexity need not lie in the interior of curve RAR'. For example, the frontier may cut the vertical axis at some point R^* that lies below R, with a perfectly well behaved segment of the frontier connecting R^* and R'. This case certainly seems implausible.

resources can get laundry as clean as it would be in the absence of smoke, then A must fall all the way to the horizontal axis (point H). That is, in the limit, the possibility locus then must consist simply of the axis segments ROR'.

The simplicity of the preceding argument may belie its generality and rigor.[8] The point is that, with any pair of commodities at least one of which interferes with the production of the other, there will be no such interference if one or the other is not produced. On the other hand, if the interference is sufficiently great, the maximal output of the activity suffering the external damage will approach zero for *any* nonzero level of output of the other and a nonconvexity in the feasible set is unavoidable.

Note that this argument holds for such a pair of commodities no matter how many goods the economy produces; so that if there is a nonconvexity in the production set for *any* pair of commodities, the full n-dimensional production set in the n-commodity economy is also necessarily nonconvex.

Thus, we have

Proposition Two. If it is sufficiently strong, a detrimental externality that arises only when the level of each of two activities is nonzero must produce a nonconvexity in the social production set.

3 A further illustration

Some readers may prefer to deal with a concrete algebraic example explicitly relating a measure of the degree of detrimental externality to the "wrong" curvature of a production-possibility frontier of the type displayed in Figure 8.2. We therefore offer a case in which the separate production sets of the two industries are strictly convex. Let y_e be the output of electricity and y_l the output of laundry services, r_e and r_l be the amounts of labor (negative leisure) used by them, and suppose

$$r_e = y_e^2/2$$
$$r_l = y_l^2/2 + wy_e y_l. \qquad (1)$$

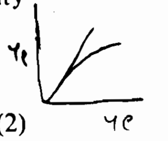
[8] See Kolm, "Les Non-Convexities d'Externalité," CEPREMAP. For an alternative and useful diagrammatic treatment of the nonconvexity issue, see J. R. Gould, "Total Conditions in the Analysis of External Effects," *Economic Journal* LXXXVII (September, 1977), 558–64. In addition, where victims engage in defensive activities, the interaction between these defensive activities and abatement measures by the generator of the externality may be a further source of nonconvexities. On this, see Hirofumi Shibata and J. Steven Winrich, "Control of Pollution When the Offended Defend Themselves," *Economica* L (November, 1983), 425–37; and W. Oates, "The Regulation of Externalities: Efficient Behavior by Sources and Victims," *Public Finance* XXXVIII (No. 3, 1983), 362–75.

Thus each industry separately is subject to strictly diminishing returns to scale in terms of its own input. The coefficient w now measures the strength of the effect of electricity output on laundry costs; the effect is detrimental if $w>0$. If a total of r units of labor is available for the two activities, we can write the implicit equation for the laundry-electricity possibility frontier as

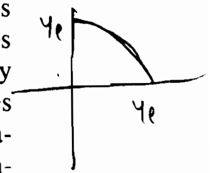
$r = r_e + r_l$

$$r = y_e^2/2 + wy_e y_l + y_l^2/2, \qquad y_e \geqq 0, \quad y_l \geqq 0. \qquad (2)$$

$\frac{\partial r}{\partial y_e} = \left[\frac{4\, y_e}{4}\right] + w y_l -$



We can deal with any such differentiable possibility locus in an obvious manner, calculating its second derivative and showing generally that when the externality parameter, w, becomes sufficiently large, that derivative must take positive values. The present illustration, however, permits us to show this result more directly. If $w=0$ (no externality), (2) describes a quarter circle in a (y_e, y_l) coordinate system. This boundary obviously has the "right" curvature. For small positive w, the boundary continues to be concave to the origin. However, when $w=1$, (2) becomes the equation of a straight line $[(y_e+y_l)^2=2r]$, and, for larger values of w, nonconvexity of the production set occurs.



In the preceding example, the boundary between convexity and nonconvexity happens to involve a value of w, that is, $w=1$, that is independent of the magnitudes of the outputs and that can, perhaps, be considered fairly large. More generally, however, the appearance of the nonconvexity will depend both on the magnitude of the externality parameters and on the values of y_e and y_l. For example, suppose in the preceding illustration, we leave the electricity-cost function unchanged but make the laundry resource requirement function

$$r_l = y_l + wy_e y_l.$$

Then the production-possibility locus is given by

$$r = r_e + r_l = y_e^2/2 + wy_e y_l + y_l.$$

A straightforward but tedious calculation of the second derivative[9] shows that the production set will be convex if and only if

$$2w^2 y_l + wy_e < 1.$$

Clearly, for w or y_e or y_l sufficiently large, this requirement will not be satisfied. In this illustrative example, the maximum feasible values of y_l occur in the vicinity of $y_e=0$. Here we have $y_l=r$ the total quantity of resource available, and it is not difficult to imagine values of w and r that

[9] See Appendix A, which also presents a more general version of the arguments for the three-output production possibility locus using the differential calculus.

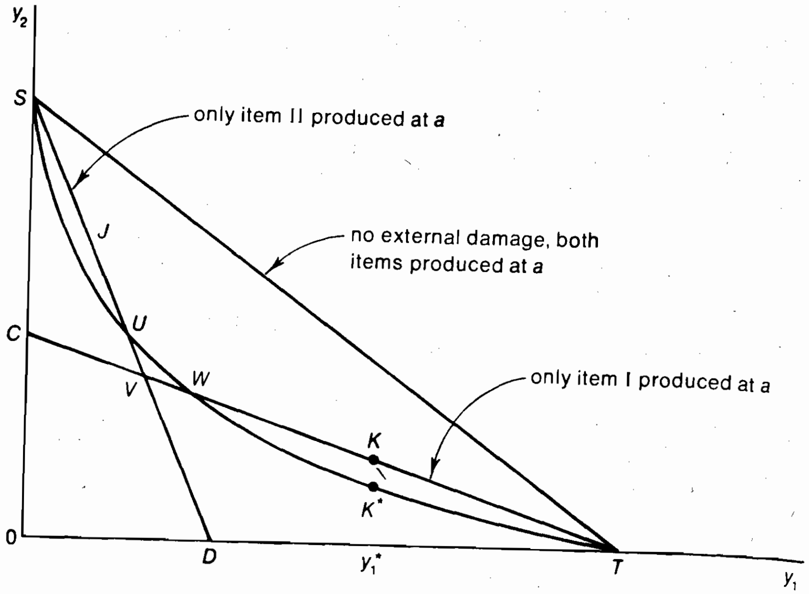


Figure 8.3

will violate the preceding convexity requirement. If r is very large, say on the order of thousands or millions of units, even a very small value of the externality parameter, w, will violate the second-order conditions. For example, if $r = 10{,}000$, then any $w > 0.01$ will have this effect.

4 Spatial separation as a palliative[10]

A lower bound to the degree of nonconvexity in the social production set arising from detrimental externalities is provided by the possibility of separating the generators and their victims geographically, for instance, by moving the laundries from the vicinity of the electricity producers or vice versa. This is illustrated by the following example:

Assume once more that we have two outputs, this time call them 1 and 2, and that these can be produced at either of two locations, a and b, with respective output levels, y_{1a}, y_{2a}, y_{1b}, and y_{2b}. To begin with, we take all substitution relationships in the absence of externalities to be perfectly linear. Let us assume that, were there no externalities, it would pay to produce both items at the same location, say A. In Figure 8.3, line segment

[10] For a very careful analysis of the location issue, see T. C. Koopmans and M. Beckmann, "Assignment Problems and the Location of Economic Activities," *Econometrica* XXV (January, 1957), 53–76.

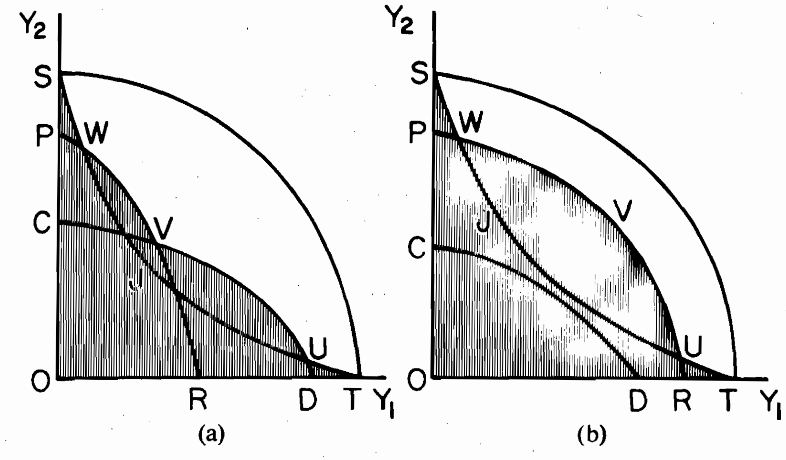


Figure 8.4

ST represents the production-possibility locus for our two items when external damage is zero and both are manufactured at the more economical location, A. SD represents the more restricted set of output levels[11] that remains possible if y_2 were still produced at A but the production of y_1 were moved to B. Because B is assumed to be a less suitable site, all of SD must lie below ST, with the exception of endpoint S, which corresponds to production of y_2 alone, which, by hypothesis, still occurs at A. Similarly, line segment CT represents the production possibilities when manufacture of y_2 is moved to B and that of y_1 takes place at A.

Now suppose that externalities generated by the production of y_1 at A grow serious, so that the locus corresponding to manufacture of both items at A shifts from the line segment ST to the convex locus $SUWT$ by the process described in the discussion of Figure 8.2. Then, if society wishes to produce, say, quantity y_1^* of item 1, it can only obtain $y_1^*K^*$ of y_2 if both goods continue to be produced at A. However, by separating the two production processes, shifting the manufacture of item 2 to site B, the community can increase its output of commodity 2 to y_1^*K.

Obviously then, if we take into account the possibility of spatial separation of output processes, the production-possibility locus becomes $SJUWKT$. In no event can externalities force this locus to retreat closer to the origin than SVT. However, even here, the feasible region $OSVT$ cannot be convex, because the boundary point V must lie below the line ST. Figures 8.4a and 8.4b generalize the argument of Figure 8.3 to the

[11] This shrinking of the possibility set takes into account any resources that must be devoted to transportation as a result of the separation of activities.

case of nonlinear substitution relationships in which it is no longer necessarily true that one location, A, is the best place for both outputs. Once again, ST is the possibility locus in the absence of externalities. The two possibility curves corresponding to the two ways of separating the two outputs geographically are PR and CD. These two curves need no longer have even a point in common with ST because along ST some of one or both items may now be produced at B as well as at A. Nor, as Figure 8.4b shows, need PR and CD intersect. They will limit the extent to which externalities can pull the possibility locus toward the origin, but they cannot prevent the appearance of a nonconvexity in the feasible region, as Figures 8.4a and 8.4b indicate. For suppose externalities transform the locus ST, along which the activities are not separated, into the curve SJT. The true possibility locus will now be $SWVUT$, yielding a feasible region $OSWVUT$ (shaded areas) that is nonconvex.

In sum, these figures illustrate

Proposition Three. Sufficiently severe externalities make locational specialization economical. Separation limits the magnitudes of the nonconvexities resulting from externalities but does not prevent them.

The figures also bring out a disconcerting possibility.

Proposition Four. The location pattern that will be optimal socially may vary with the proportions among the various outputs that is desired by the community.

Thus, in Figure 8.4a, with fairly strong externalities the production possibility function is $SWVUT$. For output combinations along segment WV, all of y_2 is produced at A, all y_1 at B. Along segment VU, the specialization is reversed. The danger of an incorrect choice by planners in this context appears clear, particularly because in this area it may be very difficult and costly to undo an incorrect decision or one that was appropriate at the time it was made but no longer is.

5 The two-location case: an alternative graphing

A somewhat different graphic representation of the two-location case from that in the preceding section may help to show how nonconvexities arise when geographic separation is possible, and will tie the discussion back to a topic discussed at the end of the previous chapter (Figure 7.5 of Chapter 7).

Suppose, once more, that there are two locations, A and B, and that it is proposed to establish at one or both of these two places two activities, at least one of which yields externalities detrimental to the other. We also still suppose that these are the only activities (other than leisure) under consideration, with y_{1a} and y_{1b} representing the quantities of the first item produced at the two locations, and y_{2a} and y_{2b}, the corresponding outputs of the other. To avoid any problems about variation in total outputs resulting from the differing effects of externalities when geographic patterns vary, let us assume that the investment plan calls for a fixed proportion between the *total* outputs of the two commodities, $(y_{1a}+y_{1b})/(y_{2a}+y_{2b})$. This leaves us, essentially, with two degrees of freedom: $v_1=y_{1a}/(y_{1a}+y_{1b})$, and $v_2=y_{2a}/(y_{2a}+y_{2b})$, the respective proportions of the two outputs produced at location A.

This formulation permits us to utilize a box diagram to describe the effect of the externalities (Figure 8.5a). Along the two axes, we represent the values of v_1 and v_2, where clearly $0 \le v_1 \le 1$ and $0 \le v_2 \le 1$. Point E in the diagram with coordinates $(1, 1)$ represents the case where both outputs are concentrated at location A and, similarly, the origin is the case where all activity takes place at B. The two other corners, C and D, are the arrangements under which the two activities are completely separated.

Now, if the externality were completely negligible or innocuous, a plausible social welfare function might very well have an interior maximum, as shown by the isoproduct curves in Figure 8.5a at point K. For example, having laundries next to electricity-generating plants will save on transmission costs, and having some of each type of plant at each location will avoid congestion costs and, perhaps, reduce the transportation costs of serving local customers. Depending on the geographic features of the two locations, the optimal scale of activity at the two locations will vary. In Figure 8.5a, the optimal solution point K involves the location of about two-thirds of each activity at A.

Now consider the opposite case, in which the emissions of one activity substantially reduce the efficiency of the other. In that case, when the emission cost becomes sufficiently great, total output will be maximized by separating the two activities completely. There will now be (at least) two local maxima. One of them will be point C, with all of output 2 located at A and all of item 1 production at B. The other local maximum will be D, where the locations are simply reversed. Figure 8.5b illustrates the isoprofit curves in such a case. Here O and E are both local minima, and the arrows indicate directions of increasing welfare. It is clear also that there can be intermediate cases when the social cost of the externality is more moderate, with the result that there exists some interior local maximum M, as well as the two corner maxima, C and D (Figure 8.5c).

The important point is that these sorts of relationships arise whenever one activity interferes with the efficiency of another, so that their separation can increase the efficiency of resource utilization. In any such case, a multiplicity of maxima is in the nature of things. It is plausible that the social welfare function will exhibit at least two local maximal values of

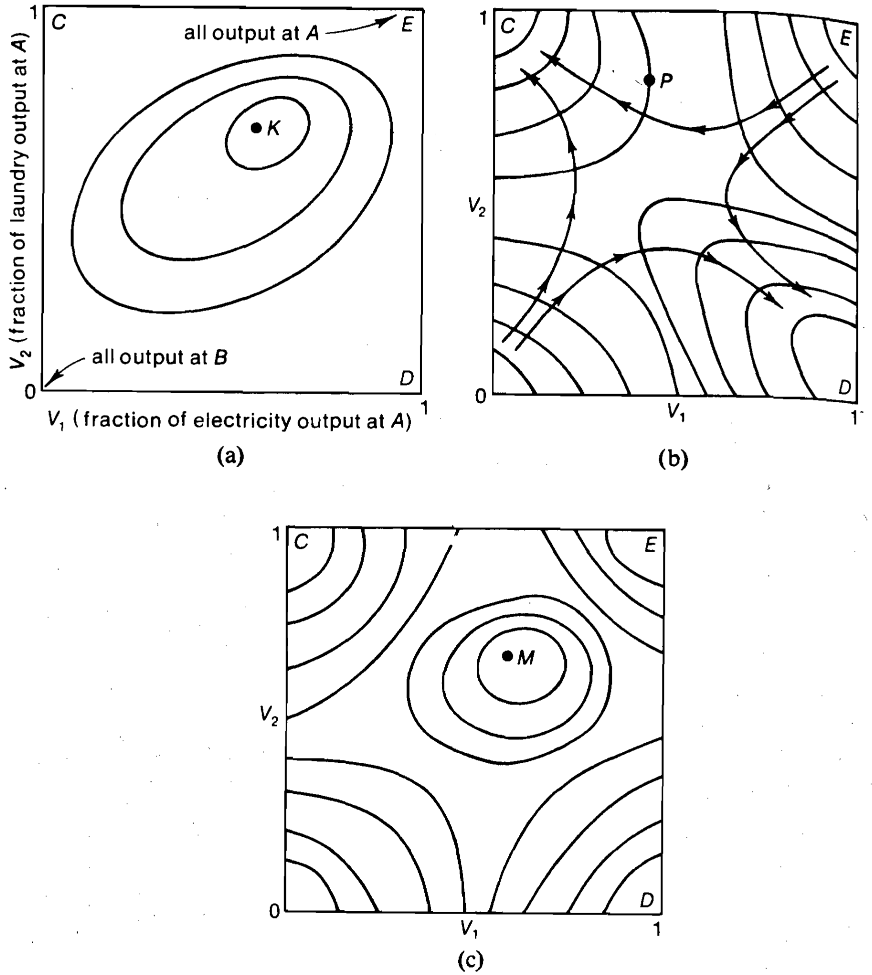


Figure 8.5

$(y_{1a}, y_{1b}, y_{2a}, y_{2b})$ occurring at $(y^*_{1a}, 0, 0, y^*_{2b})$ and $(0, y^*_{1b}, y^*_{2a}, 0)$, (that is, at the solution points in which the two activities are carried on at different locations).

To return briefly to the subject matter of the preceding chapter, the diagrams indicate once again that, in the presence of a multiplicity of local maxima resulting from nonconvexity of the possibility set, the market-determined output of an activity that generates detrimental externalities may be *below* its optimal level, contrary to the impression that seems to be so widely held. For suppose (Figure 8.5b) that the social optimum is

point D (all of y_1 produced at A, all of y_2 at B). With electricity output at A yielding harmful externalities, point P is a possible competitive equilibrium point. For with the indifference curve at P vertical, a small shift in laundry output will not change social welfare, but a small shift in electricity output from location A to B will increase social welfare (*MSC* of electricity greater than *MPC* - marginal private cost). Yet the socially optimal proportion of total output of electricity to be produced at A, as indicated by point D, is greater than it is at P, as was to be shown. The point, of course, is the well-known observation that, with a multiplicity of local maxima, a route that takes one uphill may, in fact, lead away from the highest point in the graph.

6 Generalization to *n* activities

The arguments of the preceding sections have dealt with a world in which (including leisure) there are only three "activities." However, as was already indicated, generalization of the argument to a world of *n* activities is immediate.[12] In a world of n outputs, convexity can be guaranteed only if *each* of the partial possibility loci representing substitution between a pair of commodities is concave. Any single exception, like that in Figure 8.2, means that at least two local maxima become possible. Thus, the analysis holds whether the economy encompasses two outputs or n.

There is, however, one aspect of the matter that does require explicit analysis in terms of *n* commodities. One may well ask whether and to what extent the number of local maxima is likely to grow as the number of activities in an economy increases. Here we can offer only a few observations about some polar cases, none of them rigorous. They suggest, however, that in at least some cases the number of local maxima may grow *very* rapidly with the number of activities involved.

First, however, we deal with a case in which a proliferation of activities does not necessarily increase the number of local maxima.

Polar case a: If one activity imposes external costs on *m* other activities, even if the detrimental effects are very great, no more than two local maxima need result,[13] and

[12] Our discussion has also confined itself only to *detrimental* externalities. In principle, the presence of external benefits can also produce a multiplicity of local maxima, but here it is not so clear that the problem is likely to be serious. On this see Baumol, "External Economies and Second-Order Optimality Conditions," pp. 366–67.

[13] This does not preclude the possibility that there will be more than two maxima if the relevant functions violate the appropriate concavity-convexity conditions in the absence of externalities. Even where the maximum would otherwise be unique, externalities that are of intermediate strength may lead to three (or more) local maxima, characteristically two corner maxima produced by the externalities, and one interior maximum, a vestige

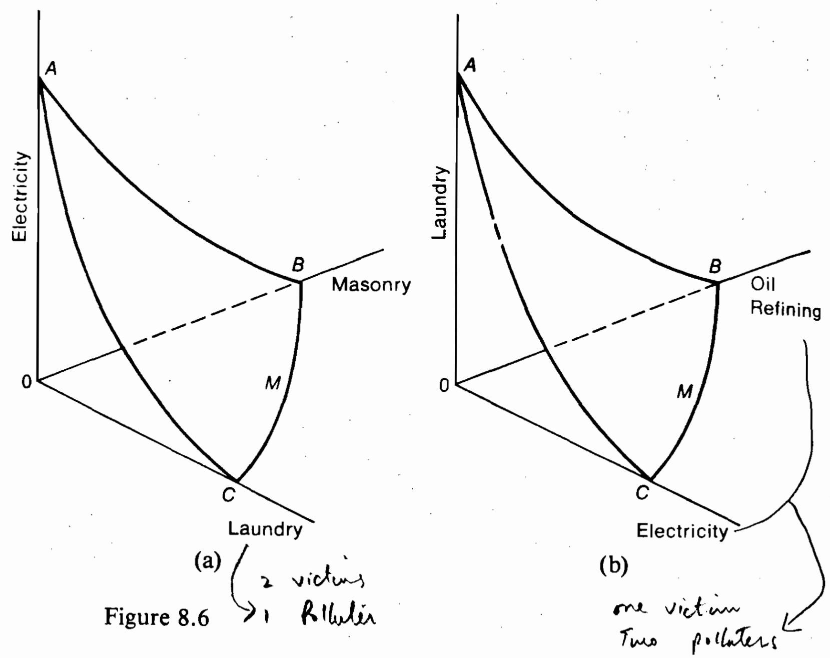


Figure 8.6

Polar case b: A similar result holds when n activities each impose external benefits on one other activity. These results are suggested by Figure 8.6a, in which the smoke from electricity production is taken to increase laundry cost and make it more expensive to produce deterioration-resistant masonry. The production locus will then tend toward the form indicated (surface ABC). Because laundry and masonry activity impose no adverse external effects upon one another, their production-possibility locus can be assumed to have the normal shape (concave to the origin) illustrated by curve CB. However, for the reasons indicated in the discussion of Figure 8.2, if smoke damage is sufficiently serious, the other two partial loci will have shapes like those of AC and AB. We may then expect two local maxima, one at A and perhaps another at a point such as M. The interpretation of Figure 8.6b is exactly the same and we merely pause to draw the reader's attention to the remarkable similarity of the diagram for the two-victim, one-polluter case with that for one victim and two polluters.

Footnote 13 *(cont.)*
of the unique maximum that would occur in the absence of externalities. An illustration occurs in Figure 8.5c. Complications such as these and the possibility of irregularities in the relevant hypersurfaces probably limit the profitability of a more rigorous discussion of the subject of this section.

Next, we come to cases involving more complex patterns of interdependence and show that here the number of local maxima may indeed increase rapidly with the number of activities involved. We have

Polar case c: If each of n activities produces and suffers from very strong *mutually* detrimental externalities and spatial separation is not possible, some n local optima can be expected.

The reason is that, in the limit, as external damage becomes sufficiently great, it will be optimal (indeed, it will only be possible) to carry on just one of the n activities because the externalities resulting from any one activity effectively prevents the operation of any other. Clearly, there are exactly n possible choices of the activity to be continued. But each such solution, $y_i > 0$, all $y_{i'} = 0$ for $i \neq i'$ is a local maximum in the sense that it yields an output whose value is greater than is possible if we attempt to set some $y_{i'} \neq 0$ when $y_i > 0$. Hence, we do indeed have n local maxima, $y_i > 0,\ y_{i'} = 0,\ i \neq i',\ i = 1, \ldots, n$.

If matters are not quite so serious, so that only a smaller number, k, of activities need be discontinued, it may be conjectured, somewhat surprisingly, that the number of local maxima actually will increase to the order of magnitude of the number of combinations of n activities chosen k at a time.

Finally, we deal with the possibility of spatial separation that, rather out of line with its role in our earlier discussion as a bound to the degree of nonconvexity, seems to increase the growth in number of maxima with the number of activities involved. We have

Polar case d: If there are n activities, each of which produces and suffers from externalities, and there are just n discrete locations into which they can be separated, then, if the externalities are sufficiently severe, we can expect at least $n!$ local maxima. Note that we have n candidates for the first location and, for each such choice, there remain $n-1$ candidates for the second location, then $n-2$ candidates for the third, and so on; this implies that there are altogether $n!$ different ways of achieving the desired isolation.

In practice, in some respects, this probably exaggerates the number of possibilities; in other ways, it understates them. There really is no fixed finite number of discrete locations, and so one will normally have more than n geographic areas in which to locate n activities. If that is the right way of looking at the matter, it is clear that the number of local maxima (that is, the number of ways of isolating each activity) will exceed $n!$. On the other hand, airborne pollution is known to travel over enormous distances. In that sense, we may have no hiding place from one another's emissions. We may then find ourselves back at the one-location case with its smaller number of local maxima but its higher levels of social damage.

7 Convexity in social and individual firms' possibility sets

In one respect the externality-induced nonconvexity poses a less-serious problem for social control than one might expect, for, as all of our examples indicate (see, notably, Figure 8.1)

Proposition Five. Nonconvexities in the social production-possibility set arising from detrimental externalities are entirely compatible with convexity in the sets over which individual producers make their choices.

This has an important theoretical consequence,

Proposition Six. Despite the presence of nonconvexities in the social production-possibility set as a result of detrimental externalities, it is possible through the use of prices and taxes alone to induce any individual firm to choose any designated point on its production-possibility frontier. We can thus use these devices to sustain any designated point on the social possibility frontier, despite its "incorrect" curvature. ?

This may be contrasted, for example, with the case of nonconvexity due to increasing returns to the scale of individual producers' production. There, if every firm's average costs decline continually with scale over some substantial range, a competitive producer confronted by a fixed price will either turn out zero output or some large quantity of output. Output combinations calling for intermediate levels of production of the good in question cannot be attained with the aid of the price mechanism alone.[14] But the nonconvexities with which we are now concerned affect only the *social* possibility set, and so they are perfectly consistent with the possibility that a producer can be induced to turn out any intermediate quantity of output by an appropriate choice of prices.

The general principle may be illustrated with the example of Section 3, involving two producers using their input fully, with input cost functions (1). If a fixed total quantity of the input is used, *any* pair of output choices by the two producers will be on the production-possibility frontier. It need, then, only be demonstrated that any attainable (y_e, y_l) combination will be chosen by them at some specifiable set of prices. Let the prices p_e for electricity (y_e) and p_l for laundry (y_l) be chosen and let

[14] Note, however, that intermediate output levels for the competitive industry are perfectly possible in these circumstances. In an industry producing two outputs, y_1 and y_2, if each firm's possibility set is nonconvex some firms will specialize in the production of y_1 and others will now produce only y_2. See Jerome Rothenberg, "Non-convexity, Aggregation and Pareto Optimality," *Journal of Political Economy* LXVIII (October, 1960), pp. 435–58, and see E. Malinvaud, *Lectures on Microeconomic Theory* (Amsterdam: North-Holland Publishing Co., 1972), Chapter 7 for a more general discussion of nonconvexities in the large numbers case.

labor be given a price of unity. The profit functions of the two firms are then given, in accord with (1), by

$$\begin{aligned} \pi_e &= p_e y_e - y_e^2/2 \\ \pi_l &= p_l y_l - y_l^2/2 - w y_e y_l. \end{aligned} \tag{3}$$

With the individual production sets being strictly convex in each firm's "own" decision variable, the profit functions are strictly concave in its own variables. That is, the second derivatives of both profit functions are negative. Specifically,

$$\frac{\partial^2 \pi_e}{\partial y_e^2} = \frac{\partial^2 \pi_l}{\partial y_l^2} = -1.$$

Hence, the first-order conditions are sufficient, as well as necessary, for profit maximization by the individual firms. These first-order conditions are obtained directly by differentiation of (3) to yield

$$\begin{aligned} y_e &= p_e \\ w y_e + y_l &= p_l. \end{aligned} \tag{4}$$

Equations (4) are obviously invertible, which means that any desired pair of outputs (y_e, y_l) can be obtained as a solution to (4) for some combination of prices. Thus despite the fact that, as shown in Section 3, for $w>1$, (that is, for externalities sufficiently strong), this set of functions yields a nonconvex social possibility set, there is a unique pair of prices that induces the firms to produce any efficient output vector (y_e^*, y_l^*) that is desired. This simple counterexample is in fact sufficient to prove our point here; that is, that nonconvexities in the social possibility set resulting from externalities *need not* result in nonconvexities in the private possibility sets and so may not prevent the price system from yielding any predetermined efficient vector of outputs.

Having dealt with the position of the firm in our world with a nonconvex social possibility region, we must next bring consumers into the picture. In Figure 8.7b, let *II* be a social-indifference curve, so constructed that along it social welfare is constant and that its slope at any point equals the common slope of all consumers' indifference curves at the corresponding distribution of the two goods.[15] A social welfare maximum involving positive outputs of the two goods must be characterized by tangency of a social-indifference curve with the production-possibility frontier, as at point *T* in Figure 8.7b. As we have just suggested, so long

[15] See P. A. Samuelson, "Social Indifference Curves," *Quarterly Journal of Economics* LXX (February, 1956), 1–22 or W. J. Baumol, *Welfare Economics and the Theory of the State* (2nd ed.), (Cambridge, Mass.: Harvard University Press, 1965); Chapter 3, Section 9, and Appendix.

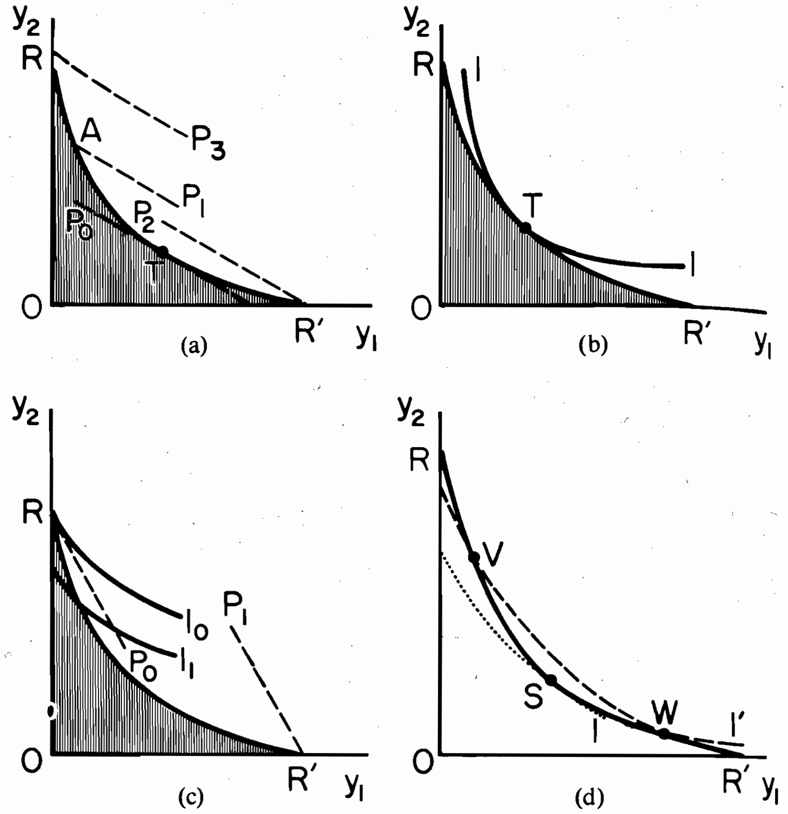


Figure 8.7

as the only source of nonconvexity is the presence of detrimental externalities, such a point can be sustained as a tax-adjusted competitive equilibrium, in which producers are maximizing profits and individuals are maximizing their utilities in the small and in the large.

With this observation we are now in a position to offer some comments on the consequences of externality-induced nonconvexities for social welfare.

8 Who needs convexity?

It has long been recognized that the absence of convexity creates problems for public policy.[16] However, aside from the fact that earlier writers generally did not see that the externalities themselves tend to produce the

[16] See, for example, the quotation from Pigou at the beginning of this chapter.

nonconvexities that are the source of the problem, they may not have recognized the full extent of the complexity that besets the policy problem here both in theory and in practice.

Where the appropriate concavity-convexity assumptions are satisfied, it will be recalled that everything works out nicely in the competitive equilibrium case:

a) There will be a set of prices that determine an optimal budget line (hyperplane). In the differentiable case with an interior maximum, this budget line will simultaneously be tangent to the production-possibility locus and to a community-indifference curve at the optimal point. More generally, the budget hyperplane will constitute a separating hyperplane for the possibility set and the preference set at that point.
b) At that optimal point and at those prices, all consumers and all producers will be in equilibrium.
c) The value of total output at the optimal prices will be maximized at the optimal point. That is, the budget line described in a) will be the highest of the family of parallel budget lines that has any point in common with the production-possibility set. It is this property, the fact that maximization of value of output coincides with maximization of social welfare, that permits us to infer the Pareto optimality of the competitive equilibrium.

With the nonconvexities introduced by externalities, the preceding properties run into complications that increase, at least in principle, the problem of formulating rules capable of leading the economy to an optimal solution.

For simplicity in the following discussion we will assume that the production-possibility curve is strictly convex (that is, that the possibility set has the simple smooth upper boundary RR' illustrated in Figure 8.7a). The reader can consider for himself the additional complexities that arise where this locus takes on a more irregular shape involving both concave and convex ranges.

As we can see in Figure 8.7a, with such a possibility set, no interior point on the possibility locus can be a point of maximum value at any positive output prices. Let the set of parallel lines labelled $P_0, P_1, \ldots$ be members of the family of price lines. Then it is clear that the point of tangency, T, between such a price line and the possibility locus must be a point of *minimum* output value, given production efficiency (that is, P_0 must be the lowest price line along RR'). At any other interior point on RR', such as A, obviously the output value will not be a maximum either. Only at R and at R' will we have two local value maxima. Which of these is the global maximum depends on the prices in question.

However, in this case it is *not* true that the social optimum must lie at one of the corner points. Figure 8.7b shows a well-behaved interior optimum at T, the point of tangency of the possibility locus RR' and the social-indifference curve II. All that is required is that the curvature of the indifference curve be greater than that of the possibility locus. Here, then, the social-optimum point obviously *cannot* be a point of maximum output value, because it does not lie on the highest price line passing through the possibility set.

Moreover, even if the social optimum occurs at a corner (Point R in Figure 8.7c), this still need not be the global *value* maximum. Thus, we observe in Figure 8.7c that if we use the prices corresponding to price line P_0 tangent to the community indifferent curve I_0 at the social optimum, then it is price line P_1R' through point R' that gives the maximum value of output.

We conclude,

Proposition Seven. With nonconvexity of the possibility set, the social optimum may or may not lie at a corner, but if the possibility frontier is convex (to the origin) throughout, there will be a local point of maximum output *value* at every corner of the possibility frontier (and nowhere else). *In neither case need the social optimum and the value maximum coincide,* as they would in the case where the usual convexity assumptions hold.

As a final curiosity, in Figure 8.7d we see a point of tangency, S, which is a point of *minimum* social welfare and, yet, which, after the imposition of Pigouvian taxes,[17] is a possible point of competitive equilibrium! After all, we assume that individual consumer and producer relationships have the convexity properties required by the second-order conditions. But at S, the first-order conditions for consumer and producer equilibrium must be satisfied, as we have just seen. Hence S now becomes a competitive equilibrium point.[18]

[17] One must keep in mind that in the competitive equilibrium under discussion here, Pigouvian taxes and subsidies have been imposed in order to induce consumers and producers to make their decisions in accord with the correct marginal rates of substitution and transformation. This point is important because our discussion is intended to show that, even after proper corrective taxes have been imposed, the nonconvexities problems remain.

[18] Whether S will be a point of *stable* equilibrium is not entirely clear. It depends in part whether Pigouvian tax-subsidy levels are adjusted when the economy leaves point S. It is our conjecture that if these tax values are not changed, with a suitable set of adjustment relationships S need not be unstable, but if taxes are varied continuously so that they are always equal to marginal social damage then S will generally be unstable. Thus, with a sufficiently sensitive taxing scheme we should at least be able to prevent the economy from settling at a welfare minimum point, such as S.

Note also that even if the point of tangency is like T in Figure 8.7b, it may only represent a local maximum. Thus, in Figure 8.7d, point W is such a tangency point, but any position on RR' to the left of V is better than W. And this is possible even when the social-indifference curves are entirely well-behaved.

9 Conclusion: the policy relevance of externality-induced nonconvexities

In sum, we can no longer utilize the familiar proof of the optimality of competitive equilibrium that depends upon convexity in the set of attainable output combinations to show that the actual output point attained as an equilibrium, in this case with appropriate corrective taxes (that is, taxes forcing producers to take externalities into account), must maximize the value of output at efficiency prices that are also market-clearing. Now that other attainable points may be more valuable at current prices, the equilibrium need no longer be Pareto optimal. Prices no longer can be depended upon to give the right signals. They do not tell us whether we are at a welfare maximum or minimum, whether a maximum is local or global, or in which direction the economy should move to secure an increase in welfare.

In short, in a world in which detrimental externalities are sufficiently severe to cause nonconvexities, efficiency prices are robbed of much of their normative usefulness. Although it remains true that an equilibrium that maximizes the value of output over all feasible outputs is Pareto optimal (this is assured by the convexity of preferences), it is no longer true that the availability of outputs that are more valuable (at current equilibrium prices) means that the current output is not Pareto optimal. Thus, in Figure 8.7b, point T is obviously the optimal output, but the most valuable output combination must lie either at R or R'. Notice that this problem arises even where the more valuable outputs can be obtained by infinitesimal (marginal) adjustments. More generally, *even if we know the entire set of feasible output points, equilibrium prices tell us nothing about the Pareto optimality of current output or the direction in which to seek improvement.* Although tax instruments may still be of some help in guiding the economy, as later chapters will suggest, the choice of the equilibrium point at which it is desired to have the economy settle must somehow be made collectively, rather than by automatic market processes.

Appendix A: Analytic representation: nonconvexities in the possibility locus with three activities

In Section 3, we presented a concrete illustration of a possibility locus to show explicitly how externalities can produce nonconvexities in such a case. This appendix generalizes the argument of Section 3 using some elementary differential calculus and derives explicitly the numerical results reported at the end of Section 3.

We again consider a three-activity economy that provides electricity (industry e), laundry (industry l), and leisure (unused labor). We have well-defined production functions for the two industries. From the two production functions, we deduce the shape of the production-possibility locus and see how it responds to changes in the coefficient of the externalities term. Both activities are taken to use the same resource, labor, as their only input. The greater the quantity of electricity generated, the more labor it takes the laundries to get a given wash to an acceptable level of cleanliness; that is all there is to the externality.

Proceeding first in general terms, we have as our resources-demand functions for the two industries

$$r_e = c^e(y_e) \qquad r_l = c^l(y_e, y_l) \tag{1}$$

where r_k = the quantity of input used by industry k and
y_k = the output of that industry.

Then, the equation of the production-possibility locus corresponding to the utilization of some fixed quantity, r, of the labor resource is clearly

$$r = c^e(y_e) + c^l(y_e, y_l). \tag{2}$$

From this, we derive immediately [letting c_e^e represent $dc^e(y_e)/dy_e$, and so on]

$$(c_e^e + c_e^l)dy_e + c_l^l dy_l = 0.$$

Because increased outputs presumably require increased quantities of inputs and because we are considering a detrimental externality, we must have

$$c_e^e > 0 \qquad c_l^l > 0 \qquad c_e^l > 0. \tag{3}$$

Consequently,

$$\frac{dy_l}{dy_e} = -\frac{c_e^e + c_e^l}{c_l^l} < 0. \tag{4}$$

We assume that there are diminishing private returns (increasing costs) to each output, so that

$$c_{ee}^e > 0 \qquad c_{ll}^l > 0. \tag{5}$$

From (4), we obtain directly

$$\frac{d^2y_l}{dy_e^2} = -\frac{\left(c_{ee}^e + c_{ee}^l + c_{el}^l \dfrac{dy_l}{dy_e}\right)c_l^l - \left(c_{le}^l + c_{ll}^l \dfrac{dy_l}{dy_e}\right)(c_e^e + c_e^l)}{(c_l^l)^2}$$

$$= \frac{-(c_{ee}^e + c_{ee}^l)c_l^l + (c_{el}^l + c_{le}^l)(c_e^e + c_e^l) - c_{ll}^l \dfrac{(c_e^e + c_e^l)^2}{c_l^l}}{(c_l^l)^2}. \tag{6}$$

If there were no externalities, so that $c_e^l = c_{el}^l = c_{le}^l = c_{ee}^l = 0$, then (6) would be ambiguously negative by (3) and (5) because its numerator would reduce simply to $-c_{ee}^e c_l^l - c_{ll}^l (c_e^e)^2 / c_l^l$. Thus, the production-possibility locus would have a negative slope by (4) and be concave by (6), as the second-order conditions require. However, with detrimental "cross-marginal" externalities (increasing marginal laundry cost with an incremental rise in smoky electricity output), we may expect $c_{el}^l = c_{le}^l > 0$, and the sign of (6) is no longer clear. The externality term $(c_{el}^l + c_{le}^l)(c_e^e + c_e^l)$ is positive. Hence, if it is sufficiently large relative to the other terms, it must give (6) a positive value, thus violating the concavity condition.

Specifically, utilizing the second illustrative example of Section 3, we have

$$r_e = c^e(y_e) = y_e^2/2 \text{ (electricity cost function) and}$$

$$r_l = c^l(y_e, y_l) = y_l + wy_e y_l \text{ (laundry cost function),}$$

so that by direct differentiation we obtain

$$c_e^e = y_e \qquad c_e^l = wy_l \qquad c_l^l = 1 + wy_e$$

$$c_{ee}^e = 1 \qquad c_{ee}^l = 0 \qquad c_{el}^l = c_{le}^l = w \qquad c_{ll}^l = 0.$$

Thus, substituting into (6) we obtain directly

$$\frac{d^2y_l}{dy_e^2} = \frac{-(1 + wy_e) + (2w)(y_e + wy_l)}{(1 + wy_e)^2} = \frac{wy_e + 2w^2 y_l - 1}{(1 + wy_e)^2},$$

which will clearly be negative if, and only if, $2w^2 y_l + wy_e < 1$, as asserted in the text. That is, for w (or y_e or y_l) sufficiently large, the production-possibility set cannot be convex.

Appendix B: A formal model of external effects and corrective taxes

by David F. Bradford

This appendix is intended to show that, when every individual producer's choice set is convex, *any* socially efficient net output vector can be sustained by profit-maximizing production with externality-offsetting taxes, as asserted in Section 7. For this purpose, we first offer a formalization of our definition of detrimental externalities of the sort discussed above. Armed with this definition, we show that social efficiency requires individual efficiency when external effects are all detrimental. A producer's net output vector (including negative entries for inputs) can be said to be "individually efficient" if no dominating net output vector is available to him without changing some other producer's net output choice. From this, we go on to derive our result about the sustainability of socially efficient output vectors.

Let $y^k = (y_{1k}, \ldots, y_{nk})$ be the net output vector of the kth producer, where negative entries represent net inputs. We assume that y^k is chosen from a *feasible set* Y^k. For the usual reasons,[19] we assume that Y^k always includes the origin and the negative orthant of Euclidian n-space (free disposal), and that Y^k has no elements other than the origin in the nonnegative orthant (no outputs without inputs).

The size and shape of Y^k depend on the net output choices of *other producers*. Let Y stand for the matrix of net output choices of the m producers in the economy, whose (i, k)th element, y_{ik}, is the net output of commodity i by producer k. We shall represent the dependence of Y^k, the feasible set for k on the choices of other producers, as a functional relationship, mapping Y into subsets of n-space, and denote this relationship by $Y^k = Y^k(Y)$. Thus $Y^k(Y)$ is defined as the set $\{y^k \mid y^1, \ldots, y^{k-1}, y^{k+1}, \ldots, y^m\}$. We shall say that *these relationships embody detrimental external effects if for any two different producers, k and k'*

$$\lambda > 1 \Rightarrow Y^{k'}(\ldots \lambda y_{ik} \ldots) \subset Y^{k'}(Y),$$

where $(\ldots \lambda y_{ik} \ldots)$ *denotes the matrix obtained from Y by replacing* y_{ik} *by* λy_{ik}. This definition implies that every producer tends to hurt every (strictly, "at best doesn't help any") other producer by increasing the intensity of any of his own net outputs *or* net inputs. Obviously, a definition of beneficial external effects would be obtained by reversing the set-inclusion sign in this definition. The definition can also be made to apply specifically to a particular element, y_{ik}, so that variables can be taken to exhibit either detrimental or beneficial external effects. We confine our attention to relationships involving only detrimental externalities, which, by the definition, include the case of zero externality.

a *Requirements of socially efficient production*

Under this definition, it follows trivially that socially efficient production (total net output of some one item maximized for any set of given totals of the other net outputs) requires efficiency on the part of every individual producer. For, if a producer has chosen an individually inefficient net output vector, he can alter his choice in a way that preserves his net output but reduces his net input usage. Because the external effect of the latter action in our case must, if anything, *enhance* the productive opportunities of the other producers, such a choice is clearly required by social efficiency.

Because, by assumption, the feasible set of each producer, considering only variations in the vector under his control, is convex, any point in that set that is efficient from the producer's point of view will be a profit-maximizing choice for some vector of prices. And since, as we have just shown, any socially efficient point will be composed of a sum efficient for each producer, it follows that any socially efficient net output vector can be sustained as a profit-maximizing point for all producers if the prices are appropriately adjusted for each producer by a set of taxes. It remains only to show that the "appropriate" taxes are precisely equal to the marginal external damages arising from changes in output and input choices.[20]

For this demonstration, it will be convenient to assume that the feasible set of the kth producer is defined by the inequality $f^k(Y) \leqq 0$, where f^k is a differentiable function. Recall that Y is a *matrix* of which the typical element, y_{ik}, specifies the net output (negative for inputs) of the ith commodity by the kth producer. Fixing net output vectors $y^{k'}$ for $k' \neq k$, $f^k(Y) = 0$ defines the "private production possibility frontier" constraining y^k, the net output vector choice of the kth producer. By assumption, the set of vectors y^k satisfying $f^k(Y) \leqq 0$ in this case is convex.

If the rows of the matrix Y^* sum to a point on the social production-possibility frontier, then it is a solution to the nonlinear programming problem

$$\text{maximize} \sum_{k=1}^{m} y_{1k} \quad \text{(maximize total output of commodity 1)}$$

subject to

$$\sum_{k=1}^{m} y^*_{ik} - \sum_{k=1}^{m} y_{ik} \leqq 0 \quad (i = 2, \ldots, n) \quad \text{(no reduction in any other output)}$$

$$f^k(Y) \leqq 0 \quad (k = 1, \ldots, m).$$

By a simple extension of the Kuhn-Tucker theorem on optimization with inequality constraints, necessary conditions[21] for a solution to this problem

[19] See, for example, J. Quirk and R. Saposnik, *Introduction to General Equilibrium Theory and Welfare Economics* (New York: McGraw-Hill, 1968).

[20] Note the formal similarity of the following argument to the basic analysis of Chapter 4.

[21] Strictly speaking, a certain "constraint qualification" must be satisfied at the solution values to assure the necessity of these conditions. The qualification concerns a possibility that we may take to be pathological in this context. See any textbook treatment of the Kuhn-Tucker theorem.

are that there exist nonnegative multipliers $\lambda_2, \ldots, \lambda_n$, corresponding to the constraints requiring no reduction in availability of commodities other than commodity 1, and $\gamma_1, \ldots, \gamma_m$, corresponding to the individual production constraints, such that

$$1 - \sum_{k'=1}^{m} \gamma_{k'} f_{1k}^{k'} = 0 \qquad (k=1, \ldots, m)$$

$$\lambda_i - \sum_{k'=1}^{m} \gamma_{k'} f_{ik}^{k'} = 0 \quad \begin{matrix}(k=1, \ldots, m) \\ (i=2, \ldots, m).\end{matrix}$$

(The notation $f_{ik}^{k'}$ stands for the partial derivative of $f^{k'}$ with respect to y_{ik}.) By the usual interpretation, λ_i equals the amount of commodity 1 (in effect here, the numeraire commodity) obtainable by a unit reduction in the amount of commodity i produced. The multiplier γ_k is the value (in commodity 1 terms) of the extra output that could be obtained if firm k's production constraint were relaxed by requiring $f^k(Y) \leqq 1$ instead of $f^k(Y) \leqq 0$.

b Requirements of individual-producer equilibrium

Consider next the profit-maximizing problem faced by producer k faced with a vector $p = (p_1, \ldots, p_n)$ of prices *and* a vector $t^k = (t_{1k}, \ldots, t_{n+k})$ of taxes:

$$\text{maximize } \sum_{i=1}^{m} (p_i - t_{ik}) y_{ik},$$

$$\text{subject to } f^k(Y) \leqq 0,$$

where all variables other than the "own" vector, y^k, are treated as exogenously fixed in the constraint. By the Kuhn-Tucker theorem, if y^k is a solution, there necessarily exists a nonnegative multiplier, δ_k, such that

$$p_i - t_{ik} - \delta_k f_{ik}^k(Y) = 0 \quad (i=1, \ldots, n).$$

Furthermore, because the constraint set is convex, these conditions, together with the constraint, are sufficient as well as necessary for a constrained maximum. The multiplier δ_k indicates the profit that would be *lost* to the kth producer if his production constraint were "tightened" by one unit.

c Synthesis: producer equilibrium and productive efficiency

Now we need only put the two problems together. If Y is a set of individual producer vectors summing to a point on the social production possibility frontier, use the Lagrange multipliers from the associated nonlinear programming problem and set

$$p_1 = 1, \qquad p_2 = \lambda_2, \ldots, p_n = \lambda_n$$

$$t_{ik} = \sum_{\substack{k' \neq k \\ k'=1}}^{m} \gamma_{k'} f_{ik}^{k'} \quad \begin{matrix}(k=1, \ldots, m) \\ (i=1, \ldots, n)\end{matrix}$$

Then the Kuhn-Tucker conditions for the social production possibility frontier reduce immediately to

$$p_i - t_{ik} - \gamma_k f_{ik}^k = 0.$$

Thus, we see that y^k, a point that satisfies these social frontier requirements, is associated with a set of prices and taxes at which y^k also satisfies the necessary and sufficient conditions for a profit maximum for producer k, with the multiplier δ_k of his problem equal to γ_k in the economy-wide problem.

To interpret this result, note that for $k' \neq k$, $f_{ik}^{k'}$ is, in effect, the *constriction* in the k'th production constraint per unit increase in the kth producer's net output of the ith good. Hence, $\sum_{k' \neq k} \gamma_{k'} f_{ik}^{k'}$ is the total external social cost per unit increase in y_{ik}. Furthermore, because $\delta_{k'} = \gamma_{k'}$, the external social cost will also exactly equal the marginal external profit loss per unit increase in output of Y_i by firm k. That is, when the proper corrective taxes are applied, the marginal tax on a firm that generates externalities will exactly equal the marginal profit loss it imposes on other firms.

CHAPTER 9

On optimal pricing of exhaustible resources[1]

As some growing scarcities have begun to alarm the public, the pricing of exhaustible resources has claimed increased attention. Thus, it seems appropriate to consider the issue here even though it represents something of a digression from the main line of our discussion. Here, again, optimality of pricing is defined in terms of resource allocation, but in this case the central issue is allocation among time periods rather than output categories. The results we will describe are all based largely on standard propositions of capital theory going back to the work of Irving Fisher and Bohm-Bawerk.

Yet when applied to exhaustible resources, some of our conclusions may be slightly surprising. For example, our instincts are likely to suggest that items in danger of depletion should tend to rise in price with the passage of time. We will see, however, that this is by no means generally true, and that, in some cases, optimality requires prices that decline, not only in discounted present value, but in current terms as well. Moreover, we will find that, although an optimal policy may call for prevention of the depletion of certain types of exhaustible resources, in other cases we should encourage their current utilization; obviously, this will be true of an item whose early use makes it possible to preserve some other resource whose returns to the future are larger.

Clearly, in dealing with the allocation of resources over time, the issue of intergenerational equity arises unavoidably. Most of the discussion of this chapter avoids direct consideration of this problem that the careful work of some of the most distinguished writers in the field has failed to resolve. Rather, we deal with the matter by the extension of the Pareto

[1] There now exists a large theoretical literature on the optimal use of exhaustible and renewable resources. The classic paper on the subject is Harold Hotelling's "The Economics of Exhaustible Resources," *Journal of Political Economy* XXXIX (April, 1931), 137–75. For a more recent and comprehensive treatment complete with an extensive bibliography, see Anthony C. Fisher, *Resource and Environmental Economics* (Cambridge: Cambridge University Press, 1981). Some of this literature addresses two issues that we will not examine in this chapter: the common-property characteristics of certain resources (such as fish), and the dynamics of resource depletion (in which, for example, the time path of fishing activity depends upon the size of the remaining fish population, and vice-versa).

criterion to the interests of individuals living in different time periods, taking as our object the maximization of the welfare of some arbitrarily selected member of an arbitrarily selected generation, with no loss in utility to any other individuals in his or any other generation.

1 Three prototype cases

A little consideration of the matter suggests that the depletable resource case really encompasses several heterogeneous phenomena. As a standard of reference, we begin with the case that we call *pure resource depletion* (although it is one that is probably not even approximated in reality). Suppose that a fixed stock of a useful and perfectly divisible material (which we will call *glob*) is available at one single location and that it is certain that there are no undiscovered deposits of glob. Thus, there is no way of augmenting its supply and no prospect that it will increase of its own account. In addition, we take glob to incur no cost of storage and not to deteriorate. We assume, finally, that the marginal cost of acquisition, transportation, and utilization of glob does not change as its stock decreases. The pile in which it is kept simply grows smaller, like a stack of lumber in a lumberyard. If it is used at a steady rate, one simply runs out of it and that is the end of the story.

The second prototype we may call the *autonomous regeneration case*. 2
This is a somewhat oversimplified representation of the depletion of a living species that is in danger of extinction by hunting, fishing, cutting, and so on. The essence of this case is that the available quantity of the resource will grow at a rate dependent on the quantity *not used up* at that moment. The exponential growth case (with which we will deal) is that in which growth is *proportionate* to the existing stock of the resource.

We may describe our third prototype as the case of *rising supply costs*. 3
Here the available stock of the resource in question may or may not be exhausted completely in the foreseeable future. The critical characteristic of this case is that the marginal cost of obtaining the item increases as its cheaper sources are used up.[3] The obvious examples of this case are the depletion of scarce mineral resources and the depletion of energy sources

[2] The model assumes away a variety of complications that are considered in the literature, such as the possibility of overpopulation of the species and the resulting fall in the growth rate. This does not, however, seem highly pertinent for a species threatened with extinction, the case with which we are concerned here.

[3] This is essentially the Ricardian case, in which cheaper sources are taken to be utilized before the more expensive ones. Note that sometimes there is little choice in the matter. One may have to mine coal that lies near the surface before it is possible economically to get to the deeper deposits. Of course, this "Ricardian" case is not properly to [illegible] to Ricardo, who admittedly did not discover the "Ricardian" rent theory. There is also a

(the "fuel crisis"). The latter is clearly an example in which resources will not be exhausted in the pertinent future. We may use up our petroleum reserves, but then we can turn to nuclear or solar energy at a higher cost.

These three prototypes: pure depletion, autonomous regeneration, and the case of increasing costs perhaps do not represent the full range of phenomena falling under the heading "resource depletion."[4] However, they all capture important aspects of resource depletion problems, and their analysis will certainly serve to illustrate some of the relevant relationships.

2 The basic model

In most of our models in this chapter we will assume that there are three items to be consumed and whose consumption is to be allocated over time: our depletable resource, a second (storable) good whose production requires labor, and leisure (labor). Only labor is taken to be a productive input with our depletable resource serving only as a consumers' good. To keep the number of variables finite, we will also assume that there is a finite horizon and, hence, a finite future population. Because those finite numbers can be as large as we wish, and particularly because we can take the horizon to be well *beyond* the time at which scientists predict the demise of human life (or even the universe, if one wishes), this premise is not really very restrictive. Accordingly,[5] let

x_{jt} = the quantity of the depletable resource consumed by person j in period t, where $(j=1,2,\ldots,m)$, $(t=1,2,\ldots,h)$
a_t = the unconsumed quantity of the resource at the end of t
a_0 = the initial stock of the depletable resource
k = rate of growth of the resource
q_{jt} = the quantity of the second good consumed by j during t
q_t = the total output of commodity Q in period t
b_t = the unconsumed quantity of Q remaining at the end of t

Footnote 3 *(cont.)*
series of writings, including Volume III of *Capital,* in which it is argued that those natural resources whose utilization is ~~less expensive are not~~ necessarily used first.

Note also that rising costs, in the sense used here, need not always involve costs that increase monotonically with the passage of time because autonomous improvements in technology may offset the rise in expenses that would otherwise occur.

[4] Obviously, combinations of these cases are encountered in practice. For example, the marginal cost of fishing increases as the stock of fish grows smaller, making this a case of both the autonomous regeneration and the rising cost prototypes.

[5] In our discussion, we will not concern ourselves with individual producers and their outputs so that there is no need for a separate set of variables distinguishing output from consumption. To avoid a proliferation of subscripts, we use different letters to represent different outputs (inputs).

r_{jt} = the quantity of leisure consumed by j during t
r = the total labor time available per period
$f(q_t)$ = the labor time required to produce q_t
$u^j(x_{j1},\ldots,x_{jh},q_{j1},\ldots,q_{jh},r_{j1},\ldots,r_{jh})$ = j's utility function.

This set of utility functions includes not only individuals alive at the time the calculation is carried out but also all members of generations yet unborn whose interests must be considered symmetrically with those of our contemporaries in a full analysis of Pareto optimality.

3 The autonomous regeneration case

We begin by considering not the pure depletion case but that of autonomous regeneration, because the regeneration case is in fact easier to understand. Pure depletion is best examined as a special case of autonomous regeneration: that in which the regeneration rate is zero.[6] Moreover, it is convenient to begin with the regeneration prototype, because that is the case in which Pareto optimality may most clearly call for prices that fall with the passage of time.

The basic device we will utilize to represent the automatic replenishing of our resource is simple. With a_t left over at the end of period t, we assume it will grow at rate k and thus add $(1+k)a_t$ to the amount available during period $t+1$.

Our problem, then, is to

$$\text{maximize } u^1(\cdot) \tag{1}$$

subject to

$$u^j(\cdot) \geq u^{*j} \text{ (constant)} \quad \text{[for all individuals, } (j=2,\ldots,m) \text{ in current and all future generations]} \tag{2}$$

$$\sum_j x_{jt} + a_t \leq (1+k)a_{t-1} \quad \text{why } < \tag{3}$$

$$\sum_j q_{jt} + b_t \leq q_t + b_{t-1} \quad (j=1,\ldots,m)\ (t=1,\ldots,h) \tag{4}$$

$$f(q_t) + \sum_j r_{jt} \leq r, \tag{5}$$

the initial values of a_t and b_t given and all variable values required to be nonnegative. Here constraint (4) implies that storage of q can be carried out without cost and without either increase or loss in the quantity of the commodity that has been put into inventory.

[6] Smith also treats pure depletion as a special case of autonomous regeneration. See his "Economics of Production from Natural Resources," *American Economic Review* LVIII (June, 1968), 409–31.

The preceding relationships immediately yield the Lagrangian[7]

$$L=\sum_j \lambda_j[u^j(\cdot)-u^{*j}]+\sum_t \alpha_t\left[(1+k)a_{t-1}-\sum_j x_{jt}-a_t\right]$$

$$+\sum_t \beta_t\left[q_t+b_{t-1}-\sum_j q_{jt}-b_t\right]+\sum_t \nu_t\left[r-f(q_t)-\sum_j r_{jt}\right], \qquad (6)$$

where the λ_j, ν_t, α_t and β_t are Lagrange multipliers whose values are required to be nonnegative. We obtain from (6) the Kuhn-Tucker conditions

?

$$\lambda_j u^j_{xt}-\alpha_t\le 0 \qquad x_{jt}(\lambda_j u^j_{xt}-\alpha_t)=0 \qquad \qquad (7)$$

$$\lambda_j u^j_{qt}-\beta_t\le 0 \qquad q_{jt}(\lambda_j u^j_{qt}-\beta_t)=0 \qquad (t=1,\ldots,h) \qquad (8)$$

$$\lambda_j u^j_{rt}-\nu_t\le 0 \qquad r_{jt}(\lambda_j u^j_{rt}-\nu_t)=0 \qquad \qquad (9)$$

$$\boxed{(1+k)\alpha_{t+1}-\alpha_t\le 0} \qquad a_t[(1+k)\alpha_{t+1}-\alpha_t]=0 \qquad \qquad (10)$$

$$\beta_{t+1}-\beta_t\le 0 \qquad b_t(\beta_{t+1}-\beta_t)=0 \qquad (t=1,\ldots,h-1) \qquad (11)$$

$$\beta_t-\nu_t f'(q_t)\le 0 \qquad q_t[\beta_t-\nu f'(q_t)]=0 \qquad (t=1,\ldots,h) \qquad (12)$$

where we write u^j_{xt} to represent $\partial u^j/\partial x_{jt}$, and so on. First, simply as a manifestation of the horizon premise that, in effect, assumes that the end of the world occurs after period h, we prove

Proposition One. If $u^j_{xh}>0$ for any[8] individual j for whom $\lambda_j>0$, then $a_h=0$, that is, all stocks of our depletable commodity will be used up by the end of period h.

For because there is no α_{h+1} in our maximand, for $t=h$, (10) yields $\alpha_h a_h=0$. But by (7), $\alpha_h>0$ so that necessarily $a_h=0$, as was to be shown. Thus in our model the resource in question will be consumed *and*, eventually, completely exhausted.[9]

To come now to the essential issue, assume that prices for our goods for each period are somehow assigned. We will examine now what values of these prices are necessary to sustain a Pareto-optimal consumption plan in accord with the Kuhn-Tucker requirements (7)–(12). Let p_{xt} represent the price of x in period t, *discounted to the initial period*, and so

[7] Here again, to put the Lagrangian into more conventional form we may set $\lambda_1=1$, $u^{*1}=0$, though given the appropriate convexity assumptions there is no need for these restrictions.

[8] That is, roughly speaking, for any individual who "counts" in the social welfare function made up of the weighted sum of utilities $\sum\lambda_j u^j$. Obviously individual 1 is such a person if we take $\lambda_1=1$, in accord with the comment in note 7. These weights must, of course, be those derived from the maximization problem as the u^{*j} values are varied.

[9] This proposition need not be taken to suggest that the assumption of a finite horizon is an unacceptable oversimplification. After all, h can be very long – longer than the expected duration of human life.

on. We will presently specify the units in which the prices can be measured. However, because for the moment we are concerned only with relative prices of a given commodity at different dates, that is not immediately relevant. Now if j is a utility maximizer, he will make his consumption decisions both among commodities and among time periods so that the relevant marginal rate of substitution between any two items that he actually uses is always equal to the corresponding price ratio. We thus have for any individual j who during t consumes some of the item in question that

$$c_j p_{xt}=u^j_{xt}, \quad c_j p_{qt}=u^j_{qt}, \quad c_j p_{rt}=u^j_{rt}. \quad (c_j \text{ some constant}) \qquad (13)$$

Now if person j consumes some of our depletable resource in two consecutive periods t and $t+1$, then, if his choice is to be consistent with the requirements of intertemporal Pareto optimality, we must have by (13), (7), and (10)

$$\frac{p_{xt}}{p_{xt+1}}=\frac{u^j_{xt}}{u^j_{xt+1}}=\frac{\alpha_t}{\alpha_{t+1}}=(1+k)>1. \qquad (14)$$

This gives us

Proposition Two. The present values of the prices that will sustain a Pareto-optimal choice pattern by individuals for a self-reproducible resource must *decline* with the passage of time over periods when the item is consumed. These present values will decline at precisely the same rate as the resource reproduces itself.

This paradox has a simple explanation. The reduced future price is just a bonus for postponed consumption of the item. For in every period that consumption is postponed, the corresponding supply will increase by itself in the proportion $(1+k)$. As standard capital theory tells us, optimal pricing in such a case must put a premium on the postponement of the utilization of the resource and that is precisely what our result (14) calls for.

Thus we should perhaps not be so surprised that discounted prices decline with time, ~~because we are~~ used to prices in the distant future being discounted more heavily than prices that are closer to us. However, in our simple model, the same relationship can easily be shown to hold for prices expressed in some appropriate current terms, specifically, in terms of the quantity of q in period t for which the resource will exchange at time t.

from 11: $\beta_t=\beta_{t+1}$

For by (13), (8), and (11) we derive at once for any two consecutive periods in which stocks of q are not consumed completely but [so that $b_t>0$ and hence (11) becomes an equality]

$$p_{qt}/p_{qt+1}=\beta_t/\beta_{t+1}=1 \qquad (15)$$

$$\frac{P_{qt}}{P_{qt+1}}=\frac{U^j_{qt}}{U^j_{qt+1}}=\frac{\beta_t/c_t}{\beta_{t+1}/c_t}=\frac{\beta_t}{\beta_{t+1}}=\frac{\beta_t}{\beta_t}=1$$

so that by (14)

$$\frac{p_{xt}/p_{qt}}{p_{xt+1}/p_{qt+1}} = \frac{p_{xt}}{p_{xt+1}} = (1+k). \tag{16}$$

Moreover, assuming that the production function and the range in variation of outputs as determined by the maximization process are such that the marginal product of labor is approximately constant over the same two periods, the same is true if we measure the price of our resource in wage units of period t, because by (13), (9), (11), and (12)

$$p_{rt}/p_{rt+1} = v_t/v_{t+1} = \frac{\beta_t/f'(q_t)}{\beta_{t+1}/f'(q_{t+1})} \cong 1.$$

Thus we have

Proposition Three. Even measured in current terms in the simple economy described by (1)–(5), the optimal price of the depletable resource may decline and perhaps decline steadily in any sequence of periods in which the resource is consumed.[10]

Moreover, so far, discounting makes little difference to this result, because our model has up to now largely ruled out opportunity costs in terms of roundabout (time-using) methods of production.[11] That is, there is no way in our construct for the "other commodity," Q, to be produced more effectively by the use of time-consuming processes. To show the importance of this consideration, we now modify our production relationships to introduce roundaboutness in the simplest possible manner.[12] We will assume that Q is something like unfelled lumber (trees). Once the labor is expended to plant the trees, people can, if they wish, leave the trees to grow further, say at a constant rate g.[13]

[10] The argument assumes there is at least one person who consumes the resource in any two such consecutive periods. However, for the proposition to hold in the interval from t to $t+2$ it is sufficient for our purpose if j consumes some X in both t and $t+1$, while some other person, j', consumes some of X in both $t+1$ and $t+2$.

[11] There is one way in which the opportunity cost of time does enter: people can reduce their current consumption of X by using more of Q instead. This will give more time for growth to the portion of X whose consumption has been postponed.

[12] It is noteworthy that in our model the superior productivity of time-consuming methods of production will now be seen to suffice to introduce a positive discount rate; in its absence there will be no discounting as shown by comparison of (14) and (16), apparently regardless of the nature of the utility functions (that is, whether or not consumers have a subjective preference for present over future consumption). Actually this is more a matter of appearance than of substance. We have, in effect, assumed a diminishing marginal rate of substitution between consumption in two different periods. By (4) we have implicitly assumed that there is a *fixed* technological rate of transformation between q_t and q_{t+1}; that is, the former can be transformed into the latter by storage with neither loss nor gain. In equilibrium, the consumers' marginal rates of substitution must be adjusted and equated to that marginal rate of transformation.

In that case constraint (4) must be replaced by

$$\sum_j q_{jt} + b_t \le q_t + (1+g)b_{t-1}, \tag{4*}$$

in obvious analogy with (3). Kuhn-Tucker condition (11) is then replaced by

$$(1+g)\beta_{t+1} - \beta_t \le 0 \qquad b_t[(1+g)\beta_{t+1} - \beta_t] = 0, \tag{11*}$$

and finally, assuming stocks of commodity Q are not exhausted completely in period t, so that $b_t > 0$, (15) becomes

$$p_{qt}/p_{qt+1} = (1+g). \tag{15*}$$

It is now easy to show that undiscounted current prices of X measured in terms of Q need no longer fall with the passage of time, for by (14) and (15*), (16) is immediately changed into

$$\frac{p_{xt}/p_{qt}}{p_{xt+1}/p_{qt+1}} = \frac{1+k}{1+g} < 1 \quad \text{if } g > k. \text{ [redacted]} \tag{16*}$$

In effect, then, with time contributing to the productivity of labor in other substitutable outputs, we obtain a discount factor, $1/1+g$, for prices are measured in terms of Q, and if g is sufficiently great it can produce the rising *current* prices that intuition may lead us to expect for exhaustible resources. But note that the *discounted* price of our self-replenishing resource must continue to fall at the rate indicated by (14), for, even in our modified model, (14) continues to be a necessary condition for Pareto optimality. Thus we have

Proposition Four. The prices that will sustain a Pareto optimum for a resource that regenerates itself at rate $k > 0$ will always fall with the passage of time when expressed in discounted present value. However, if expressed in terms of some commodity that grows (or for which productivity increases) at a rate in excess of k, the current price of the resource will rise with time.

Once again, these conclusions are not difficult to explain intuitively. Our new relationship of current prices, as given by (15*), reflects the possibility that although postponement of consumption of X is productive, postponement of the consumption of Q will be more productive still. Consequently, in this case society will come out ahead of the game if it lives initially on its stock of X that multiplies itself slowly, thereby leaving

[13] This relationship can, of course, be incorporated directly into the production function.

its stock of Q to grow, unconsumed, until later periods. Thus, despite the fact that our model permits no *direct* technical substitution in the production of X and Q, it does permit indirect substitution that is equally effective in imparting a high opportunity cost to postponed consumption of our depletable resource, X.

We can also show

Proposition Five. If X and Q are perfect substitutes in consumption, but Q grows more rapidly than X, then, if it is optimal for any person to consume commodity Q during some period, t, it will never be optimal for anyone to consume X in any period after t.

In other words, when they are perfect substitutes, it will always be optimal to consume at an earlier date the commodity for which waiting contributes less to future output.

Proof (by *reductio ad absurdum*): Assume the contrary (that is, assume $q_{jt}>0$, $x_{j't+1}>0$, for some individuals j, j'. Then by (7) and (8) and the premise that X and Q are perfect substitutes

$$\alpha_t \geq \lambda_j u^j_{xt} = \lambda_j u^j_{qt} = \beta_t, \qquad \alpha_{t+1} = \lambda_{j'} u^{j'}_{xt+1} = \lambda_{j'} u^{j'}_{qt+1} \leq \beta_{t-1}. \tag{17}$$

But because X is, by assumption, not producible, if $x_{j't+1}>0$ some of it must have been left over from the previous period, that is, we must have $a_t>0$. Thus (10) becomes an equality and so by (10), (17), and (11*)

$$\alpha_{t+1}(1+k) = \alpha_t \geq \beta_t \geq \beta_{t+1}(1+g)$$

so that with $g>k$,

$$\alpha_{t+1} > \beta_{t+1}. \tag{18}$$

Now, because $x_{j't+1}>0$, the second relation in (17) holds so that

$$\alpha_{t+1} \leq \beta_{t+1}$$

contradicting (18).

Thus, we have proved that if $q_{jt}>0$ for any j, we cannot have $x_{jt+1}>0$ for any j', and a direct extension of the argument shows the same result for any future period beyond $t+1$. Q.E.D.

Proposition Five tells us, in effect, that if investment in Q is more productive than in X, it will pay the community to consume all of its stock of X before beginning to consume any of Q. For we have seen, in Proposition One, that the stock of X should be used up entirely at a time no later than the horizon period. But Proposition Five indicates that no X should ever be consumed *after* the consumption of Q begins. Hence, society's stock of X must be exhausted no later than the date at which consumption of Q begins.

4 The pure depletion prototype

As has already been noted, the pure depletion analysis is a special case of autonomous regeneration in which the autonomous growth rate, k, equals zero. We obtain our solution at once, for (14) becomes simply

$$p_1 = p_2 = \cdots = p_n. \tag{19}$$

That is, the solution calls for prices whose discounted present value remains completely unchanged over the period during which the stock of the commodity is exhausted. There is a simple explanation of this result that we obtain with the aid of a reformulation of our model. If we consider a plan formulated initially for the entire h periods, we see that there really are not h independent constraints. In fact, there is only one effective constraint circumscribing the entire decision process:

$$x_1 + x_2 + \cdots + x_h \leq \alpha_0.$$

That is, the total quantity of the resource, glob, used over the entire period cannot exceed the initial stock. Because there is only one constraint, there will be only one corresponding shadow price, that for the depletable resource, and, hence, the optimal price of glob will also remain unchanged as indicated by the constancy of this dual value.

In terms of current values, however, the optimal price of glob may rise with time, if price is measured in terms of a commodity, Q, whose output is increased by roundabout processes (that is, for which $g>0$). For the reasons noted earlier, if p^*_t is the current price of X in terms of Q in period t, we will have

$$\frac{p^*_t}{(1+g)^t} = p_t = p_{t+1} = \frac{p^*_{t+1}}{(1+g)^{t+1}} \quad \text{so that} \quad \frac{p^*_t}{p^*_{t+1}} = \frac{1}{1+g}.$$

Current prices of glob will then, indeed, be rising.

Obviously, the current *money* price of glob *must* be rising so long as the discount rate is positive, for otherwise in terms of present values these prices would be falling, in violation of (19). In sum, we have

Proposition Six. Pareto optimality requires a constant discounted price for an item whose supply is fixed and whose supply cost does not rise as it is used up. This means that the annual rate of increase in its current price must equal the interest rate used in the discounting process.

5 The case of rising costs

We come, finally, to the case so important in practice, in which depletion of our resource manifests itself through rising production costs. Our model will continue to include the labor resource in terms of which costs can be expressed. Rising labor cost will then be interpreted as a rising labor input requirement per unit of output of our resource, as the cumulative consumption of the resource grows.[14] Under the appropriate convexity conditions, Pareto optimality therefore calls for us to maximize for all arbitrarily assigned set of weights, λ_j, the analog of our previous objective function

$$\sum_j \lambda_j[u^j(x_{j1},\dots,x_{jh},r_{j1},\dots,r_{jh})-u^{*j}] \tag{20}$$

subject to

$$\sum_j x_{jt} \le x_t$$

$$\sum_j r_{jt} \le r_t$$

$$w_t = x_1 + x_2 + \cdots + x_{t-1}$$

$$f(x_t, w_t) + r_t \le R_t \quad (t=1,\dots,h)$$

where

x_{jt} is the quantity of resource consumed by individual j in period t,
x_t is the total output of the processed resource in period t,
w_t is the cumulative past consumption of the resource (leaving out consumption before the initial period as a "sunk" element),
r_{jt} is unused labor (leisure) of individual j in period t,
$f(x_t, w_t)$ is the total labor cost of processing the resource in period t, and
R_t is total labor resource available in t.

We assume

$$f_{xt} > 0 \quad f_{wt} > 0 \quad \text{and} \quad f_{xwt} > 0, \tag{21}$$

where f_{xt} represents $\partial f/\partial x_t$, f_{xwt} represents $\partial^2 f/\partial x_t \partial w_t$, and so on. That is, we take the marginal cost of X to be positive, and both the unit and marginal cost of processing to be increased by resource depletion.

Our Lagrangian is

$$\sum_j \lambda_j[u^j(\cdot)-u^{*j}] + \sum_t \nu_t[R_t - f(x_t,w_t) - r_t] + \sum_t \alpha_t\left(x_t - \sum_j x_{jt}\right)$$
$$+ \sum_t \beta_t\left(r_t - \sum_j r_{jt}\right) + \sum_t \gamma_t\left(w_t - \sum_{s=1}^{t-1} x_s\right)$$

[14] We can easily continue to include in the calculation the consumption of other commodities. However, it is readily verified that their inclusions do not affect any of the Kuhn-Tucker conditions used to derive our conclusions; they merely increase the number of necessary maximum conditions, but these additional conditions are not used in our argument.

We obtain as Kuhn-Tucker conditions for all $x_{jt} > 0$, $r_{jt} > 0$ (so that necessarily $x_t > 0$, $r_t > 0$, $w_t > 0$)

$$\lambda_j u^j_{xt} - \alpha_t = 0 \tag{22}$$

$$\lambda_j u^j_{rt} - \beta_t = 0 \tag{23}$$

$$-\nu_t f_{xt} + \alpha_t - \sum_{s=t+1}^{h} \gamma_s = 0 \tag{24}$$

$$-\nu_t + \beta_t = 0 \tag{25}$$

$$-\nu_t f_{wt} + \gamma_t = 0. \tag{26}$$

Eliminating α_t, β_t, and γ_t by substitution of (24), (25), and (26) into (22) and (23) we have

$$\left.\begin{aligned} \lambda_j u^j_{xt} &= \nu_t f_{xt} + \sum_{s=t+1}^{h} \nu_s f_{ws} \quad &(27)\\ \lambda_j u^j_{rt} &= \nu_t. &(28)\end{aligned}\right\} \quad (t=1,\dots,h)$$

Hence, substituting for ν_t and ν_s from (28) into (27) and dividing through by λ_j we obtain

$$u^j_{xt} = f_{xt} u^j_{rt} + \sum_{s=t+1}^{h} f_{ws} u^j_{rs} \tag{29}$$

or

$$u^j_{xt}/u^j_{rt} = f_{xt} + \sum_{s=t+1}^{h} f_{ws} u^j_{rs}/u^j_{rt}.$$

If prices p_{xs}, and p_{rs} are somehow assigned to x and r in period s, for the usual reasons, we may assume that the utility maximizing individual who consumes some of each of these items will select quantities such that their relative price equals the marginal rate of substitution. Thus (29) becomes

$$p_{xt}/p_{rt} = f_{xt} + \sum_{s=t+1}^{h} f_{ws} u^j_{rs}/u^j_{rt}. \tag{30}$$

Equation (30), which for convenience can be rewritten as

$$p_{xt} = p_{rt} f_{xt} + p_{rt} \sum_{s=t+1}^{h} f_{ws} u^j_{rs}/u^j_{rt}, \tag{31}$$

is the relationship we are seeking. It tells us

Proposition Seven. Pareto optimality requires that the price of an item whose supply cost increases as it is used up be made up of two components: the marginal input cost of the item (that is, its marginal private cost),

$p_{rt} f_{xt}$, plus an expression that represents, in terms of inputs, the cost that current utilization imposes on future consumers of the commodity.

The interpretation of this last term in (31) is not difficult to justify. Because, by definition, $\partial w_s / \partial x_t = 1$ for $s > t$, it follows that

$$f_{ws} = \frac{\partial f}{\partial w_s} \frac{\partial w_s}{\partial x_t} = \frac{\partial f(R_s, W_s)}{\partial x_t}$$

represents the incremental labor cost in period s resulting from a unit increase in x_t. Therefore, because u^j_{rs}/u^j_{rt} is the *MRS* of labor in s and t, we see that $p_{rt} f_{ws} u^j_{rs}/u^j_{rt}$ represents the marginal cost that x_t imposes on production in period s measured in terms of labor of period t.

Two significant conclusions can be drawn from pricing equation (31):

1. Because by definition $w_{t+1} \geq w_t$, then by (21), $f_{xt+1} \geq f_{xt}$. Hence, there is at least one component in (31), the expression for the Pareto-optimal discounted price of our resource, that is monotonically nondecreasing over time. In other words, this is the only one of our three cases in which it is at least possible for the time path of Pareto-optimal *discounted* prices for the depletable resource to follow the rising pattern that we might have expected in advance, though even here we cannot be certain of it. Much depends on the time path of the price of labor and the behavior of the summed terms in (31) as the horizon date approaches and the number of these remaining terms consequently declines.

2. Our second conclusion from (31) is that current consumption in this case imposes an increased production cost on future generations so that the optimal price of the resource must exceed its current marginal resources cost. Strictly speaking, this cost is not an externality; it is rather a case where a certain quantity of resources is available to a group of individuals, so that the more that is consumed by one of them, the less there is left for the others. What is involved, therefore, is not really an externality but rather a redistribution of the available stock of resources.[15]

It is nevertheless appropriate for us to ask whether the market is likely to misallocate such resources by pricing them improperly. The answer here is that, generally, it need *not* do so. Suppose there were a single proprietor-supplier of the depletable item and that his lifetime were expected to extend beyond horizon period h. If he were to follow the dictates of his own interests he would then surely price in accord with (30), making consumers pay for all the costs that are incurred in supplying goods to them. Just as monopolization can internalize an externality that extends

[15] It may also be interpreted as a user cost – a case where wear and tear resulting from usage of an item reduces its efficiency in future use – again, not something we would normally call an externality. We are grateful to F. M. Peterson for this observation and for saving us from several errors in the following paragraphs.

within an industry, a single ownership that lasts through the full set of relevant periods can lead to the setting of a price that eliminates the adverse consequences of the intertemporal interdependencies in our model.

But we know that if this is true for a single owner, it may also hold for the entire community. That is, an ideal futures market for our scarce resource can lead to current prices that reflect fully the social costs of consumption of the item. The market may be able to achieve this even if the rise in costs is introduced through a switch in technology and a concomitant change in the source of the output (input) in question. If exhaustion of our petroleum reserves simply hastens the day when we will have to make use of solar energy which, we may assume, will be very costly to process, the price of oil will rise as the date of substitution approaches, because of its rising opportunity cost; in a competitive market, this will be reflected as a higher current price. Of course, to the extent that markets are imperfect, that our telescopic faculty really is defective, or that interest rates differ from the appropriate social discount rate, the allocation produced by the market will depart from an intertemporal Pareto optimum.

PART II

On the design of environmental policy

CHAPTER 10

Introduction to Part II

We have now completed our discussion of the basic theoretical framework. There is much to the theory of externalities that we have made no attempt to cover, for our central objective is the formulation of an analytic structure for the study of environmental policy.

At this point, we seem to have an illuminating, but somewhat destructive, set of results – one that creates severe difficulties for the application of theory to practical problem solving. In this part of the book, we decrease the level of abstraction of our discussion and seek to approach more closely the problems of application. Here too, we will encounter obstacles, though of a different kind from the theoretical complications of Part I. For example, we will find reason to suspect that many proposed environmental programs may well make the distribution of income more unequal.

Nevertheless, we will argue that these obstacles do not preclude the design of effective environmental programs, and, in spite of the difficulties encountered in Part I, that economic theory can be very helpful in the design of these programs.

In particular, Chapter 11 presents a proposal for a feasible tax or fee program. We suggest what we believe to be a practical and effective procedure for the protection of the environment: the use of pollution charges to achieve a predetermined set of standards for environmental quality. Some degree of arbitrariness in the design of such standards is inevitable. And in agreeing to such a procedure, one gives up any attempt to reach the true social optimum. Yet this proposal, which is essentially a "satisficing"[1] approach to the problem, can be shown to offer some significant optimality properties. Aside from the administrative savings made possible by avoidance of central direction and direct controls, we will show that the proposed procedures, properly designed and implemented, can lead to the attainment of the selected standards and that in appropriate circumstances, they can do so at something approximating minimum cost to society.

[1] That is, there is no attempt to seek any sort of optimum. Rather, one seeks merely to find policies capable of meeting some preset standards and, so, of producing results considered acceptable or "satisfactory." The term *satisficing* was coined by Herbert Simon.

Chapter 12 describes and analyzes an alternative pricing instrument for the attainment of any predetermined environmental standards: a system of marketable emission permits. We find that a properly designed permit system, like a set of fees, possesses the least-cost property; it too can achieve the standards at minimum social cost. In addition, we shall suggest that in a policy setting, the permit approach may, in certain circumstances, have some important advantages over a fee regime. In particular, it promises to give the environmental authority more direct control of levels of pollution without necessarily imposing a new form of cost on current sources of emissions. It may, therefore, represent a more attractive approach to the introduction of pricing measures for environmental protection.

Chapter 13 represents a sharp departure from the economist's usual policy recommendations; here, we suggest that direct controls can be a useful supplement to a system of charges for the continuing maintenance of acceptable environmental conditions. Their usefulness arises from the inflexibility of tax rates and the comparative ease with which certain types of direct controls can be instituted, policed, and removed. The problem is that the state of environmental quality at any time depends not only on the level of emissions but on such essentially stochastic influences as wind velocity and rainfall, which determine the rapidity of the dispersion of accumulated pollutants. As a result, we can expect occasional environmental crises that can, at best, be predicted only a short time before they occur. It would be too costly to society to keep tax rates sufficiently high to prevent such emergencies at all times. Instead, it may be less expensive in such cases to make temporary use of direct controls, despite their static inefficiency. The chapter ends with the description of a nonlinear programming model that illustrates the logic of the design of an optimal mixed program (that is, a program utilizing both fiscal methods and direct controls in a way that minimizes society's expected cost of achievement of its environmental targets).

Chapter 14 turns to a third pricing instrument for the control of detrimental externalities: the use of subsidies as a reward for decreased damage by those who generate the externalities. First, we describe formally the conditions under which fees and subsidies are equivalent. Here we find that the equivalent subsidy is a very strange sort of construct, one that we are unlikely to encounter in practice. Next, we show that subsidies in the more conventional sense are, at least theoretically, a poor substitute for taxes. Although the two may be equally effective in reducing emissions by the individual firm, the subsidy encourages the entry of new firms (or plants) into the industry, whereas taxes encourage their exit. As a result, we can expect that a subsidy program will be less effective in

discouraging pollution than a tax program with similar marginal rates. In particular, we find that, under pure competition, if emissions are uniquely determined by the industry's output level and rise monotonically with output, a subsidy program will necessarily backfire. Although the subsidy will produce a reduction in the emissions of each firm, it will lead to an entry of new firms that more than offsets it. Total emissions under a subsidy program will in this case *always* be greater than they would have been if no cleanup subsidy program had ever been instituted!

Chapter 15 discusses a practical issue that can be of considerable significance for environmental policy. Measures designed to improve the quality of life may, unfortunately, make it more difficult to deal with a second of the major issues of our time: the distribution of income. We will suggest, on theoretical grounds, that under a variety of circumstances the rich can be expected to value the benefits flowing from an environmental program more highly than the poor. Using the Samuelson and Tiebout models of public goods as polar constructs, we argue that programs offering similar observable benefits to everyone are likely to offer greater welfare gains to the affluent, and that even programs whose effects differ by income class cannot be presumed to favor the impecunious. Moreover, it is by no means clear that progression in the tax system means that the rich will bear a disproportionate share of the costs. For example, where waste-treatment plants are financed locally, a considerable share of the costs may well fall on the central cities with their heavy concentrations of the poor. In addition, a review of the available empirical evidence (which is, unfortunately, very limited in quantity and subject to all sorts of qualifications) certainly does not suggest that taxes on pollutants and other types of environmental damage are likely to be progressive. Given the types of activity that are prime candidates for such charges and the pattern of consumption by income class of the outputs from these activities, there is some reason to suspect the reverse.

In Chapter 16, we turn to the international side of environmental policy. Here we discuss two issues: the effects of measures for environmental protection on the balance of payments and the level of income of the country that imposes them; and the control of environmental damage that flows across the borders of the source country and affects welfare in neighboring states.

On the first of these issues, we contend that matters are not as cut and dried as intuitive judgment is likely to suggest. The analysis indicates that there are circumstances under which a country's balance of payments can be improved by its unilateral adoption of effective environmental policies, and that its domestic employment may also be stimulated in the process. The analysis specifies conditions under which this can occur, as well as circumstances under which such measures can, in fact, aggravate the country's short-run economic problems. Next, we consider what the rest of the world can do about a country whose economic activity generates externalities that are harmful to people outside its borders. In such a case, the usual free-trade argument may no longer apply, and an appropriate set of tariffs against the offending products may serve as a partial substitute for Pigouvian taxes; we find that nonzero tariffs are generally required for international Pareto optimality, taking into account the interests of the externality-generating country as well as those of the rest of the world.

In Chapter 17, the concluding chapter, we return to environmental decision-making in the domestic context. Here we examine an issue in regulatory federalism: Which level of government should determine standards for environmental quality? Should the central government set uniform national standards, or should "local" governments determine standards appropriate to their own jurisdictions? A purely economic view suggests an unambiguous answer to this question: Standards for environmental quality should balance marginal gains against marginal control costs, jurisdiction by jurisdiction, for pollutants that do not travel across the boundaries of the jurisdiction - standards for such pollutants should thus be local in nature. However, the political economy of local decision-making complicates matters. What if local agencies, in their eagerness to attract new business investment and jobs, reduce environmental standards to attract new firms? Will not the result be destructive interjurisdictional competition leading to excessive environmental degradation? Chapter 17 explores these issues and finds that for the basic case, local competition need not lead to inefficiently low levels of local environmental quality. Local-standard setting can lead to desirable outcomes. However, we find that there are various sorts of circumstances where fears that excessive pollution will result from local decisions are justified. Here, some constraints on local choice may well be justified.

CHAPTER 11

Efficiency without optimality: the charges and standards approach

The results arrived at in Chapter 8 may seem to constitute insuperable barriers to a rational environmental policy. The very presence of externalities is likely to produce a large number of local maxima among which, in practice, it seems impossible to choose with any degree of confidence; we may not even know in which direction to modify the level of an externality-generating activity if we want to move toward an optimum. It should be emphasized that these problems beset equally all attempts to achieve optimality by any of the means usually proposed - direct controls and centralized decision-making at one extreme and pricing schemes, such as the Pigouvian taxes and subsidies, at the other.

Nevertheless, we believe that it is possible to design policies for the control of externalities that are reasonably efficient. The approach that we will propose in this and the next chapter consists of the use of a set of standards that serve as targets for environmental quality coupled with fiscal measures and other complementary instruments used as means to attain these standards. The standards, while admittedly somewhat arbitrary, are, in principle, not unlike the growth or employment goals that have guided governmental macroeconomic policies. In both cases, employment and environmental policy, the approach is, in practice, basically of the "satisficing" variety, with acceptability standards based on individual judgments and, often, compromise. Yet, in both cases, the choice of effective *means* to achieve the established goals has been facilitated by a substantial body of economic theory. This theory suggests that fiscal measures can contribute to the efficiency of a program to control externalities. Moreover, the use of these fiscal measures in combination with standards for acceptable environmental quality, avoids, at least in part, the policy problems that have been raised in Chapters 7 and 8.

Much of the material in this chapter is taken from W. J. Baumol and W. E. Oates, "The Use of Standards and Prices for Protection of the Environment," which originally appeared in *Swedish Journal of Economics* LXXIII (March, 1971), 42–54 and was reprinted in P. Bohm and A. Kneese, Eds., *The Economics of the Environment: Papers from Four Nations*, London & Basingstoke: Macmillan, 1971.

Although in this chapter we emphasize the efficiency properties of effluent fees, we should not be taken to argue that this is always the best or the only way to deal with externalities. In the following chapters, we expand the analytic framework to allow the introduction of other policy tools and show that, under certain circumstances, an optimal environmental policy requires the use of several such measures.

1 Information requirements for optimization policy

The use of predetermined standards as an instrument of environmental policy recommends itself primarily because of the vast information required by the alternative approaches. Economists have long been aware of the enormous amount of information necessary to achieve anything that can even pretend to approximate optimality by means of centralized calculation. This is a major component of the Mises-Hayek argument against the potential effectiveness of full-scale central planning and direction. For the case of externalities, the argument is, if anything, strengthened by the analysis of Chapters 7 and 8, which emphasizes that data relating only to the neighborhood of an economy's initial position are particularly likely, in the presence of externalities, to lead the planner in the wrong direction.

Prohibitive information requirements not only plague centrally directed environmental programs, they raise similar difficulties for the calculation of optimal Pigouvian taxes and subsidies. The proper level of the Pigouvian tax (subsidy) upon the activities of the generator of an externality is equal to the marginal net damage (benefit) produced by that activity, and it is usually not easy to obtain a reasonable estimate of the money value of this marginal damage. There is a promising body of work applying a variety of techniques to the valuation of the damages from a polluted environment.[1] However, it is hard to be sanguine about the availability, in the foreseeable future, of a comprehensive body of statistics reporting the marginal net damage of the various externality-generating activities in the economy. The number of activities involved and the number of persons affected by them are so great that, on this score alone, the task assumes Herculean proportions. Add to this the difficulties in quantifying many of the most important consequences – the damage to health, the aesthetic costs – and the problems in determining a money equivalent for marginal net damage become quite apparent.

This, however, is not the end of the story. The optimal tax level on an externality-generating activity is not equal to the marginal net damage it generates *initially*, but rather to the damage it would cause if the level of the activity had been adjusted to its *optimal* level. To make the point more specifically, suppose that each additional unit of output of a factory now causes fifty cents worth of damage, but that after the installation of the appropriate smoke-control devices and other optimal adjustments, the marginal social damage would be reduced to twenty cents. As our results in Part I indicate, the correct value of the Pigouvian tax is twenty cents per unit of output, that is, the marginal cost of the smoke damage *corresponding to an optimal situation.* A tax of fifty cents per unit of output corresponding to the current smoke damage would lead to an excessive reduction in the smoke-producing activity, a reduction beyond the range over which the marginal benefit of decreasing smoke emission exceeds its marginal cost.

The relevance of this point for our present discussion is that it compounds enormously the difficulty of determining the optimal tax and benefit levels. If there is little hope of estimating the damage that is currently generated, how much less likely it is that we can evaluate the damage that would occur in an optimal world that we have never experienced or even described in quantitative terms.

One alternative route toward optimality may seem to be more practical. Instead of trying to go directly to the optimal tax policy, as a first approximation, one could base a set of taxes and subsidies on the current net damage (benefit) levels. In turn, as outputs and damage levels were modified in response to the present level of taxes, the taxes themselves would be readjusted to correspond to the new damage levels. It might be hoped that this would constitute a convergent iterative process with tax levels affecting outputs and damages, these, in turn, leading to modifications in taxes, and so on.

Unfortunately, such an iterative process also requires information that is very difficult to acquire. At each point in the sequence of learning steps, one must be able to evaluate what the preceding step has achieved and to determine the directions to further improvement. But, knowing neither the relevant costs nor the incremental damages corresponding to each conceivable step, that is precisely what we cannot calculate. Because we are unable to measure social welfare, and because we do not know the vector of inputs and outputs that characterize "the optimum," we simply do not know whether a given change in the tax rate has moved us toward that optimum or has even been able to improve matters. There seems to be no general way in which we can get the information necessary to implement the Pigouvian tax-subsidy approach to the control of externalities.[2]

[1] For a useful survey of the techniques for estimation of the value of environmental amenities, see A. Myrick Freeman, *The Benefits of Environmental Improvement* (Baltimore: Johns Hopkins University Press, 1979).

[2] There may be particular instances where careful analyses can produce some rough estimates of benefits and costs that can serve as the basis for a Pigouvian tax. For an interesting

2 The environmental charges and standards approach

Preference

The economist's predilection for the use of the price mechanism makes him reluctant to give up the Pigouvian solution without a struggle. There is a fairly obvious way to avoid recourse to direct controls and retain the use of the price system as a means to control externalities: it involves the selection of a set of standards for an acceptable environment.[3] On the basis of evidence concerning the effects of unclean air on health or of polluted water on fish life, one may, for example, decide that the sulfur-dioxide content of the atmosphere in the city should not exceed x percent, that the oxygen demand of the foreign matter contained in a waterway should not exceed y, or that the decibel (noise) level in residential neighborhoods should not exceed z, at least 99 percent of the time. These acceptability standards, x, y, and z, then amount to a set of constraints that society places on its activities. They represent the decision maker's subjective evaluation of the minimum standards that must be met in order to achieve what may be described as "a reasonable quality of life." The defects of this procedure are obvious, and, because we do not want to minimize them, we shall examine the problem of the choice of standards in a later section.

For the moment, however, we want to emphasize the role of the price system in the realization of these standards. The point here is simply that the public authority can impose a system of charges that would, in effect, constitute a set of prices for the private use of social resources, such as air and water. The charges (or prices) would be selected so as to achieve specific acceptability standards rather than attempting to base them on the unknown value of marginal net damages. For example, one might tax all installations emitting wastes into a river at a rate $t(b)$ cents per gallon, where the tax rate, t, paid by a particular polluter, would, for example, depend on b, the BOD[4] value of the effluent, according to some fixed schedule. Each polluter would then be given a financial incentive to reduce the amount of effluent he discharges and to improve the quality of the discharge (that is, reduce its BOD value). By setting the tax rates sufficiently high, the community would presumably be able to achieve whatever level of purification of the river it desired. It might even be able to eliminate at least some types of industrial pollution altogether.[5]

In marked contrast to an attempt at optimization, should iterative adjustments in tax rates prove desirable in a charges and standards approach, the necessary information would be easy to obtain. They require no data on costs or damages – only figures on current pollution levels. If the initial taxes did not reduce the pollution of the river sufficiently to satisfy the preset acceptability standards, one would simply raise the tax rates. Experience might soon permit the authorities to estimate the tax levels appropriate for the achievement of a target reduction in pollution.[6]

One might even be able to extend such adjustments beyond the setting of the tax rates to the determination of the acceptability standards themselves. If, for example, attainment of the initial targets were to prove unexpectedly inexpensive, the community might well wish to consider making the standards stricter.[7] Of course, such an iterative process is not costless. It means that some of the polluting firms and municipalities will have to modify their operations as tax rates are readjusted. At the very least, they should be warned in advance of the likelihood of such changes so that they can build flexibility into their plant design, something that may itself not be cheap.[8] But at any rate it is clear that, through the adjustment of tax rates, the public authorities can usually realize whatever standards of environmental quality have been selected.

Footnote 2 *(cont.)*
application to the control of airport noise levels, see D. Harrison, "The Regulation of Aircraft Noise," in T. Schelling, Ed., *Incentives for Environmental Protection* (Cambridge, Mass.: M.I.T. Press, 1983), 41–143.

[3] This proposal is not new. Most attempts to write a system of effluent charges into law are based on a set of prescribed standards.

[4] BOD, biochemical oxygen demand, is a measure of the organic waste load of an emission. It measures the amount of oxygen used during decomposition of the waste materials. BOD is used widely as an index of the quality of effluents, but it is only an approximation at best. Discharges whose BOD value is low may nevertheless be considered serious pollutants because they contain inorganic chemical poisons whose oxygen requirement is nil because the poisons do not decompose.

3 Optimality property of the pricing and standards technique: cost minimization

Although the pricing and standards procedure will not, in general, lead to Pareto-optimal levels of the relevant activities, it is nevertheless true

[5] Here it is appropriate to recall the words of Chief Justice Marshall when he wrote that "The power to tax involves the power to destroy" (*McCulloch v. Maryland*, 1819). In terms of reversing the process of environmental decay, the power to tax can be also the power to restore.

[6] Of course, the political problems likely to beset either iterative process must not be minimized.

[7] In this way, the charges and standards approach might be adapted to approximate the Pigouvian outcome. If the standards were revised upward whenever there was reason to believe that the marginal benefits exceeded the marginal costs, and if these judgments were reasonably accurate, the two might well arrive at the same end product, at least if the optimal solution were unique.

[8] See A. G. Hart, "Anticipation, Business Planning and the Cycle," *Quarterly Journal of Economics* LI (February, 1937), 273–97.

that the use of unit taxes (or subsidies) to achieve specified quality standards does possess one important property: under appropriate conditions,[9] it is the least-cost method for the achievement of these targets.[10]

A simple example may serve to clarify this point. Suppose that it is decided in some metropolitan area that the sulfur-dioxide content of the atmosphere should be reduced by 50 percent. An obvious approach to this matter, and the one that often recommends itself to the regulator, is to require each smoke producer in the area to reduce his emissions of sulfur dioxide by the same 50 percent. However, a moment's thought suggests that this may constitute a very expensive way to achieve the desired result. If, at current levels of output, the marginal cost of reducing sulfur-dioxide emissions for Factory *A* is only one-tenth of the marginal cost for Factory *B*, we would expect that it would be much cheaper for the economy as a whole to assign *A* a much greater decrease in smoke emissions than *B*. Just how the least-cost set of relative quotas would be arrived at in practice by the regulator is not clear, because this obviously would require calculations involving simultaneous relationships and extensive information on each polluter's marginal cost function.

It is easy to see, however, that the unit-tax approach can *automatically* produce the least-cost assignment of smoke-reduction quotas without the need for any complicated calculations by the enforcement authority. In terms of our preceding example, suppose that the public authority placed a unit tax on smoke emissions and raised the level of the tax until sulfur-dioxide emissions were in fact reduced by 50 percent. In response to a tax on its smoke emissions, a cost-minimizing firm will cut back on such emissions until the marginal cost of further reductions in smoke output is equal to the tax. But, because all economic units in the area are subject to the same tax, it follows that the marginal cost of reducing smoke output will be equalized across all activities. This implies that it is impossible to reduce the aggregate cost of the specified decrease in smoke emissions by rearranging smoke-reduction quotas: any alteration in this pattern of smoke emissions would involve an increase in smoke output by one firm

[9] These conditions are spelled out later in this and the next chapters. Specifically, we will see in Chapter 13 that the presence of stochastic influences can sometimes make other instruments of control more efficient than taxes.

[10] This proposition is not new. For some early discussions, see, for example, Kneese and Bower, *Managing Water Quality,* Chapter 6; and L. Ruff, "The Economic Common Sense of Pollution," *The Public Interest* XIX (Spring, 1970), 69–85. There is a similar proof by Charles Upton in "Optimal Taxing of Water Pollution," *Water Resources Research* IV (October, 1968), 865–75. The theorem takes no explicit account of metering costs which can, of course, be substantial. However, there seems to be little reason to expect these to be out of line with the enforcement costs associated with other environmental protection methods.

the value of which to the firm would be less than the cost of the corresponding reduction in smoke emissions by some other firm. A formal proof of this least-cost property of unit taxes for the realization of a specified target level of environmental quality is provided in the next section.

It is significant that the validity of this least-cost theorem does not require the assumption that the firms generating the externalities are profit maximizers or perfect competitors. All that is necessary is that they minimize costs for whatever output levels they select, as would be done, for example, by an oligopolistic firm that seeks to maximize its growth or its sales, and that the market prices of the inputs reflect reasonably well the opportunity costs of their utilization.[11]

4 Derivation of the cost-minimization theorem

Let us turn now to a formal derivation of the optimality property of the charges approach that was described in the preceding section. We will show that, to achieve *any* given vector of final outputs along with the attainment of the specified quality of the environment, the use of unit taxes (or, where appropriate, subsidies) to induce the necessary modification in the market-determined pattern of output will permit the realization of the specified output vector at minimum cost to society.

Although this theorem may seem rather obvious (as the intuitive discussion in the last section suggests), its proof does point up several interesting properties. As already emphasized, unlike many of the propositions about prices in welfare analysis, the theorem does not require a world of perfect competition. It applies alike to generators of externalities who are pure competitors, monopolists, or oligopolists, so long as each of the firms involved seeks to minimize the private cost of producing whatever vector of outputs it selects and has no monopsony power (that is, no influence on the prices of inputs) and so long as input prices approximate their opportunity costs. The firms need not be simple profit-maximizers; they may choose to maximize growth, sales (total revenues), their share of the market, or any combination of these goals (or a variety of other objectives). Because the effective pursuit of these goals typically entails minimization of the cost of whatever outputs are produced, the theorem applies to whatever set of final outputs society should select (whether by central direction or the operation of the market).[12]

[11] A similar argument suggests that the rationing of pollution by the sale of pollution licenses (rights) at a market-clearing price offers the same advantages in cost minimization. We shall demonstrate the validity of this argument in the next chapter.

[12] The theorem may even be extended to certain agencies that are not cost-minimizers overall, but have incentives to minimize expenditures on pollution control. See W. Oates and

We shall proceed initially to derive the first-order conditions for the minimization of the cost of a specified overall reduction in the emission of wastes. We will then show that the independent decisions of cost-minimizing firms subject to the appropriate unit tax on waste emissions will, in fact, satisfy the first-order conditions for overall cost minimization.

Let

r_{ik} represent the quantity of input i used by plant k $(i=1,\dots,n)$, $(k=1,\dots,m)$;

s_k be the quantities of waste it discharges;

y_k be its output level;

$y_k = f^k(r_{1k},\dots,r_{nk},s_k)$ be its production function;

p_i be the price of input i; and

s^* the desired level of $\sum s_k$, the maximum permitted discharge of waste per unit of time.

In this formulation, the value s^* is determined by the administrative authority in a manner designed to hold waste emissions in the aggregate to a level consistent with the specified environmental standard (for example, the sulphuric content of the atmosphere). Note that the level of the firm's waste emissions is treated here as an argument in its production function; to reduce waste discharges while maintaining its level of output, the firm will presumably require the use of additional units of some other inputs (for example, more labor or capital to recycle the wastes or to dispose of them in an alternative manner).

The problem now becomes that of determining the value of the r_{ik} and s_k that minimize input cost for all firms together:

$$\min c = \sum_i \sum_k p_i r_{ik}, \tag{1}$$

subject to the output constraints

$$f^k(r_{1k},\dots,r_{nk},s_k) = y_k \geq y_k^* = \text{constant} \quad (k=1,\dots,m)$$

and the constraint on the total output of pollutants

$$\sum_k s_k \leq s^*.$$

It may appear odd to include, as a constraint, a vector of given outputs for the firms, because the firms will presumably adjust output levels as

Footnote 12 *(cont.)*
D. Strassmann, "Effluent Fees and Market Structure," *Journal of Public Economics* XXIV (June, 1984), 29–46.

well as the pattern of inputs in response to taxes or other restrictions on waste discharges. This vector, however, can be *any* vector of outputs (including that which emerges as a result of independent decisions by the firms). What we determine are first-order conditions for cost-minimization that apply to *any* given vector of outputs no matter how it is reached.[13]

Using $\lambda_1,\dots,\lambda_m$, and λ as our $m+1$ Lagrange multipliers, we obtain as Kuhn-Tucker conditions

$$\begin{aligned}
\lambda - \lambda_k f_s^k &\geq 0 & s_k(\lambda - \lambda_k f_s^k) &= 0\\
p_i - \lambda_k f_i^k &\geq 0 & r_{ik}(p_i - \lambda_k f_i^k) &= 0\\
y_k^* - f^k(r_{1k},\dots,r_{nk},s_k) &\leq 0 & \lambda_k[y_k^* - f^k(r_{1k},\dots,r_{nk},s_k)] &= 0\\
\sum s_k - s^* &\leq 0 & \lambda(\sum s_k - s^*) &= 0
\end{aligned} \tag{2}$$

for all i, k, where we have written f_s^k for $\partial f^k/\partial s_k$ and f_i^k for $\partial f^k/\partial r_{ik}$.

Now let us see what will happen if the m plants are run by independent managements whose objective is to minimize the cost of whatever outputs their firm produces, and if, instead of the imposition of a fixed ceiling on the emission of pollutants, this emission is taxed at a fixed rate per unit, t_s. So long as its input prices are fixed, firm k will wish to minimize the cost of whatever output level it produces; that is, it will minimize[14]

$$c = t_s s_k + \sum_i p_i r_{ik} \tag{3}$$

subject to

$$f^k(r_{1k},\dots,r_{nk},s_k) \geq y_k^*.$$

Direct differentiation of the m Lagrangian functions for our m firms immediately yields the first-order conditions (2); these are the same conditions

[13] The reason for prespecification of the vector of output has its analogue in the elementary theory of the firm. Where we use a cost-minimization premise in the analysis of the firm's input choices, it is obviously not correct to assume that it seeks to operate at as low a cost per unit as possible, without specifying its output level. For the firm's output level is determined by demand relationships as well as costs, and the output it decides to produce may be far from that which minimizes average costs. It is, however, reasonable to posit that whatever the output level it selects for itself, the firm will seek to produce it at as low a cost as possible. Our premise here is the analogue of this last assumption.

[14] Note again that this assumes identity between the prices in (1) and (3), that is, that input prices to the private firm correspond to the cost of their use to society. Thus, although our result does not require pure competition in the regulated firm, it does call for input prices that are not too far from their competitive values.

as before,[15] provided t_s is set equal to λ where λ (and hence t_s) is the shadow price of the pollution constraint – the marginal social cost of an increase in the stringency of the pollution standard.[16]

We have thus proved

Proposition One. A tax rate set at a level that achieves the desired reduction in the total emission of pollutants will satisfy the necessary conditions for the minimization of the program's cost to society.[17]

The preceding discussion indicates, incidentally, that pricing can play an effective role as a substitute for part of the information that is pertinent in the presence of externalities. In an illuminating remark, S. C. Kolm reminds us that the choice of efficient measures for the control of externalities requires, in principle, detailed information both about the benefits these measures offer the various members of the economy and the costs they impose on each of them.[18] The pricing mechanism offers no help with respect to the first of these because the very presence of externalities means that an individual decision maker's behavior does not reflect all of the relevant social benefits.

However, pricing does serve to eliminate the need for detailed cost information.[19] Under a system of central direction, a planner who wants to calculate the least-cost allocation of pollution quotas among the firms under his control must, as is shown in (2), have at his disposal data giving

[15] The last of the Kuhn-Tucker conditions, $\sum s_k \leq s^*$, obviously has no counterpart in the calculation of the individual firm. However, it will clearly be satisfied if the s_k corresponding to a given set of prices is unique.

[16] Clearly, the value of λ is an important datum and would be helpful in selecting a standard if that figure were available. Unfortunately, this information is lost in the standards and charges approach because no optimality calculation is carried out in the process. There are, indeed, no free lunches.

[17] In addition to satisfying these necessary first-order conditions, cost minimization requires that the production functions possess the usual second-order properties. An interesting treatment of this issue is available in Portes, "The Search for Efficiency in the Presence of Externalities," in *Unfashionable Economics*. We should point out also that our proof assumes that the firm takes t_s as given and beyond its control. Peter Bohm in "Pollution, Purification, and the Theory of External Effects," *Swedish Journal of Economics* LXXII, No. 2 (1970), 153–66, discusses some of the problems that can arise where the firm takes into account the effects of its behavior on the value of t_s. See also our discussion in Chapter 6.

[18] S. C. Kolm, "Économie de l'Environment" (unpublished manuscript), Chapter 2.

[19] "This advantage, not needing to know the value of the right to pollute, is one of the great points of interest of the method of regulation by taxation (or subsidy). It is a property of *decentralization* of decisions: by requiring everyone to pay a financial charge equal to the damage he causes, one leaves the necessity of knowing the value of the right to pollute entirely in the hands of the person who knows it best – the polluter himself." Kolm, *ibid.*, Chapter 2, p. 4.

all of the f_s^k and f_i^k (that is, the marginal product figure for every input, i, and for every polluting plant, k). The herculean proportions of the task of collecting this mass of information and then carrying out the requisite calculations is clear.[20] A pricing approach dispenses with the need for all these data and computations because it gives that portion of the optimization calculation over to an automatic process. Th[illegible]at the charges and standards approach may be looked upon as a procedure that frankly abandons any attempt to obtain extensive information on benefits but which uses the pricing system where it is at its best, in the allocation of damage-reducing tasks in a manner that approximates minimization of costs, even though detailed data on the costs of these tasks are unavailable.

5 Geographical and other appropriate variations in tax rate[21]

Even the cost-minimization claims for the standards and pricing approach must be qualified carefully. The theorem as stated runs into several problems in practice that may complicate its applicability.

One relevant assumption implicit in the preceding analysis asserts that there is a direct and additive relationship between the emission of pollutants and the degree of welfare loss suffered by the community. However, that is not always the case. A firm that emits waste into the upper parts of a river may do more or less damage to the community than one that discharges the same amount of effluent downstream. The upstream emissions may be less damaging than those downstream if the upper part of the river is sufficiently unpolluted to permit natural processes to disperse or degrade a considerable portion of the wastes before anyone is affected by them. On the other hand, if there is little natural cleansing of the upstream discharges, they may well be more costly to society than discharges into the lower parts of the river because people and activities along the entire length of the river may be affected primarily by upstream emissions.

Because the social damage caused by upstream and downstream discharges obviously differs, it is not appropriate to tax them at the same rate. In such circumstances, an equal tax per unit of effluent in the two

[20] Although the calculation has ignored the costs of surveillance, obviously such outlays would be required under any system of environmental regulation. There seems to be reason to believe that, in many applications, the routine metering costs that would be needed will be considerably smaller than the costs of surveillance *and* judicial enforcement that are the instruments of direct controls.

[21] This section is based on comments by Elizabeth Bailey and on two illuminating papers: Thomas H. Teitenberg, "Taxation and the Control of Externalities: Comment," *American Economic Review* LXIV (June, 1974); and Susan Rose-Ackerman, "Effluent Charges: A Critique," *Canadian Journal of Economics* VI (November, 1973), 512–28.

regions will generally *not* minimize the cost of a specified reduction in pollution as a simple counterexample demonstrates. Suppose that only the area near the mouth of the river is polluted so that the objective of the program is to reduce the level of pollution in that portion of the waterway. Suppose, moreover, that treatment of emissions will cost fifteen cents per gallon in a typical downstream plant but only ten cents per gallon upstream. Finally, assume that although all of the downstream firms' discharges add directly to the filth in the polluted part of the river, half of the upriver plants' discharges are eliminated automatically by natural processes. In that case, a tax of twelve cents per gallon of effluent will induce only the upstream plants to cleanse or reduce their emissions, because only their private costs of treatment per gallon are smaller than the tax rate. But to society this is an inefficient outcome, for ten cents nets it only a *half* gallon reduction in filth downstream, whereas treatment by a downstream plant would reduce pollutant discharge by a full gallon for only fifteen cents.[22]

Not only geographic accidents of location can lead to this problem. It may arise out of the range of decisions available to the firm itself, with the result that a uniform tax on discharges can induce management to make the wrong decisions. Turvey cites the case of a firm that has the option of building a high or a low chimney for its smoke.[23] If the high chimney can disperse pollutants sufficiently to render them harmless, it may yield the same contribution to human welfare as the suppression of smoke emissions and do so at a lower cost in resources. However, a tax based on emissions will clearly always favor smoke suppression rather than dispersion via higher chimneys, whatever their relative social costs.[24]

The upshot of all this is that, for the minimum-cost theorem to hold, it is necessary for the tax to be based on the *effect* of an emission on the community, and not necessarily on the amount generated. In practice this can sometimes be done in a rough-and-ready way (for example, by basing effluent charges on, say, two parameters – the quantity emitted and the quality of the receiving waters, or the amount of smoke emitted and on chimney height). Another device that may sometimes work reasonably well involves the establishment of different zones, based on con-

Quantity + Quality

[22] This is obviously a highly simplified illustration. Engineering models of waterways describing the differential impact on water quality of emissions at different locations use relationships that are much more complex. See Rose-Ackerman's discussion of the Delaware Estuary Model, "Efficient Charges: A Critique."

[23] Ralph Turvey, "On Divergences Between Social Cost and Private Cost," *Economica* New Series XXX (August, 1963), 309–13.

[24] Higher chimneys can, of course, lead to other sorts of problems, such as distant acid-rain.

centration of population and current pollution levels, with different tax rates imposed in different zones.[25] Where some such simple provision will do the trick, the issues raised in this section create no insuperable difficulties for the charges and standards procedure. However, where delicate differentiations are essential, the attractive simplicity of the proposal can dwindle rapidly.[26]

One instructive way of looking at the matter is that differences in the effects of equal quantities of emission upon the effective level of pollution require the policy maker to retreat part way toward explicit evaluation of the social damage resulting from an emission. He must determine the extent to which various emissions influence the level of pollution. Note, however, that the charges and standards procedure still does not require the calculation of the effects of pollution on health, recreation, and psychic pleasure, and the translation of each of these into common (money) units.

What all this suggests is that, although the charges and standards procedure should never be as difficult to implement as the ideal Pigouvian tax,[27] it may still be quite complicated to take advantage of all the cost savings it offers in theory, in applications where the level of pollution damage responds differently to emissions from alternative sources or locations. The importance of this qualification obviously depends upon the circumstances at hand. As was just noted, where such differential effects of emissions are unimportant or where some simple device, such as variations in the charge by zone can deal with them (at least roughly), the charges and standards procedure retains its appeal.

The magnitude of the cost savings promised by more efficient systems of pollution control is quite large. There is now a substantial empirical literature encompassing a variety of air and water pollutants that provides estimates of the potential cost-savings from the use of pricing measures instead of direct controls.[28] These studies typically make use of simulation models for particular pollutants. Such a model has two basic components: a dispersion model that traces emissions from each source to the resulting pollutant concentrations at each receptor (or measurement) point in the air shed or waterway, and a set of control cost functions for the

[25] For further discussion of this proposal, see T. Tietenberg, "Spatially Differentiated Air Pollutant Emission Charges: An Economic and Legal Analysis," *Land Economics* LIV (August, 1978), 265–77.

[26] We shall explore this issue more systematically in the next chapter.

[27] Obviously, the ideal Pigouvian tax would also have to be adjusted for any differential effects of emissions from different sources.

[28] For a useful survey of these studies, see T. Tietenberg, *Emissions Trading: An Exercise in Reforming Pollution Policy* (Washington, D.C.: Resources for the Future, 1985), Chapter 3.

sources. With such a model, it is possible to simulate the outcomes under different systems of environmental management. The typical procedure is to calculate the cost of attaining some predetermined level of environmental quality under the current direct control system and then to compute the least-cost solution. A comparison of the two provides a measure of the excess costs under the current system. Such studies have generally found that the least-cost solution entails costs that are only a modest fraction of those under the current direct control system. The estimates range from a high of roughly 50 percent of current costs to less than 10 percent. A system that can approach the least-cost solution thus can typically promise very large cost-savings. As we have discussed in this section, it probably involves something of an overestimate of the potential savings to assume that a system of effluent fees can realize the least-cost solution, for any system in practice will involve administrative compromises that will prevent the attainment of the least-cost outcome. Nevertheless, existing studies indicate that the costs of current programs involve inordinately excessive costs; if fee systems in practice could at least go some distance in the direction of the least-cost solution (which surely must be true), the cost-savings would be very large.

6 The charges and standards approach and multiple local optima

In one important respect, the charges and standards approach avoids completely the problem posed for the Pigouvian solution and for central planning by nonconvexities and the resulting presence of a multiplicity of local optima. Because it is a satisficing procedure, it makes no attempt to search for an optimum, and so there is no occasion for the decision maker to aim mistakenly for what is in fact a local optimum instead of the global one.

So long as the emission of a pollutant is a monotonically decreasing function of the magnitude of the charge imposed on it, a function that is not bounded away from zero, one can choose a set of tax levels sufficient to guarantee attainment of whatever standards happen to have been selected. If the quantity of pollutant S still exceeds the level called for by the adopted standards, one need merely increase the charge upon the emission of S until its quantity has been reduced to the "acceptable" level, and that is all there is to the matter.

The presence of a multiplicity of maxima does, however, require one significant qualification of the cost-minimization theorem. For although, at least in principle, the use of charges guarantees that a given set of standards will be achieved at some sort of minimum cost, this may, in fact, be a local rather than a global minimum. Suppose, for example, that there are two ways of avoiding the pollution produced by some commodity X, an increase in the output of smoke suppressors, or the substitution of another commodity, Y, which emits little pollution. Assume, moreover, that there are decreasing average costs both in the production of smoke suppressors and in the manufacture of Y. In that case, there will be two cost-minimizing ways of getting the pollution down to the desired level, the elimination of a sufficient amount of X and its replacement by a suitable amount of Y, or through the production of a sufficient quantity of pollution-suppression equipment. Toward which of these minima the market process will converge depends on the initial position, for that will determine the relative initial costs of Y and suppressors. There certainly is no guarantee that the process will converge toward the less costly of the two minima.

However, the likelihood that this problem will be encountered is apparently unrelated to the presence or absence of externalities. Unlike the issues discussed in Chapter 8, the multiplicity of equilibria that is relevant for the cost calculation does not seem to be made more likely by the presence of externalities. For the nonconvexities induced by externalities stemming from X arise both in the social production possibility set for X and the activity Z, that is damaged by it. But the externality caused by X need not affect activities W and V whose purpose is to offset the pollution produced by X. Thus, it need not introduce nonconvexities into the XW or the WV production sets, which are the production sets pertinent for the determination of the cost-minimizing program of pollution control corresponding to a given output vector. Consequently, although it is true that the cost-minimization property of the charges and standards approach can run into multiple maximum problems, it seems no more likely to encounter these difficulties than a decision process in some other economic area. There seems to be no special reason to expect it to run afoul of the nonconvexities that are built into the economy by the presence of externalities and which serve as booby traps that threaten the effectiveness of any attempt to design an *optimal* externalities policy.

7 Where the charges and standards approach is appropriate

As we have emphasized, the most disturbing aspect of the charges and standards procedure is the somewhat arbitrary character of the criteria selected. There does presumably exist some optimal level of pollution (that is, quality of the air or a waterway), but in the absence of a pricing mechanism to indicate the value of the damages generated by polluting activities, one knows no easy way to determine accurately the set of taxes necessary to induce the optimal activity levels.

Although this difficulty should not be minimized, it is important to recognize that the problem is not unique to the selection of acceptability standards. In fact, as is well known, it is a difficulty common to the provision of nearly all public goods. In general, the market will not generate appropriate levels of output where market prices fail to reflect the social damages (benefits) associated with particular activities. As a result, in the absence of the proper set of signals from the market, it is typically necessary to utilize a political process (that is, a method of collective choice) to determine the level of the activity. From this perspective, the selection of environmental standards can be viewed as a particular device utilized in a process of collective decision-making to determine the appropriate level of an activity involving external effects.

Because methods of collective choice, such as simple majority rule or decisions by an elected representative, can, at best, be expected to provide only rough approximations to optimal results, the general problem becomes one of deciding whether the malfunction of the market in a certain case is sufficiently serious to warrant public intervention. In particular, it would seem to us that such a blunt instrument as acceptability standards should be used only sparingly, because the very ignorance that serves as the rationale for the adoption of such standards implies that we can hardly be sure of their consequences.

In general, intervention in the form of acceptability standards can be utilized with a degree of confidence only where there is reason to believe that the existing situation imposes a high level of social costs *and* that these costs can be significantly reduced by feasible decreases in the levels of certain externality-generating activities. If, for example, we were to examine the functional relationship between the level of social welfare and the levels of particular activities that impose marginal net damages, the argument would be that the use of acceptability standards is justified only in those cases where the curve, over the bulk of the relevant range, is both decreasing and steep. Such a case is illustrated in Figure 11.1 by the curve *PQR*. In a case of this kind, although we obviously will not have an accurate knowledge of the relevant position of the curve, we can at least have some assurance that the selection of an acceptability standard and the imposition of a unit tax sufficient to achieve that standard will lead to an increase in social welfare. For example, in terms of the curve *PQR* in Figure 11.1, the levying of a tax sufficient to reduce smoke outputs from level *OC* to *OA* to insure that the quality of the air meets the specified environmental standards would obviously increase social welfare.[29]

[29] The relationship depicted in Figure 11.1 is to be regarded as an intuitive device employed for pedagogical purposes, not in any sense as a rigorous analysis. However, some further explanation may be helpful. The curve itself is not a social welfare function in the usual sense; rather it measures, in terms of a numeraire (for example, dollars), the value, summed over all individuals, of the benefits from the output of the activity minus the private *and* net social costs. Thus, for each level of the activity, the height of the curve indicates the *net* benefits (possibly negative) that the activity confers on society. The acceptability constraint indicates that level of the activity that is consistent with the specified minimum standard of environmental quality (for example, that level of smoke emissions from factories that is sufficiently low to maintain the quality of the air in a particular metropolitan area). There is an ambiguity here in that the levels of several different activities may jointly determine a particular dimension of environmental quality (for example, the smoke emissions of a number of different industries will determine the quality of the air). In this case, the acceptable level of polluting emissions for the firm or industry will clearly depend on the levels of emissions of others. If, as we discussed earlier, unit taxes are used to implement the acceptability standards, there will result a least-cost pattern of levels of the relevant externality-generating activities. If we understand the constraint in Figure 11.1 to refer to the activity level indicated by this particular solution, then this ambiguity disappears.

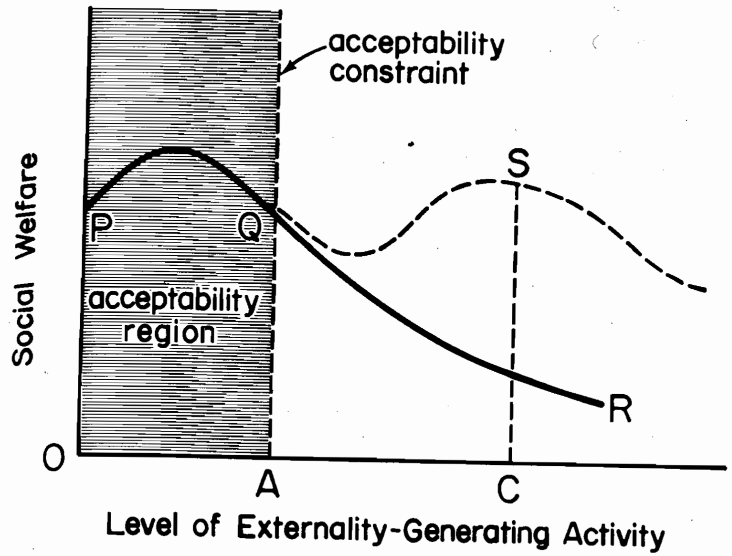


Figure 11.1

On the other hand, if the relationship between social welfare and the level of the externality-generating activity is not monotonically decreasing, the changes resulting from the imposition of an acceptability standard (for example, a move from *S* to *Q* in Figure 11.1) clearly may lead to a reduction in welfare. Moreover, even if the function were monotonic but fairly flat, the benefits achieved might not be worth the cost of additional intervention machinery that new legislation requires, and it would

1 Marketable permits versus fees in a policy setting

Although both effluent fees and systems of marketable permits have the capacity to achieve a set of environmental standards at least cost, they are by no means equivalent policy instruments from the viewpoint of an environmental agency. We shall consider first the grounds on which the environmental authority might prefer such permits to fees and shall then turn to the case for fees.

The first, and a major, advantage of marketable permits over fees is that permits promise to reduce the uncertainty and adjustment costs involved in attaining legally required levels of environmental quality. The environmental authority cannot be completely sure of the response of polluters to a particular magnitude of an effluent charge; in particular, if the authority inadvertently sets the fee too low, environmental standards will not be met. As we discussed in the preceding chapter, the fee may have to be raised and then altered again to generate an iterative path converging toward the target level of emissions. This means costly adjustments and readjustments by polluters in their levels of waste discharges and the associated abatement technology. The need for repeated changes in the fee is also an unattractive prospect for administrators of the program. In contrast, under a permit scheme, the environmental agency directly sets the total quantity of emissions at the allowable standard; there is, in principle, no problem in achieving the target.

Second, and closely related to the issue just discussed, are the complications that result from economic growth and price inflation. Continuing inflation will erode the real value of a fee; similarly, expanding production of both old and new firms will increase the demand for waste emissions. Both of these will require the fee to be raised periodically if environmental standards are to be maintained. The burden of initiating such corrective action under a system of fees falls necessarily upon environmental officials; they are forced to choose between unpopular fee increases or nonattainment of standards. Under a system of permits, market forces automatically accommodate themselves to inflation and growth with no increase in pollution. The rise in demand for permits, real and nominal, simply translates itself directly into a higher price.

Third, the introduction of a system of effluent fees may involve enormous increases in costs to polluters *relative* to alternative regulatory policies. This point may seem somewhat paradoxical in light of the widespread recognition that systems of pricing incentives promise large savings in aggregate abatement costs. But the two are not inconsistent. Although a system of effluent charges will reduce total abatement costs, it will impose a new financial burden, the tax bill itself, on polluting firms. Although

these taxes represent a transfer payment from the viewpoint of society, they are a cost of operation for the firm. Some recent evidence on this issue suggests that the figures can be rather staggering. One such study of the use of pricing incentives to restrict emissions of certain halocarbons into the atmosphere estimates that aggregate abatement costs under a realistic program of direct controls would total about $230 million; a system of fees or of marketable permits would reduce these costs to an estimated $110 million (a saving of roughly 50 percent).[2] However, the cost of the fees or permits to polluters would total about $1,400 million so that, in spite of the substantial savings in abatement costs, a program of pricing incentives would, in this instance, increase the total cost to polluters by a factor of *six* relative to a program of direct controls! Some studies of other pollutants also suggest that fees can be a major source of new costs.[3] It is true that a system of marketable permits *making use of an auction for the initial acquisition of these rights* is subject to the same problem, because sources face high prices for permits. However, there is an alternative that gets around the problem: A permit system can be initiated through a *free* initial distribution of the permits among current polluters. This version of the permit scheme effectively eliminates the added costs for existing firms without any necessarily adverse consequences for the efficiency properties of the program and with some obvious and major advantages for its political acceptability. It is interesting in this regard that existing systems of marketable permits in the United States embody a kind of "grandfathering" scheme involving an initial distribution of emission permits or "rights" among polluters based on historical levels of emissions.

Fourth, as we noted in the preceding chapter, there may be instances where geographical distinctions among polluters are important. In fact, for several important air and water pollutants, various studies indicate that it is imperative for the environmental authority to differentiate among polluters according to their location if environmental standards are to be realized in a cost-effective way.[4] Sources at a highly polluted location within an air shed cannot be allowed to increase their emissions on a one-to-one basis in exchange for emissions reductions by other sources at a less-polluted point. As we have indicated, it can be administratively quite

[2] A. Palmer, et al., *Economic Implications of Regulating Chlorofluorocarbon Emissions from Nonaerosol Applications* (Santa Monica, Calif.: The Rand Corporation, 1980).

[3] See, for example, E. Seskin, R. Anderson, Jr., and R. Reid, "An Empirical Analysis of Economic Strategies for Controlling Air Pollution," *Journal of Environmental Economics and Management* X (June, 1983), 112–24.

[4] See, for example, Seskin, et al., "An Empirical Analysis of Economic Strategies for Controlling Air Pollution."

cumbersome to deal with the spatial problem under a system of effluent charges, for it will typically require the environmental agency to determine a separate effluent fee for each source, depending upon its location in the air shed or river basin (or alternatively, it will be necessary to introduce a system of zones with different charges). Such discrimination among sources in fee levels may either be explicitly illegal or politically infeasible. In contrast, a system of marketable permits (as will become clear in the next section) can address these spatial dimensions of the pollution problem in a manner that is less objectionable.

Fifth, marketable permits may well be the more feasible approach on grounds of familiarity. The introduction of a system of effluent fees requires the adoption of a wholly new method of controlling pollution, new both to regulators and polluters. Such sharp departures from established practice are hard to sell; moreover, some real questions have been raised about the legality of charging for pollution. In contrast, permits already exist, and it may be a less-radical step to make these permits effectively marketable.

There is thus a strong case on administrative grounds for favoring marketable permits over effluent fees. But the case is far from ironclad. Where charges are feasible, they represent a most attractive source of revenues for the public sector. Most taxes in the economy have undesired side effects: they distort economic choices in various ways. Income taxes, for example, can induce individuals to choose untaxed leisure activities rather than work; excise taxes shift peoples' purchases away from the taxed goods; and so on. Such taxes generate an "excess burden" on the economy - a cost in addition to the reduced disposable income directly attributable to the revenues. Effluent fees, in contrast, have a beneficial side effect: They tend to correct distortions in the economy while at the same time generating public revenues. Such fees can be said to impose a "negative excess burden." Fees, then, to the extent they are feasible, are a very desirable source of public revenues in terms of economic efficiency.

One can also make an equity argument on behalf of fees. The Organization for Economic Cooperation and Development has done just this in terms of what they call the "Polluter-Pays-Principle."[5] Under this approach, society's environmental resources, including clean air and water, are taken to belong to the public at large. Those who "use" these resources must then compensate the "owners" (i.e., the public) for any environmental degradation that occurs. The equity issue is, however, a complicated one. In certain instances, for example, a firm may have adopted measures that minimize the damage from discharges, only to find some

[5] *OECD and the Environment* (Paris, 1979), p. 26.

years later that the recent arrival of residents and other firms now makes these discharges objectionable. Just who *should* bear the cleanup costs in such cases is not wholly clear on equity grounds. Moreover, as a practical matter, most polluters have already been required to institute extensive control measures to reduce their waste discharges. Grandfathering would thus involve a free distribution of permits for only the remaining, or residual, discharges. This may perhaps represent a reasonable compromise on equity grounds.

There is yet another argument favoring effluent fees - one that involves savings in certain transactions costs. A system of marketable emission permits requires an initial distribution of the permits. However, if this initial distribution is based on the grandfathering principle or some other mechanism that does not reflect the relative marginal abatement costs of the different sources, a series of transfers (purchases and sales) of permits will be required if the least-cost allocation is to be attained. The incentives for such transfers exist: Buyers who can reduce emissions only at a higher real cost will be willing to pay more than the reservation price of sellers. But there may well be significant search costs and elements of strategic behavior that impede the transfers of emissions entitlements that are necessary to achieve the least-cost outcome. In contrast, under a system of fees, no such transfers of permits are needed - each source simply responds directly to the incentive provided by the fee. It may thus prove easier in certain circumstances to attain the least-cost allocation of waste emissions under a set of fees than under a system of marketable permits.

2 The design of a system of marketable emission permits

Although the case, in principle, for marketable emission permits is impressive, it is a long way from a general decision on policy strategy to the design of an actual system of marketable permits. We turn in this section to an exploration of some alternative forms of a permit market and their properties.[6]

It will facilitate the discussion to provide here a more specific and formal statement of the control problem in which we shall incorporate explicitly the geographical dimension of polluting activities. Let us consider a particular region consisting either of an air shed or system of waterways in which there are m sources of pollution, each of which is fixed in location. Environmental (air or water) quality is defined in terms of pollutant concentrations at each of n "receptor points" in the region;

[6] This section draws heavily on A. Krupnick, W. Oates, and E. Van De Verg, "On Marketable Air Pollution Permits: The Case for a System of Pollution Offsets," *Journal of Environmental Economics and Management* X (September, 1980), 233-47.

this implies that we can describe environmental quality by a vector $Q = (q_1, \ldots, q_n)$ whose elements indicate the concentration of the pollutant at each of the receptors. The dispersion of waste emissions from the m sources is described by an $m \times n$ matrix of unit diffusion (or transfer) coefficients:

$$D = \begin{bmatrix} & \vdots & \\ \ldots & d_{ij} & \ldots \\ & \vdots & \end{bmatrix}.$$

In this matrix, the element d_{ij} indicates the contribution that one unit of emissions from source i makes to the pollutant concentration at point j.

The environmental objective is to attain some predetermined level(s) of pollutant concentrations within the region; we denote these standards as $Q^* = (q_1^*, \ldots, q_n^*)$. Note that the standard need not be the same at each receptor point; the environmental authority can, for example, prescribe lower concentrations as the target in densely populated areas.

The problem thus becomes one of attaining a set of predetermined levels of pollutant concentrations at the minimum aggregate abatement cost. Or, in other words, we are looking for a vector of emissions from our m sources, $E = (e_1, \ldots, e_m)$, that will minimize abatement costs subject to the constraint that the prescribed standards are met at each of the n locations in the region. The abatement costs of the ith source are a function of its level of emissions: $c_i(e_i)$. So our problem, in formal terms, is to

$$\begin{aligned} &\text{Minimize} \quad \sum_i c_i(e_i) \\ &\text{s.t.} \qquad\quad ED \leq Q^* \\ &\qquad\qquad\quad\;\; E \geq 0. \end{aligned}$$

There are two basic approaches to the design of a marketable permit system that deals with this control problem. First, the environmental authority can simply issue q_j^* permits at each receptor point, with these permits defined in terms of an allowed contribution to the pollutant concentration at j. This would effectively create a separate market corresponding to each receptor point, and a source, to justify its emissions, would have to procure a "portfolio" of permits from the various receptor points at which its emissions contribute to pollution levels. More specifically, source i would have to obtain $e_i d_{ij}$ permits from the jth receptor market. This form of permit market is an ambient-permit system (APS) in which the permits refer, not to a source's emissions, but to the effects of these emissions on levels of pollution at a particular point. Note that this implies that emissions entitlements will not, in general, exchange for one another on a one-for-one basis; a source whose emissions per unit are more damaging to a particular receptor will have to purchase commensurately more emissions entitlements from another source whose discharges contribute less per unit to pollutant concentrations at that receptor point.

Alternatively, the environmental agency can introduce an emissions permit system (EPS). Here the agency would divide the region into zones, and within each zone sources would trade emissions entitlements on a one-for-one basis. The EPS system has some obvious attractions in terms of simplifying transactions among sources.

We turn next to the properties of the two permit systems. For the APS scheme, Montgomery, in a seminal paper, has shown that, if the sources of pollution are cost-minimizing agents, the emissions vector and shadow prices that emerge from the preceding minimization calculation satisfy the same set of conditions as do the vectors of emissions and permit prices for a competitive equilibrium in the permits market.[7] In short, if the environmental authority were simply to issue q_j^* permits (defined in terms of pollutant concentrations) for each of the n receptor points, competitive bidding for these permits would generate an equilibrium solution that satisfies the conditions for the minimization of total abatement costs.

The APS system can thus, in principle, achieve the least-cost outcome. Two properties of this form of permit market are noteworthy. The first is the utter simplicity of the system from the viewpoint of the environmental agency. In particular, officials need have no information whatsoever regarding abatement costs; they simply issue the prescribed number of permits at each receptor point, and competitive bidding takes care of matters from there. Alternatively, the environmental authority could make an initial allocation of these permits among current polluters. In a competitive setting, subsequent transactions will then lead automatically to the cost-minimizing solution. As Montgomery proves formally, the least-cost outcome is independent of the initial allocation of the permits. Second, in contrast to the modest burden it places on administrators, this system can be extremely cumbersome for polluters. Note that a firm emitting wastes must assemble a "portfolio" of permits from *each* of the receptor points that is affected by its emissions: A source at point i will have to acquire permits from each receptor point j in the amount $d_{ij}e_i$. There will, therefore, exist n different markets for permits, one for each receptor point, and each polluter will participate in the subset of these markets corresponding to the receptor points affected by his or her emissions. Transactions costs for polluters may be high.

[7] W. E. Montgomery, "Markets in Licenses and Efficient Pollution Control Programs," *Journal of Economic Theory* V (December, 1972), 395–418.

The APS system suffers from a second deficiency that is potentially quite troublesome. The analysis here has run in terms of a given and fixed set of receptor points at which the attainment of predetermined levels of air quality are required. However, the Clean Air Act in the United States requires that the National Ambient Air Quality Standards (NAAQS) be met at *all* locations. But for pollutants with more localized effects (and this includes most of the major air and water pollutants), it is possible for changing location patterns of emissions to generate "hot spots" that do not coincide with designated receptor points. To prevent the occurrence of localized hot spots for such pollutants, a relatively fine mesh of receptor points will be needed, implying a large number of receptor markets with comparatively high transactions costs. Further, since each receptor is associated with an individual permit market, receptor points would tend to become "institutionalized." The moving of a receptor point to adapt it to a new pattern of pollution would create dislocations: It would alter the structure of permit markets and would probably give rise to difficult administrative and legal problems. And it would not preclude the need for future readjustments. The APS form of the permit market is not without serious problems.

As noted earlier, the EPS can greatly simplify life for polluters. Instead of assembling the requisite portfolio of permits from different receptor markets, each source would find itself assigned to a single zone within which emissions entitlements would exchange one-for-one. However, the EPS system cannot, in general, achieve the least-cost solution, and it makes enormous demands on an administering agency that tries to approximate this solution. Since polluters with somewhat varying dispersion coefficients are aggregated into the same zone, one-for-one trades of pollution entitlements will ignore the differences in the concentrations contributed by their respective emissions. In short, the price of emissions to each polluter will not correspond accurately to the shadow price of the binding pollution constraint. This objection to EPS need not be serious, if the dispersion characteristics of emissions within each zone are not very different. However, this is often not true. The ambient effects of emissions do not depend solely on the geographical location of the source; for air pollutants, for example, they depend significantly on such things as stack height and diameter and on gas temperature and exit velocity. EPS cannot readily incorporate such elements without losing the basic simplicity of one-for-one transfers of emissions entitlements.

A further difficulty besetting EPS is that, even were there no differences in the dispersion characteristics of emissions within each zone, the environmental authority must still determine how many permits to assign to each zone. And this determination requires *the complete solution* by the

administrator of the cost-minimization problem. To reach this solution, the administering agency must have not only an air-quality model (to provide the d_{ij}) and a complete emissions inventory, but source-specific abatement cost functions and the capacity to solve the programming problem. With less-than-perfect information, the agency's assignment of permits may not result in the attainment of the ambient air-quality targets. If pollution were excessive, the authority would have to reenter the market (in at least some of the zones, where the pattern of zonal purchases would again require a fairly sophisticated analysis) and purchase or confiscate permits. Such an iterative procedure is not only cumbersome for the administrator of the system, but may create considerable uncertainty for firms about the future course of permit prices. Note, moreover, that this procedure involves more than just groping once and for all toward an unchanging equilibrium. Altered patterns of emissions resulting from the growth (or contraction) of existing firms, the entry of new firms, and changing abatement technology will generate a continually shifting least-cost pattern of emissions among zones. Under EPS, the environmental authority faces a dynamic problem that will require periodic adjustments to the supplies of permits in each zone.

3 The pollution-offset system

Both the APS and EPS forms of marketable permit systems are, then, subject to some serious problems. However, there is a third alternative, a kind of hybrid system, that may be able to circumvent these problems: the pollution-offset (PO) system.[8] Under this approach, permits are defined in terms of emissions (e.g., the permit allows the discharge of X pounds of the pollutant, say, per week). However, sources are not allowed to trade permits on a one-to-one basis. More specifically, *transfers of permits under the PO scheme are subject to the restriction that the transfer does not result in a violation of the environmental quality standard at any receptor point.* This is the sole constraint on trades of permits.

The key to the working of the PO system is its implication that if a proposed transfer encounters a binding pollution constraint at some receptor point, then emissions must trade at a rate equal to the ratio of the sources' transfer coefficients (the d_{ij}'s), for the ratio of the transfer coefficients indicates the rate at which emissions from one source can substitute for emissions from the other with no change in pollutant concentrations at the binding receptor point. For example, if a unit of emissions from source

[8] See Krupnick et al., "On Marketable Air Pollution Permits: The Case for a System of Pollution Offsets."

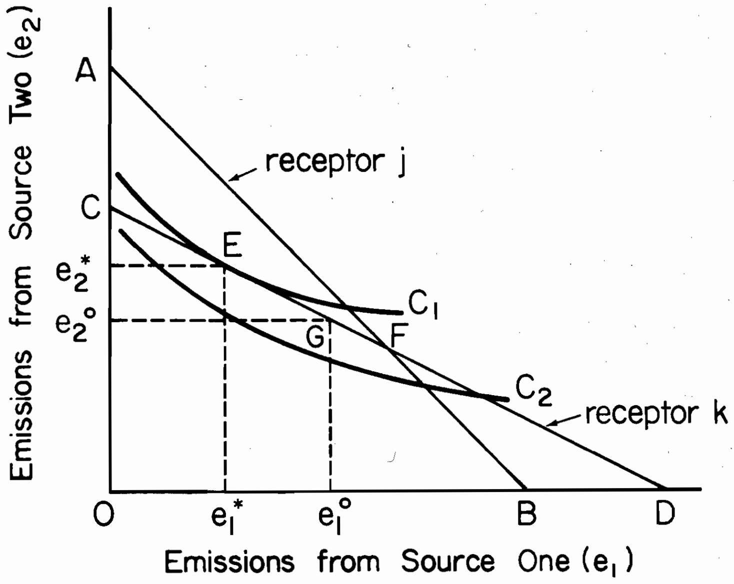


Figure 12.1

A contributes twice as much to pollutant concentrations at binding receptor point *I* as a unit of source *B*'s emissions, then *A* will be required to acquire two of *B*'s unit permits before *A* is allowed to increase its own emissions by one unit. Although permits are defined in terms of emissions, as under EPS, trades are really governed by the effects of emissions on ambient air quality, in the spirit of APS.

The PO system shares with the APS the important property that mutually beneficial trades among sources can lead to the least-cost solution and that this result is independent of the initial allocation of permits. This coincidence of the "trading equilibrium" with the least-cost solution can be seen with the aid of Figure 12.1. In the figure, the horizontal and vertical axes measure, respectively, the levels of emissions of firms 1 and 2 (i.e., e_1 and e_2). The curves C_1 and C_2 are iso-cost curves for pollution abatement costs.[9] Note that higher curves correspond to lower total abatement costs. The line *AB* depicts the pollution constraint associated with receptor *j*. Points on *AB* denote combinations of e_1 and e_2 for which $q_j = q_j^*$; the slope of the line equals the ratio of the transfer coefficients (i.e., the rate at which emissions from firm 2 can substitute for emissions from firm 1 with no change in pollution concentrations at receptor *j*). Similarly, *CD* depicts the pollution constraint for receptor *k*. The combinations of emissions from firms 1 and 2 that satisfy the pollution constraint at both receptors are thus the set of points *OCFB*. We see immediately that the least-cost solution occurs at *E*, at which point we reach the highest iso-cost curve consistent with the pollution constraint. At this point, the ratio of marginal abatement costs equals the ratio of the transfer coefficients.

Suppose, however, that the environmental authority selected for the initial distribution of permits point *G* instead of the least-cost outcome *E*. (Recall that the authority has no knowledge of sources' abatement cost functions and hence is unable to determine e_1^* and e_2^*.) In this instance, source two would find it profitable to purchase permits from source one. The effective rate of exchange of permits would be the slope of the line *CD*, since receptor *k*'s constraint is, in this case, the one that is binding. At this rate of exchange, the transfer of emissions from source one to source two will result in a decrease in aggregate abatement costs. The gains from trade would be exhausted at *E*, where the ratio of the sources' marginal abatement costs become equal to the rate of exchange of permits. We thus find that the "trading equilibrium" under the PO system coincides with the least-cost solution.[10]

Like APS (and unlike EPS), the PO scheme makes modest information demands on the environmental authority. Officials need to know the dispersion characteristics of emissions within the air shed or waterway (i.e., the *D* matrix), but need have no information on sources' abatement costs. The authority does not have to solve the cost-minimization problem to determine the initial allocation of permits: any allocation will do. This, incidentally, is an important property of the system, because it provides the degrees of freedom that will probably be needed to reach a "fair" and politically acceptable distribution of pollution rights.

Unlike APS, however, the PO system does not require sources to trade in a multitude of separate permit markets. Instead, a firm purchases emissions permits directly from other sources. The PO scheme thus promises substantial savings in transactions costs to sources relative to APS. In addition, it is not subject (as is APS) to the requirement that a fixed and

[9] A sufficient (but not necessary) condition for the iso-cost curves to have the desired curvature in Figure 12.1 is that both firms face a schedule of rising marginal abatement costs.

[10] We refer to this as a "trading" equilibrium rather than a "market" equilibrium, because we have not shown formally that there exists a specific set of prices that will sustain an equilibrium among buyers and sellers corresponding to the efficient allocation of permits among polluters. The discussion suggests that the only allocation of permits for which there exist no potential gains from trade (the definition here of a "trading equilibrium") corresponds to the least-cost allocation of emissions entitlements.

"institutionalized" set of receptor points be established. Receptor points can easily be redefined with respect to each trade to coincide with potential hot spots and thus ensure that there are no violations of the environmental standard at any point in the air shed or waterway. Receptor points, incidentally, need not coincide with monitoring locations where air or water quality is actually measured; receptors serve as reference points where pollutant concentrations may be monitored or alternatively inferred from a knowledge of emissions and a dispersion model of the region.

The PO system thus offers a promising approach to the design of a system of marketable emission permits. There may be cases, however, where a system of zones with one-for-one transfers within each zone promises a reasonably efficient outcome and is preferable because it simplifies trading. The attendant gains and losses under the various forms of permit markets need to be evaluated for different pollutants in different areas.[11]

4 On the choice among policy instruments

In the last two chapters, we have explored two alternative approaches to the use of pricing incentives to attain a predetermined set of environmental standards: effluent fees and marketable emission permits. Each approach, as we have seen, can in principle achieve the desired standards at the least cost to society. We reiterate the importance of this property in the light of recent experience with environmental policies. Study after study of current policies making use of direct controls has found that they incur excessively large costs. These pricing approaches thus offer an opportunity for enormous cost-savings in environmental programs. This is particularly important during times of sluggish overall economic performance, when environmental programs are likely to come under very close scrutiny as a source of increased costs to industry. If we cannot achieve our professed environmental objectives in a reasonably efficient way, it is likely that it will be these objectives, and not industrial performance, that will have to give. Thus, the standards of environmental quality that society is willing to accept may themselves depend upon the efficiency of the policy instruments we adopt to achieve the standards.

The choice between a system of effluent fees and one of marketable emission permits depends, as we have seen, on the pertinent circumstances: the nature of the pollutant and its geographical setting, and on various political and administrative considerations. Each policy instrument has its place. Where it is important to distinguish among individual sources, we are inclined to believe that a permit system is the more promising approach. Under such circumstances, one can introduce a pollution-offset system in which sources are allowed to trade permits subject only to the restriction that their trades do not result in any violations of the standards. Trades under this system automatically incorporate the differential effects of the sources' emissions on environmental quality. The PO system thus offers a very attractive and straightforward design for a permit system, one that has already been embodied, in essence, in some programs for the control of both air and water pollution.[12] Alternatively, where a uniform pricing signal is satisfactory, a single effluent charge, applicable to all sources, becomes more appealing. Each source would then respond directly to the fee, with no need for any permit transactions with other sources. Alternatively, the environmental authority can adopt a permit system with a single zone in which the permits trade one-for-one. Here, various administrative issues may suggest the approach that is to be preferred.

In the next two chapters, we shall examine some other policy instruments for the protection of the environment. As we shall see, it is important to understand the particular advantages and disadvantages of the different policy tools, for an effective overall program for the management of environmental quality will be one that embodies the appropriate *mix* of these tools.

[11] There are two recent "experiments" in the United States with systems that allow the transfer of emissions entitlements. The first, emissions trading, provides for the exchange of discharges of air pollutants among sources. The second, the Wisconsin system of transferable discharge permits, involves the transfer of BOD emissions among sources along certain rivers in the state of Wisconsin. Both of these systems, incidentally, are not "pure" systems of marketable emissions permits. They are embedded in a broader set of command-and-control measures that impose certain requirements upon control techniques, etc. It is interesting that both systems are in the spirit of the PO system discussed in this chapter in that they permit transfers of emissions entitlements subject to the absence of violations of the predetermined environmental standards. On emissions trading, see T. Tietenberg, *Emissions Trading: An Exercise in Reforming Pollution Policy* (Washington, D.C.: Resources for the Future, 1985); on the Wisconsin TDP system, see W. O'Neil, M. David, C. Moore, and E. Joeres, "Transferable Discharge Permits and Economic Efficiency: The Fox River," *Journal of Environmental Economics and Management* X (December, 1983), 346–55; for a brief and nontechnical description of both systems, see W. Oates, "Markets for Pollution Control," *Challenge* (May/June, 1984), 11–17.

[12] A straightforward variant of the PO system can, where desired, prevent deterioration in environmental quality in areas where existing pollutant concentrations are less than those allowed by the standard. On this, see A. McGartland and W. Oates, "Marketable Permits for the Prevention of Environmental Deterioration," *Journal of Environmental Economics and Management* XII (September, 1985), 207–228.

CHAPTER 13

Stochastic influences, direct controls, and taxes

This chapter seeks to show that, in addition to the pricing measures advocated in the preceding chapters, there is room in a well-designed environmental policy for at least one instrument that has attracted virtually no defenders among economists – the direct controls, so popular outside the profession.

After the demonstration in the preceding chapters that pricing methods have important efficiency advantages over direct controls, our advocacy of the use of the latter may appear somewhat inconsistent. However, we are not suggesting that the preceding discussion is basically incorrect, but rather that it omits an important consideration. Environmental problems do not always develop smoothly and gradually. Instead, they are often characterized by infrequent but more or less serious crises whose timing is unpredictable. Such emergencies may require rapid temporary changes in the rules of the control mechanism, and it is here that pricing measures appear subject to some severe practical limitations. In this chapter, we will show how the uncertainty associated with environmental conditions greatly complicates the implementation of a program of fees or subsidies.[1]

We will not conclude from this that such programs are useless. We still believe that they have an important role to play and that economists have been right in trying to convince policy makers of their advantages. Rather, we suggest that the ideal policy package contains a mixture of instruments, with taxes, marketable permits, direct controls, and even moral suasion each used in certain circumstances to regulate the sources of environmental damage.

Before proceeding further, it is desirable to indicate more formally how we distinguish between direct controls and taxes or fees. This is not as obvious a difference as one might think at first blush, for direct controls are

[1] The analysis in this chapter will use taxes or fees as the prototypical pricing instrument to be contrasted with direct controls. Much of what is said about fees applies also to a system of marketable emission permits. However, it is possible that a more rapid response can sometimes be obtained by modification of the provisions of a permit at a time of environmental crisis than through alteration in the relevant tax rate.

presumably enforced through fines or other penalties and the difference between a fine and a tax requires some elucidation. To us, a direct control must involve a directive to *individual* decision makers requiring them to set one or more output or input quantities at some specified levels or prohibiting them from exceeding (or falling short of) some specified levels. If the activity levels satisfy these requirements, they are considered legal and no penalty is imposed. However, if they are violated, whether by small or large amounts, the individual is considered to be a lawbreaker who is subject to punishment. With taxes or fees on the other hand, even if they are based on standards *for the community as a whole*, no individual is told what input or output levels to select. Moreover, taxes and fees utilize no knife's-edge criterion. The amount of the decision maker's payment will vary with his pertinent activity levels, with no imputation of illegality to the activity levels he chooses.

1 Exogenous influences and the social cost of emissions

In some cases, the damage done by an emission depends almost exclusively upon its magnitude and on the number of persons whose location makes them vulnerable to its effects. The annoyance generated by a loud noise may plausibly be taken to depend largely on its decibel level and on the number of persons within earshot.

However, under many other circumstances, the social costs of a particular activity depend on variables beyond the control of those directly involved. For example, the polluting effects of a given discharge of effluent into a river will depend upon the condition of the waterway at that time – whether it has just been replenished by rainfall or depleted by a drought. The amount of water and the speed of its flow are critical determinants of the river's assimilative capacity. Similarly, stagnant air can trap atmospheric pollutants, perhaps even collecting them until they become a danger to health and life.[2]

The point of all this is that emission levels that are acceptable and rather harmless under usual conditions can, under other circumstances, become intolerable. Moreover, these conditions depend on the values of variables that are largely outside the control of the policy maker and often are not predictable much in advance. Meteorological conditions,

[2] Note, however, that the careful studies by Lave and Seskin of the evidence on the mortality effects of air pollution suggest that fears about the consequences of air pollution *crises* may be exaggerated considerably. See Lester Lave and Eugene Seskin, "Acute Relationships Among Daily Mortality, Air Pollution and Climate," in Edwin Mills, Ed., *Economic Analysis of Environmental Problems* (New York: Columbia University Press, 1975), pp. 325–47.

for example, must, for most purposes, be considered largely exogenous and only imperfectly foreseeable.[3]

Such exogenous influences contribute to an important class of serious environmental problems: the occasional crises that call for the imposition of emergency measures and that, in some instances, have grown into widely publicized disasters. Typically, we cannot predict these crises much in advance or with any degree of certainty; we can, however, be certain that at some unforeseen time they will recur. An environmental program incapable of dealing with such emergencies is hardly likely to be greeted with overwhelming enthusiasm.

2 Administrative obstacles to the effective use of taxes

Whatever their other virtues, taxes and subsidies suffer from at least one serious practical liability as a means for the regulation of externalities: they are very difficult to change on short notice. Anyone who has followed the history of recent attempts at tax reform knows how slow and painful a process it is. Even during periods when unemployment and disappointing growth rates called for rapid tax reductions, there have been delays running into months and, in some cases, years. Certainly, the few days that are as much advance notice as one can reasonably expect for an environmental emergency are hardly enough to effect a change in the tax regulations.

Moreover, even if an environmental administrator possessed a substantial degree of flexibility in the setting of tax rates so that he could adjust them rapidly, he would still find the instrument ill-suited to short-term crises. For the sort of response one hopes to elicit from the imposition of Pigouvian taxes characteristically is not achieved overnight. One expects them to lead to the use of cleaner fuels, of production processes that emit smaller quantities of pollutants, to the adoption of equipment for the cleansing of emissions, and so on. These are measures that normally are effective only in the long run, and that it is neither reasonable, nor often possible, to press into service in a brief emergency period.

This second point really involves two sorts of problems in the implementation of a system of fees to cope with occasional periods of severe

[3] Similar arguments apply to the state of the quality of life more broadly interpreted. The effects of deterioration of a neighborhood upon crime rates clearly depend on a number of noneconomic and largely exogenous influences: the level of drug addiction, whether the country is currently engaged in military combat, on the current rainfall and temperature (recall the "hot summers" of the 1960s with their frequent outbreaks of urban violence and looting). Forecasts of the timing of the resulting disturbances are consequently highly uncertain.

environmental deterioration. First, the response to a given level of fees is difficult to predict accurately. And, second, the period of adjustment to new levels of activities is typically uncertain. These problems may not be very serious for a long-run policy designed to achieve desired standards of environmental quality. As we discussed in the preceding chapter, the environmental authority can set tax rates, observe the response in levels of polluting activities over time, and, where necessary, seek further adjustments in the level of the fee. Our point is that, *given sufficient time for the adjustment of fees to achieve the desired response*, the case for effluent fees (or taxes) is a very compelling one.

However, environmental conditions may, under certain situations, alter so swiftly that fees simply may not be able to produce the necessary changes in behavior quickly (or predictably) enough to avoid a real catastrophe. This suggests one major attraction of direct controls: *If enforcement is effective,* controls can induce, with little uncertainty, the prescribed alterations in polluting activities.[4]

Direct controls may offer another source of flexibility that is difficult to achieve with taxes. It is certainly true, as many economists have pointed out, that programs of direct controls frequently require essentially the same monitoring system (and costs of enforcement) as a program of fees. A plant that is prohibited from discharging more than x units of sulphur from its smoke stacks should have its emissions recorded just as it would if it were to be taxed t dollars per unit of sulphur emitted.

But during periods of severe environmental distress, it may be necessary to regulate activities that in normal times are left to pursue their own course. Bans or limitations on motor vehicle travel, the cessation of certain types of waste disposal, all of which are not normally of sufficient concern to require regulation, may be convenient temporary expedients. Because of the infrequency of these controls and, perhaps, the suddenness of their need, comprehensive monitoring and metering systems may not be sensible, economically. Instead, the authorities may have to be content to catch only some of the violators, imposing penalties sufficiently severe to make them an effective deterrent to others. Then punishment itself becomes a stochastic process, with penalties higher than those that would be appropriate if their imposition were certain and uni-

[4] This, incidentally, suggests another reason for the popularity of direct controls among regulators. Having had little experience in the use of effluent taxes, they seem to fear that a program introducing a fee for the first time will fall far short of its intended goal and that a subsequent increase in tax rates sufficiently high for the purpose will prove unacceptable politically. A set of quotas, they argue, does not proceed so indirectly; it can give the community far greater assurance of achieving its objectives than can an untried program of taxes.

versal.[5] The landlord whose incinerator continues to run despite an emergency prohibition on trash burning may be jailed for sixty days rather than being fined the relatively small fee that would otherwise be called for. This seems not to be too bad a description of the way in which direct controls actually work in emergency situations.

Just because they do not require metering, direct controls of this sort can be imposed cheaply and quickly, avoiding the fixed costs that supplementary taxes may require.[6]

3 Tax rates and exogenous determinants of damage: an illustrative model

Using an elementary model, we can illustrate an environmental process and see why fiscal controls by themselves can sometimes be an excessively costly instrument for environmental protection.

The basic relationship is built about a random variable, k_t, where $0 \leq k_t \leq 1$. We take k_t to depend on exogenous forces (which, for convenience, we call *wind velocity*); in particular, k_t represents the proportion of the previous period's pollution that is not dispersed by the time the current period begins. The current pollution level, P_t, equals this residue from the previous quantity of pollution, $k_t P_{t-1}$, plus current emissions:[7]

[5] Presumably, in a stochastic punishment process, the expected value of the penalty to a violator who has (as yet) not been caught should bear some direct relation to the fee rates appropriate where a charge is certain and universal.

[6] One might argue that any degree of reduction in polluting activities can be achieved by a tax that is sufficiently high. A tax of $100,000 per motor vehicle on the streets of a city should effectively curtail all motor traffic. Moreover, such a tax can also be imposed haphazardly, falling only on those who happen to be caught violating the pertinent rules or standards. Aside from the purely semantic problem of distinguishing between such randomly collected taxes and the fines used to enforce direct controls, the preceding example also suggests that in practice an environmental protection agency is unlikely to have the authority to levy taxes of such magnitudes, although it is likely to be able to enlist the support of the police and the courts in imposing emergency controls.

[7] We believe that this is not a bad representation of the facts of the matter. Rather similar relationships have long been used in the engineering literature in the field of water quality analysis. See, for example, H. W. Streeter and Earle B. Phelps, *A Study of the Pollution and Natural Purification of the Ohio River,* U.S. Public Health Bulletin, #146 (Washington, D.C.: Government Printing Office, February, 1925); J. Donald O'Connor, "The Temporal and Spatial Distribution of Dissolved Oxygen in Streams," *Water Resources Research* 111, No. 1, (1967), 65–79; W. E. Dobbins, "BOD and Oxygen Relationships in Streams," *Journal of Sanitary Engineers Division,* American Society of Civil Engineering, XC, No. SA3, (June, 1964), 53–78. We note also that the logic of our analysis holds for a much broader range of functional forms, say $P_t = \phi(P_{t-1}, k_{1t}, \ldots, k_{qt}) + nf(r)$, where the k_{jt} are random variables. All is well so long as we can, from the probability distribution for the k_{jt}, calculate G, the distribution for P_t.

$$P_t = k_t P_{t-1} + nf(r) \tag{1}$$

where

n is the number of polluters in the community
r is the tax rate on emissions[8] and
$f(r)$ is the level of emission of a representative polluter.

Equation (1) is, of course, a linear, first-order difference equation with a stochastic coefficient, and it is nonhomogeneous.

Let us illustrate the workings of the model by starting off with the case where wind velocity is not subject to stochastic influences. Then the equilibrium solution of (1) for $k_t = k$ (nonrandom) is

$$P_e = nf(r)/(1-k). \tag{2}$$

If, in addition, we assume that the waste emissions by a representative firm are a linear function of the tax rate (they can be expressed as $f(r) = a - br$ where r is the tax rate),[9] then the equilibrium level, P_e, is given as

$$P_e = n(a-br)/(1-k). \tag{3}$$

Let D be the maximum level of accumulated pollutants consistent with a given set of standards; then the tax rate, r, necessary to maintain the equilibrium level of P_e at the critical level is obtained as a solution to

$$P_e = \frac{n(a-br)}{1-k} = D.$$

Or, solving for the tax rate, r,

$$r = \frac{a}{b} - \frac{D(1-k)}{nb}. \tag{4}$$

This gives us a nonincreasing linear relation between r and the pollution dispersion rate, $(1-k)$. In Figure 13.1, we depict this relationship for various values of D. For example, in the case $D=0$, the second term in the RHS of (4) drops out so that r takes the constant value a/b as indicated by horizontal locus QR in the figure. This, of course, is the case of zero waste emissions. As D rises, indicating a higher permissible level of discharges, the curve pivots down about the fixed vertical intercept, a/b. All the loci have this same vertical intercept because, for $(1-k)=0$, we have $r = a/b$ for all values of D.

[8] In this chapter we depart from our notation elsewhere, using r rather than t to represent the tax rate to avoid confusion with the conventional time subscript, t.

[9] $f(r)$ depends in part on how the polluter's costs are affected by the quantity of his emissions. This relationship will enter the discussion explicitly later in the chapter when we construct a model for an optimal mixed policy, that is, a policy using both taxes and direct controls.

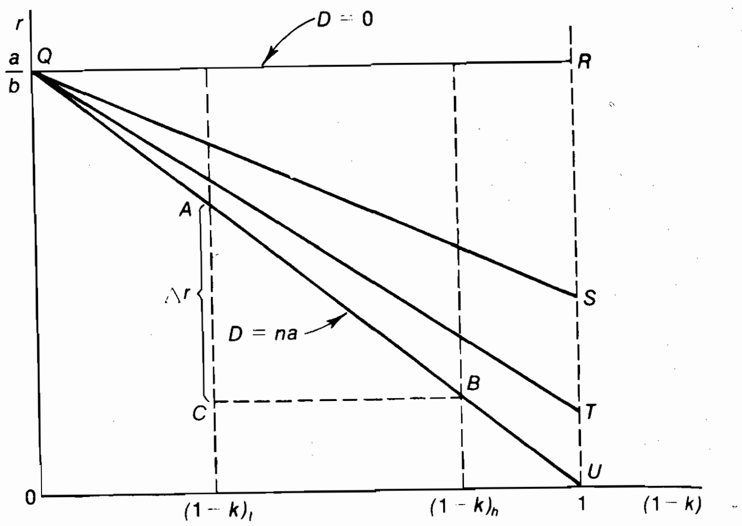


Figure 13.1

The linear case we have just discussed assumed implicitly that the marginal cost of pollution control is constant. In fact, the cost of eliminating pollution normally rises sharply as its level approaches zero. To illustrate this possibility, we can utilize the emissions function $f(r)=ce^{-vr}$, which implies that the reduction in emissions resulting from a given rise in the tax rate will level off asymptotically. Arguing as before, we now obtain

$$D=P_e=\frac{nf(r)}{1-k}=\frac{nce^{-vr}}{1-k}$$

a − b r

$$\frac{D(1-k)}{nc}=e^{-vr}$$

$$-vr=\ln D+\ln(1-k)-\ln(nc)$$

$$r=\frac{\ln(nc)}{v}-\frac{\ln D}{v}-\frac{\ln(1-k)}{v}. \qquad (5)$$

The relationship[10] between r and $(1-k)$ is illustrated by curve $R'R$ in Figure 13.2.

[10] Note that because $0\leq(1-k)\leq1$, then $\ln(1-k)\leq0$, and approaches zero as $1-k$ approaches unity.

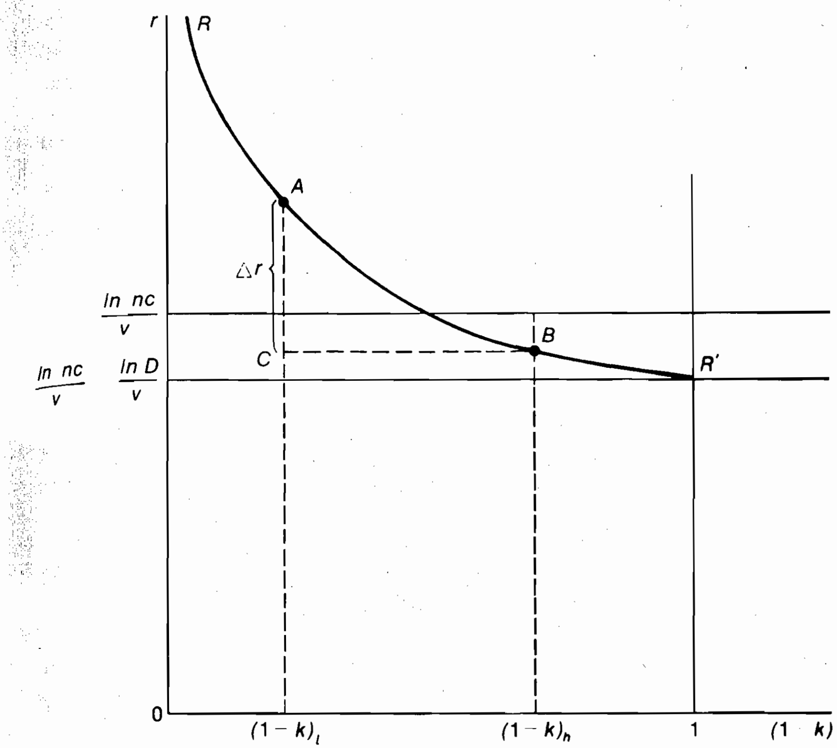


Figure 13.2

4 Some qualitative observations

Several broad conclusions are suggested by these simple deterministic models: i) Increasing D (a lowering of standards) permits a reduction in r but does so at a declining rate (because it restores pollution whose elimination is decreasingly expensive). This result follows directly from (5). It obviously depends on the assumption that the marginal cost of reducing waste emissions rises as the level of emissions falls. For example, as (4) indicates, this result does not hold in the linear model. ii) An increase in n, the number of polluters, increases r, but at a decreasing rate. With more sources of emission there will be more pollution, but each increase in r also elicits the associated decrease in emissions from a correspondingly larger number of polluters. In both (4) and (5), it is easy to show $\partial^2r/\partial n^2<0$.

This suggests that, to maintain a given level of waste discharges, a pollution tax rate in more densely populated cities should be higher than that in smaller communities, but the increase should be less than proportional to the rise in the number of polluters.[11] iii) Finally, as is to be expected, a rise in $(1-k)$, the rate of natural dispersion of pollutants, reduces the tax rate necessary to meet a given set of standards, for from (2), setting $D=P_e$,

$$f'(r)\frac{\partial r}{\partial(1-k)}=\frac{D}{n} \quad \text{so} \quad \frac{\partial r}{\partial(1-k)}<0.$$

2

5 Stochastic models and the potential superiority of direct controls

We now illustrate the workings of the model when the wind velocity is subject to stochastic influences. Unlike the deterministic case, the level of pollution in each period is a random variable; consequently, the equilibrium level of pollution is not uniquely determined but is also a random variable. It has been proved by V. S. Bawa that, for our stochastic relationship (1), the limiting or equilibrium distribution of the pollution level

[11] The declining rate of increase in r with rising n is *not* dependent on our exponential response assumption. On the contrary, the increasing cost of pollution control (that is, the $f''(r)>0$) works *against* that relationship. Indeed, it is only guaranteed to hold if $f''(r)\leq 0$. To show this we return to our basic general relationship,

$$f(r)=\frac{D(1-k)}{n}$$

(which includes both the linear and exponential models as special cases). Consequently,

$$f'(r)\frac{\partial r}{\partial n}=-\frac{D(1-k)}{n^2}, \quad \text{or} \quad \frac{\partial r}{\partial n}=-D(1-k)n^{-2}f'(r)^{-1}.$$

Because $f'(r)<0$, it follows that $\partial r/\partial n>0$.

Differentiating again, we have

$$\frac{\partial^2 r}{\partial n^2}=D(1-k)\left[f'(r)^{-1}2n^{-3}+n^{-2}f'(r)^{-2}f''(r)\frac{\partial r}{\partial n}\right].$$

Here $D(1-k)$, $2n^{-3}$, $f'(r)^{-2}$ and $\partial r/\partial n$ are all positive and $f'(r)^{-1}$ is negative, and so, if $f''(r)\leq 0$, the entire expression will be negative (that is, then r does increase at a decreasing rate with n). However, if $f''(r)>0$, the first term in the brackets will still be negative but the second will be positive so that the net result will depend on their relative magnitudes as it does in our exponential model. In economic terms, the reason for the ambiguity introduced by the last term is that, with $f''(r)>0$, the higher value of r required by a larger n runs into diminishing returns and this offsets the scale advantages of having more persons reduce their emissions in response to a given rise in r.

always exists and is given uniquely as a function of the distribution of the random variable, k_t.[12]

First, for illustrative purposes assume that the dispersion rate, $(1-k)$, of Equation (2) can take two values: the high usual value $(1-k)_h$ that occurs on most days, and the low emergency-dispersion rate $(1-k)_l$ that occurs only infrequently. Then the maximum level of emissions during emergency periods is (approximately)[13] $nf(r)/(1-k)_l$, but the normal emission level is (approximately) $nf(r)/(1-k)_h$. The tax rate necessary to keep pollution levels acceptable under ordinary wind conditions is illustrated by B in Figures 13.1 and 13.2, and the higher tax rate A is required to be certain of coping with emergencies.[14] Note that, if the tax were set high enough to deal with crises and were not reduced at other times, it would require the community to pay an "excess" tax rate, $\Delta r = CA$, during most of the year when $(1-k)$ is at its normal level. The expected excess cost to society per period is the resulting outlay on the reduction of emissions below normal levels, multiplied by the probability that the tax rate is excessive.

The concept of the excess tax is, of course, not dependent on our use of the probability distribution encompassing only two possible states, which we have introduced purely for expository simplicity. Using Bawa's results described in the Appendix to this chapter, one can, in an analogous manner, calculate the expected excess cost for any given distribution of k_t.

This result is important because it follows that

Proposition One. In the presence of stochastic influences, taxes may sometimes be more costly to society than direct controls as a means to limit environmental damage.[15]

If the cost induced by the excess tax is sufficiently high, it can always offset the static allocative efficiency offered by the tax program that we discussed in the preceding chapter. That is, even if taxes incur only a fraction

[12] Bawa derives these results formally in the Appendix to this chapter. If $G(P_t)$ is the distribution of P_t, we define the equilibrium or limiting distribution as the limit of G as P_t approaches P_e.

[13] We must say "approximately" because we have not accounted for the level of pollution not yet dispersed from earlier periods. The actual pollution level will always be lower than this if the value $(1-k)_l$ does not hold indefinitely, because pollution can then be expected to approach the "equilibrium level," $nf(r)/(1-k)_l$, asymptotically from below, and hence will never actually reach that level.

[14] In Figure 13.1, this assumes $D=na$ so that the relevant locus of r and $(1-k)$ values is QU.

[15] Of course, this result depends on our earlier argument that taxes are subject to short-run rigidities and uncertainty that can be circumvented by direct controls.

of the social costs imposed by direct controls in stationary conditions, with unforeseeable variability in those conditions, safety may require the maintenance of an extremely high tax rate that generates heavy, unnecessary costs in nonemergency periods. We cannot simply assume that taxes will always be the more efficient of the two regulatory instruments.

6 Mixed systems of regulation

Indeed, the analysis suggests that neither reliance solely on fiscal methods nor on direct controls will constitute an optimal regulatory strategy. Rather, it may be less costly to society to employ a mixed system that makes use both of taxes and direct controls. The environmental authority would set effluent charges and other pollution tax rates so as to meet prescribed environmental standards during normal periods. Flexible direct controls might then be adopted on a standby basis, to be put into effect when (unforeseeable) circumstances call for them. The environmental authority, for example, might have available a series of regulations of increasing severity, with the choice among them depending on the magnitude of the threatened danger at the time the decision is made. During a mild intensification of air pollution, apartment house incinerators may, for example, be shut down. If atmospheric conditions continue to deteriorate, the environmental agency could ban private passenger cars from the streets, and so on. In fact, several cities have already defined and formulated corresponding policy measures for sequences of increasingly serious "air pollution alerts."

In this way, we may be able to realize the best of both worlds by taking advantage of the efficiency properties of tax measures in normal circumstances and invoking direct controls to cope with temporary periods of accentuated environmental deterioration.

7 An optimal mixed program: graphic discussion[16]

We can use our model to show, at least formally, how to determine an optimal mixed policy to achieve a prescribed environmental standard. Assuming for illustrative purposes that we have only one type of direct control, there is only one degree of freedom in the selection of the mixed policy. Specifically, once the effluent tax rate is determined, the remainder of the policy follows directly.

This is illustrated in Figure 13.3, which shows schematically how the level of pollution in some particular area might vary over time with the

[16] Formal proofs of the results used in this section are given in the Appendix.

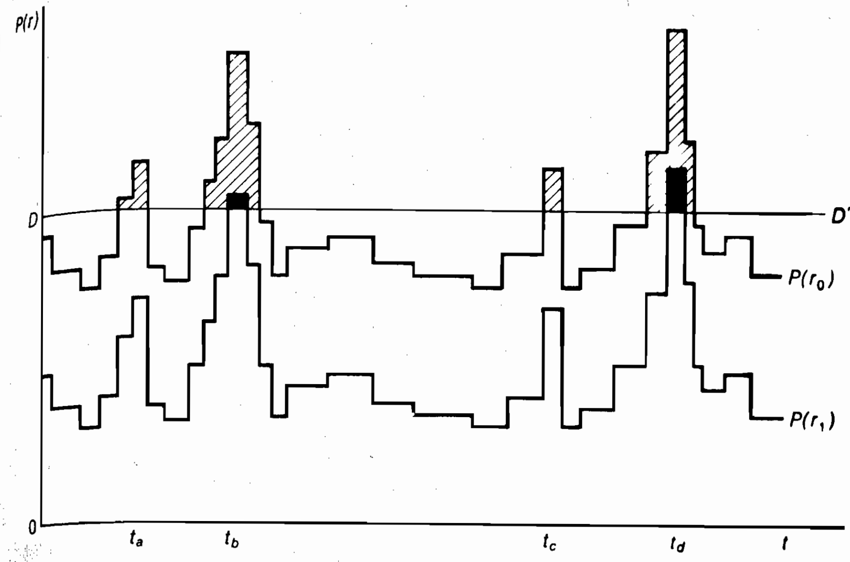


Figure 13.3

tax rate set for the entire period at some specific level, $r = r_0$ (the upper curve). If the inviolable pollution standards call for pollution levels that never exceed danger level, D, it is clear that there are four periods of time, t_a, t_b, t_c, and t_d, when the environmental authority will have to invoke direct controls. The extent of the controls will vary with the amount of excess pollution that might otherwise be expected, as indicated by the shaded areas above line DD'. Now suppose that the tax rate had instead been set for the entire period at some higher level, $r = r_1 > r_0$. Emissions will now be lower than they would have been otherwise, and the pollution curve must shift downward correspondingly, say, to the lower curve in the figure. Now, two of the periods that formerly required direct controls, t_a and t_c, will no longer need them. Moreover, the two remaining periods of high potential pollution, t_b and t_d, will now require much milder doses of controls, as indicated by the black areas remaining above DD'.

We see that the choice of the value of r determines unambiguously, in retrospect, both the periods when direct controls are invoked and the strength of these measures. But an optimality calculation must, of course, be prospective rather than retrospective. We must therefore deal with the probability distribution of $P_t(r)$ and with the corresponding expected values of the pollution-control costs.

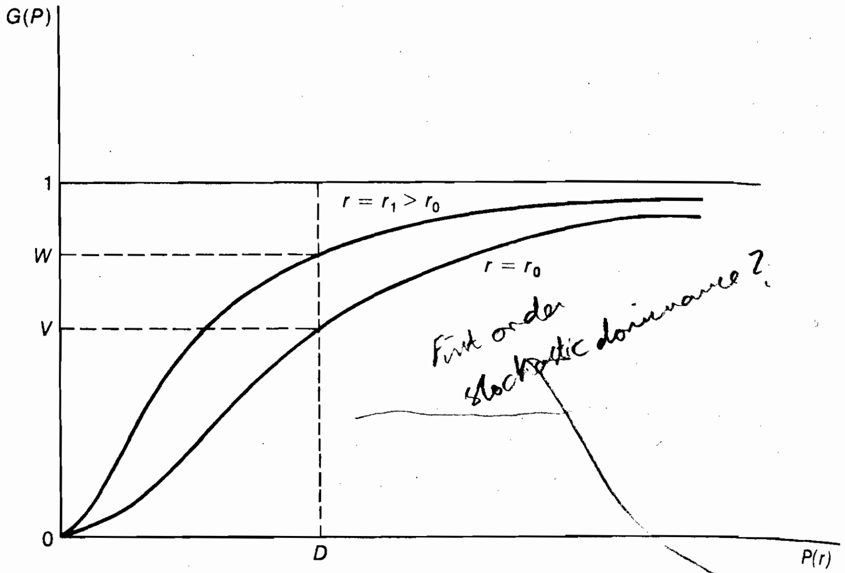


Figure 13.4

V. S. Bawa has proved that for our stochastic relationship,

$$P_t = k_t P_{t-1} + nf(r),$$

given the probability distribution of our random variable, k_t, the equilibrium or limiting distribution of P_t exists and can in principle be determined (though its precise calculation can be very difficult). Let us then take $G[P(r)]$ to represent that distribution.

We will now describe our optimality calculation graphically and then express it more explicitly with the aid of algebraic notation. Figure 13.4 shows two probability distributions of $P(r)$ corresponding to $r = r_0$ and $r = r_1 > r_0$. The curve corresponding to r_0 lies below that for r_1 because the former involves larger frequencies of higher pollution levels. Once again, we see that as r is reduced, the expected use of direct controls will automatically increase. That is, there will be a greater expected frequency of $P(r) > D$, represented by VW in Figure 13.4, as r decreases from r_1 to r_0.

Figure 13.5 now translates this observation into cost terms. The curve TT' shows the total social cost of the reductions in emissions induced by the taxes. This will obviously be a monotonically increasing function, because a rise in the tax rate will normally induce less (and certainly no

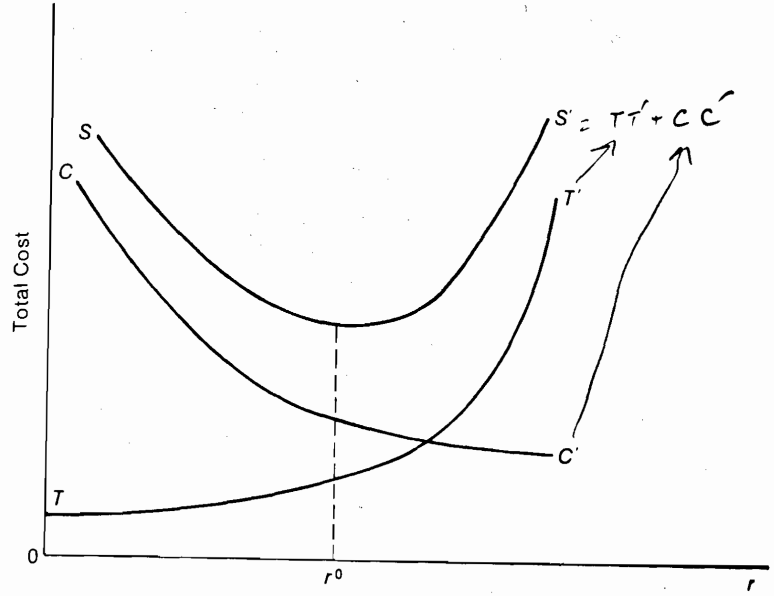


Figure 13.5

more) waste emissions. The curve CC' is the same relationship for the program of direct controls. The slope of this curve will, of course, be negative, because with an increased tax rate, r, the use of direct controls will fall and so will the total cost they impose on polluters. Adding these two costs vertically, we obtain curve SS' giving the total cost of the mixed program.[17] The minimum point on SS', at which the marginal cost of two component programs are equal, yields the optimal tax rate r^o.[18]

8 A model for determination of the optimal mixed policy

To formalize this process, we will formulate an expected social cost function that is to be minimized by a suitable choice of tax rate, r. This mini-

[17] We should note that SS' measures the cost to polluters of various combinations of tax rates and controls that will maintain the level of environmental quality at *or* above the prescribed standard *at all times*. This calculation does not allow for the added social benefits that a higher tax rate generates by providing environmental quality in excess of the standard during normal times. The analysis is still framed in terms of the objective adopted in Chapter 11: the attainment of *prescribed* standards at minimum cost.

[18] The curve SS' can have a number of local minima. Monotonicity of CC' and TT' is not enough to prevent this possibility. We can be confident that SS' will have at least one

mization process is, of course, constrained by a set of relationships restricting pollution to a level no higher than D and invoking direct controls whenever the tax rate does not suffice to do the job. We will first describe the constraints, leaving specification of the objective function until later.

Assume that for each polluter, i, there is a cost function

$$c_i(s_i, \ldots)$$

representing total cost as a function of his emission level, s_i, among other variables that, for our current purposes, we need not specify.

Then, with tax rate r and no direct controls, we will presumably have

$$c_{is} = \frac{\partial c_i}{\partial s_i} = r \tag{6}$$

or, assuming we can solve for the inverse, $c_{is}^{-1}(r)$, of this derivative we have in the absence of direct controls[19]

$$s_i = c_{is}^{-1}(r). \tag{7}$$

That is, the emission level of firm i will be adjusted to the level at which the cost of reducing emissions by one additional unit equals the unit tax.

However, in times of crisis in the absence of further restraints for all firms together, this level of emissions will be unacceptably high. For these circumstances we may define[20]

$$\text{Excess emissions} = \Delta = \sum_i c_{is}^{-1}(r) + k_t P_{t-1}(r) - D. \tag{8}$$

Excess emissions are the excess of accumulated pollutants over the maximum acceptable level, D. Note that this includes new emissions of all firms plus pollutants undispersed from the previous period. To meet the prescribed standard corresponding to D, we require direct controls to reduce total emissions by the amount Δ *if* $\Delta > 0$ (if there really are excess emissions); but we require no direct controls if $\Delta \leq 0$, so that there is no

[18] Footnote 18 *(cont.)*
minimum in any closed interval because CC' and TT' cannot take negative values. CC' and TT' can be expected to take *very* high values toward the left and rightward ends of the diagram, respectively, so that we may expect SS' to be roughly U-shaped. However, that is not necessary for the curve to have at least one minimum.

[19] Note that $\sum_i c_{is}^{-1}(r)$ equals $nf(r)$ of Equation (1).

[20] Note again that, although for concreteness of illustration we continue to use $k_t P_{t-1}$ to represent the pollutants left over from the previous period, obviously such a multiplicative relationship need not always hold. But nothing is changed by substituting into (8) the more general relationship $f(P_{t-1}, k_{1t}, \ldots, k_{qt})$ for $k_t P_{t-1}$, where the k_{it} are all random variables, provided we can determine probability distributions for the k_{it}, and from them can calculate a probability distribution for $P_t(r)$, in accord with Bawa's results.

threat of emergency. More formally, we require direct controls to reduce emissions by the amount δ, where

$$\delta = \Delta \quad \text{if } \Delta > 0$$

$$\delta = 0 \quad \text{if } \Delta \leq 0.$$

This is equivalent to requiring[21]

$$\delta \geq \Delta, \tag{9}$$

$$\delta(\delta - \Delta) = 0 \tag{10}$$

and

$$\delta \geq 0. \tag{11}$$

The direct controls on emissions must in some way assign to each polluter, i, an emission quota

$$s_i = c_{is}^{-1}(r) - w_i \delta \tag{12}$$

where

$$\sum w_i = 1 \tag{13}$$

so that total emissions will be reduced by the required amount $\sum w_i \delta = \delta$. Note that relationship (12) holds at all times whether it is a "normal" or a "crisis" period, because during the latter, we will have $\delta > 0$, but during the former, (9), (10), and (11) guarantee that we will automatically have $\delta = 0$.

Relationship (12) is a rough, but not necessarily a bad, representation of emergency direct controls. For example, a directive simply to "shut down incinerators" amounts to an assigned quota for reduction of emissions independent of what other emissions the polluter finds it convenient and profitable to continue. Relation (12) distinguishes between the effect of the tax on waste emissions and that of the controls. The first term on the RHS represents the former and obviously corresponds to the necessary condition (6) for private cost minimization in the presence of emissions taxes. On the other hand, the second term is the direct controls component whose value is determined by the assignment of the weights w_i.

We turn finally to our objective function, which requires us to minimize the *expected* costs of emissions control

$$C = \int_0^{\infty} \sum_i c_i(s_i)\, dG[P(r)]. \tag{14}$$

[21] The purpose of relationships (9), (10), and (11) is to express the two regimes, the situation requiring the imposition of direct controls and the one that does not, in a single set of constraints. Equation (10) assures us that either $\delta = \Delta$ or $\delta = 0$. The other two conditions then guarantee the use of direct controls ($\delta \neq 0$) if, and only if, there are excess emissions ($\Delta > 0$).

That is, we minimize the sum over all firms, i, of the costs, c_i, of their emission levels, s_i, where the emission levels are in turn determined by the current pollution level, $P(r)$, all this multiplied by $dG(P)$, representing the probability of occurrence of that pollution level. Thus (14) is to be minimized subject to the constraints (8)–(13) and the additional nonnegativity conditions

$$r \geq 0, \qquad s_i \geq 0.$$

The solution to this nonlinear programming problem will yield the specifications of our optimal mixed policy by determining the optimal tax rate, r, and residually [by (9)–(11)] the amount, δ, the expected excess emissions to be eliminated by direct controls. It will represent the tax rate that incurs the lowest possible social cost of the overall program of pollution controls when direct controls are assigned the task of removing any unacceptable emissions that escape the influence of the fiscal incentives.

9 Concluding comment

The models of this chapter clearly have not encompassed all there is to be said for the usefulness of direct controls in environmental policy. Much of their appropriate function, arising out of issues such as relative monitoring costs, can be discussed effectively only on a more pragmatic level, as is done in the companion volume. We have intended to show here that, even considered in their own arena, that is, cost minimization, pricing measures do not have the field entirely to themselves. In many important cases, there is a significant role to be played by direct controls and other types of nonfiscal measures. We are convinced that economists are justified in continuing to emphasize the advantages of pricing methods; their relative neglect by policy makers has very likely incurred heavy costs. But we economists should also broaden the scope of the methods we are willing to espouse and should attempt to determine the appropriate functions and use of the several policy instruments that are available.

Appendix

By V. S. Bawa

As in Section 3 of this chapter, the pollution level P_t in period t, $t = 1, 2, \ldots$ is taken to be given by the following recursive relation:

$$P_t = k_t P_{t-1} + nf(r), \tag{A1}$$

where k_t, $0 \leq k_t \leq 1$, a random variable, represents that proportion of the previous period's pollution not dispersed by the current period. We

assume that $k_1, k_2, \ldots$ are a sequence of independent and identically distributed random variables with common probability distribution $F(\cdot)$.

Using (A1), we note that P_1, the pollution level in period 1, is given as

$$P_1 = k_1 P_0 + a, \tag{A2}$$

where we denote $nf(r)$ by a for typographical simplicity. P_1 is a random variable because k_1 is a random variable. Thus, if we let $G_1(\cdot)$ denote the probability distribution of P_1, then

$$\begin{aligned} G_1(y) &= \Pr\{P_1 \leq y\} \\ &= \Pr\{k_1 P_0 + a \leq y\} \\ &= \Pr\{k_1 \leq (y-a)/P_0\} \end{aligned}$$

or

$$G_1(y) = F[(y-a)/P_0]. \tag{A3}$$

Thus, knowing $F(\cdot)$, the distribution of the basic random variable k, the distribution, $G_1(\cdot)$, of P_1, the random level of pollution in period 1, is given by (A3). Similarly, using (A1), the level of pollution in period 2, P_2, is also random and given as

$$P_2 = k_2 P_1 + a, \tag{A4}$$

and if $G_2(\cdot)$ denotes the probability distribution of P_2, then

$$\begin{aligned} G_2(y) &= \Pr\{P_2 \leq y\} \\ &= \Pr\{k_2 P_1 + a \leq y\} \\ &= \int_0^1 \Pr\{P_1 \leq (y-a)/x \mid k_2 = x\}\, dF(x) \end{aligned}$$

or

$$G_2(y) = \int_0^1 G_1[(y-a)/x]\, dF(x). \tag{A5}$$

Thus, knowing $F(\cdot)$, $G_2(y)$ can be calculated recursively using (A3) and (A5). In general, it follows from this reasoning that for $t \geq 1$, P_t given by (A1) is a random variable with probability distribution function $G_t(y)$ given as

$$G_t(y) = \int_0^1 G_{t-1}[(y-a)/x]\, dF(x), \tag{A6}$$

and hence for any value of $t \geq 2$, $G_t(y)$ can be calculated by using (A3), (A5), and (A6) recursively. Although for a general distribution function $F(\cdot)$, $G_t(y)$ cannot be expressed as an explicit function, $G_t(y)$ can be evaluated numerically quite efficiently using the recursive relation (A6).

We are interested in the equilibrium, steady state, or limiting value of the pollution level. If $k_t = 1$ with probability one (that is, zero pollution is carried away each period), then it follows from (A1) that $P_t = P_0 + ta$ where $a > 0$. Hence, as would be expected intuitively, as $t \to \infty$, $P_t \to \infty$ and thus there is no way to control the pollution level. We are interested in the other, more realistic, case when $E(k_t) < 1$ (that is, at least some pollution is carried away each period). In this case, it can be shown, using standard asymptotics, that the equilibrium or steady-state pollution level, denoted P, is a proper random variable, and, as would be expected intuitively from (A6), its probability distribution, $G(\cdot)$, is given uniquely as a solution to:

$$G(y) = \int_0^1 G[(y-a)/x]\, dF(x). \tag{A7}$$

If we let $G_r(y)$ denote the distribution of P when r is the tax rate, then the effect of the tax rate r on the equilibrium pollution level P is summarized by the following:

Lemma. If $r_1 > r_0$, then for all y

$$1 - G_{r_1}(y) \le 1 - G_{r_0}(y).$$

Proof: Using (A1), we see that P_t is a stochastically increasing function of a; thus, it follows that P, the equilibrium pollution level, is a stochastically increasing function of a. Because $a = nf(r)$ is a decreasing function of the tax rate r, it follows that P is a stochastically decreasing function of r. This completes the proof of the Lemma.

This result has the intuitive interpretation that as the tax rate r decreases, the probability of a higher equilibrium pollution level increases. This is illustrated in Figure 13.4 of this chapter. The result is also useful in proving the existence of an optimal tax rate r^o. To do that, we note that the steady state total expected social costs $TSC(r)$ for a pollution control policy with tax rate r is given as

$$TSC(r) = T(r) + \int_D^\infty c(x-D)\, dG_r(x), \tag{A8}$$

where $T(r)$ represents the total social costs of emission reductions induced by tax rate r and $c(x-D)$ represents total direct control costs necessary to reduce the pollution level from x to critical level D [where $c(x-D) = 0$ for $x \le D$]. $T(r)$ is assumed to be a monotonically increasing function of r. (This is illustrated by TT' in Figure 13.5.) It is also plausible that $c(x-D)$ is an increasing function of $(x-D)$; as the level of excess pollution (that is, the amount over the critical level D) increases, the total costs of reducing the pollution level to acceptable level D increases.

Integrating by parts, (A8) can be rewritten as

$$TSC(r) = T(r) + \int_D^\infty [1 - G_r(x)]\, c'(x-D)\, dx. \tag{A9}$$

Thus, using the Lemma, it follows that the second term in (A9), represented by CC' in Figure 13.5, is a decreasing function of the tax rate r. In other words, as tax rate r is increased, there is a decrease in the frequency with which direct controls are used in short-term crises or emergencies to keep pollution levels acceptable and, hence, the expected direct control cost decreases. Moreover, both terms in (A9) are certainly nonnegative. Hence, their sum, $TSC(r)$ (represented by SS' in Figure 13.5), that is, the sum of the tax costs and expected direct control costs, must have at least one minimum in any closed interval $0 \le r \le r^*$, where we take the constant, r^*, to represent a tax rate so high that the probability of $P(r^*) > D$ is less than some arbitrarily small G. Thus, there exists a tax rate, r^o, that minimizes $TSC(r)$. We have proved the following:

Proposition Two. Given some maximal level of pollution, D, that is not to be exceeded, the optimal pollution control policy is a mixed policy completely specified by an optimal tax rate, r^o.

We note that, from the monotonicity of $T(r)$, it follows that r^o is finite. However, depending on the rate of change of $T(r)$ relative to direct control costs, it may happen that $r^o = 0$. In such a case, the optimal policy for pollution control is to impose no taxes and use only direct controls. (This may be viewed as a special case of a mixed policy with $r^o = 0$.) We also note that to guarantee the uniqueness of the optimal tax rate r^o and to obtain practical methods for the calculation of r^o, we need some more assumptions about the cost functions (for example, $T(r)$ is a convex function). Such issues are considered in detail in Bawa [see reference].

The multiplicative model (A1) considered in this chapter is an appropriate choice for problems of air pollution where there is no constraint on the level of pollution that can be carried away in each period. In some other cases (for example, water pollution problems), there may be a constraint on the level of pollution that can be carried away in a period by the natural sources and the following model may be more appropriate:

$$P_t = \max(0, P_{t-1} + a - k_t). \tag{A10}$$

For this and some other general stochastic models, it can be shown that the preceding results still hold. These general models are considered in detail in Bawa and some additional results on optimal pollution control policies are obtained.

Reference

Bawa, V. S., "On Optimal Pollution Control Policies" (unpublished paper).

CHAPTER 14

Taxes versus subsidies: a partial analysis

We can rest assured that firms and municipalities that are asked to reduce their damage to the environment will look to state and federal agencies for financial assistance. Such a request may seem uncomfortably analogous to the case of a holdup man who appeals to his victims to finance the costs of his going straight. Sometimes, however, a persuasive case *can* be made in terms of equity. What of the firm that built its smoking factories well away from the centers of population only to find itself surrounded by inhabitants a few decades later? Is it really the company that is responsible for the damage generated by its emissions of smoke?

We must admit to feeling that too much has probably been made of such cases in the literature, and that there usually is some presumption against rewarding government agencies and private enterprises for the damage they have done to the environment in the past. But whatever the virtues of the matter, the issue is a real one. There will continue to be calls for subvention of industrial activities that may otherwise find themselves at a competitive disadvantage and of local agencies whose budgets are already under heavy strain.

The central question here is whether or not it is possible to attain an optimal pattern of resource use through a program of subsidies rather than fees. In Chapter 4, we showed that there is a set of Pigouvian taxes that will sustain optimal levels of externality-generating activities in a competitive system. Can this also be achieved by some specified set of payments?

The literature has occasionally suggested an affirmative answer to this question. Some writers (including one of the present authors)[1] have argued that the public authority can use either the stick or the carrot to induce socially desirable patterns of behavior. In recent years, however, a short series of articles has shown that, on any reasonable interpretation, this is simply untrue. Kamien, Schwartz, and Dolbear[2] have demonstrated

[1] See W. J. Baumol, *Welfare Economics and the Theory of the State,* 2nd ed. (Cambridge, Mass.: Harvard University Press, 1965), p. 104.

[2] M. I. Kamien, N. L. Schwartz, and F. T. Dolbear, "Asymmetry between Bribes and Charges," *Water Resources Research* 11, No. 1 (1966), 147–57.

that where the polluter recognizes the effects of his actions on the regulatory authority, a subsidy scheme may make it profitable for the firm to start off by polluting more than it would have otherwise in order to qualify for larger subsidy payments.[3] Wenders, moreover, has suggested that, where there is this sort of interaction between the polluter's behavior and regulatory standards, there is less of an inducement for new pollution-abatement technology from a system of subsidies than a program of taxes.[4] Consider a firm that is evaluating a pollution-reducing innovation. If the introduction of the new technique (and the resulting lower level of waste emissions) is likely at some future time to induce the public authority to reduce fiscal incentives, then the decision of the firm may well depend upon whether the agency is employing taxes or subsidies. In the former case, the prospective tax reduction would promise increased profits to the firm and thus encourage the introduction of the new technology, but under a system of subsidies, the change in fiscal incentives would take the form of a reduction in the future rate of *payments* from the agency and hence reduce the profitability of the innovation.

Bramhall and Mills[5] have pointed out what to us seems to be the most important distinction between the two types of stimuli: the fact that an enterprise that would be unprofitable under a tax may be made profitable by a subsidy. Whereas a tax will typically drive firms out of a competitive industry and so generally lead to a decrease in its output, a subsidy may increase entry and induce an expansion in competitive outputs. We shall explore this issue in some depth in this chapter and will contend that it is far more significant than a casual reading of the literature would suggest. We will show, for example, that, under pure competition, although a subsidy will tend to reduce the emissions of the *firm,* it is apt to *increase* the emissions of the industry beyond what they would be in the absence of fiscal incentives! Moreover, paradoxically, the more the subsidy suc-

[3] In this case, the firm need not be very large for this sort of interdependence to arise. The pollution benchmark will presumably have to be set for each firm in light of its product line, its output level, and its inherited plant and equipment. As with price-control mechanisms, it would not be surprising to see the firm's benchmark pollution level, s^*, against which improvement is to be measured, set on the basis of its emissions during some arbitrarily chosen period. The firm might then have much to gain by emitting a great deal of pollution during that period to increase the value of the base level of its subsidies.

[4] J. T. Wenders, "Methods of Pollution Control and the Rate of Change in Pollution Abatement Technology," *Water Resources Research* II (June, 1975), 343–6.

[5] D. E. Bramhall and E. S. Mills, "A Note on the Asymmetry between Fees and Payments," *Water Resources Research* II, No. 3 (1966), 615–16. On this see also the papers by A. M. Freeman, "Bribes and Charges: Some Comments," *Water Resources Research* III, No. 1 (1967), 287–88; and T. D. Tregarthen, "Collective Supply Problems in the Allocation of an Air Basin," paper delivered to the Economics of Pollution Section of the 1971 Annual Meetings of the Western Economic Association, Simon Fraser University, August, 1971.

ceeds in limiting the emissions of the firm, the more it may stimulate those of the industry. Similar problems may well arise under oligopoly where the relevant exit and entry may, preponderantly, take the form of the opening and closing of *plants* rather than firms.

Before turning to these propositions, however, it is important to note the element of truth in the contention that there can be equivalence between the carrot and the stick. We will show formally that, *in principle,* there does exist a program(s) of subsidies that can sustain optimal levels of polluting activities. But the very character of this program suggests immediately that, although it may be an interesting theoretical construct, it is virtually inconceivable that any such program would ever be adopted in practice. We will see that any plausible systems involve fundamental asymmetries between fees and subsidies.

For expository convenience, we will for the most part deal only with detrimental externalities so that, according to the analysis of Chapter 4, the appropriate instrument for the achievement of Pareto optimality is always a set of taxes. We will find it convenient in this discussion to deal with just one polluting industry and with the firms that compose it. Thus, for most of this chapter, we leave our general-equilibrium framework and turn temporarily to a partial analysis.

One more matter remains to be settled before getting to the substance of our discussion: the nature of the subsidy program we will consider. This is not as obvious as it may seem on first thought. Several different types of subsidy programs have in fact been proposed and their effects may well differ considerably. For example, some proposals have called for a tax credit for investment in pollution-control equipment or for some other device to help cover some proportion of the cost. However, as Kneese and Bower point out, such a subsidy is, at least in principle, likely to prove quite ineffective in stimulating pollution abatement.[6] For, if the equipment adds to a firm's costs and contributes nothing to its revenues, the absorption of k percent of the cost by a government agency cannot

[6] See A. V. Kneese and B. T. Bower, *Managing Water Quality: Economics, Technology, Institutions* (Baltimore: Johns Hopkins Press, 1968), pp. 175–78. They point out that various legislative proposals introduced in Congress offer this type of subsidy in a variety of forms including rapid tax write-offs and tax credits. They argue that aside from the fact that such subsidies can never by themselves make abatement investments profitable, they suffer from at least three other defects: First, they increase the "excess burdens" imposed by the tax system; second, this sort of arrangement rewards only the installation of particular types of equipment (for example, treatment equipment), and, hence, may not induce the adoption of the most efficient pollution-control methods; and, third, this type of subsidy aids only firms that are profitable enough to invest and may not be very helpful to marginal concerns. We may note, however, that, from the point of view of efficiency, failure to rescue marginal firms may well be desirable socially.

turn its acquisition into a profitable proposition. So long as k is less than 100 percent, the installation of the equipment will lose money for the firm, and its attractiveness to management will remain doubtful, except perhaps as a public-relations gesture or as a pure act of conscience by the businessman.

The type of subsidy with which we will be concerned in most of this chapter is of quite another sort. It involves a payment to the firm based on the *reductions* in its output of a pollutant or in some other sort of damage to the environment. That is, taking s to be the firm's output of the pollutant, and s^* to be the base (benchmark) against which improvement is to be measured,[7] the subsidy payment can be described by the relationship $g(s^*-s)$, where $dg/d(s^*-s)>0$ (that is, the payments to the firm increase with the amount by which it decreases its emissions). In the bulk of our discussion we will assume that the subsidy payment per unit reduction in emissions is constant, so that the payment becomes

$$v(s^*-s), \tag{1}$$

where v and s^* are constants. Expression (1) immediately indicates one fundamental difference between programs of taxes and subsidies. With taxes, we need concern ourselves with only one parameter, the tax rate, but a system of subsidies requires that we specify values for two parameters: the unit subsidy (v) and the benchmark level of emissions (s^*).

In the subsidy programs with which we will concern ourselves, payments are made only to firms that are actually engaged in an activity that is (potentially) polluting. The firm that closes its doors ceases to receive any such payments, and no subvention is given to a firm that is considering entry into the area but has not actually done so. These are features we would expect to characterize any real subsidy program. Their critical significance for the analysis will become clear presently.

1 The formal subsidy relationship and the general case

Assume that firm k is subject to a fixed Pigouvian tax per unit of emission. Its profit function is

$$\pi_k^t = y_k p^k(y_k) - c^k(y_k, a_k) - ts^k(y_k, a_k) \tag{2}$$

where

y_k = the output produced by firm k
a_k = its abatement outlay

[7] Note that s^* may, but need not be, based on observation of the firm's past behavior (for example, its previous levels of smoke emission).

$p^k(y_k)$ = the price of its product
$c^k(y_k, a_k)$ = total production cost
t = the tax rate per unit of emission
$s^k(y_k, a_k)$ = the total emission of pollutant

and where we assume

$$s_y^k = \frac{\partial s^k}{\partial y_k} > 0, \qquad s_a^k = \frac{\partial s^k}{\partial a_k} < 0. \tag{3}$$

Similarly, it is clear that if the firm is instead offered the subsidy (1), its profit function becomes[8]

$$\pi_k^v = y_k p^k(y_k) - c^k(y_k, a_k) + v[s_k^* - s^k(y_k, a_k)]. \tag{4}$$

2 The equilibrium of the individual firm[9]

It is convenient to begin by comparing directly the subsidy profit function (4) with the tax-profit function (2); this comparison immediately yields a significant result about the relative effects of the two types of fiscal incentives on the equilibrium of the individual firm. We see at once that if $v=t$, the two profit functions differ only by the constant quantity vs^*. If the company is a profit maximizer and *continues to engage in the same types of activity under either fiscal program,* we see that the choice between a tax and subsidy system will not affect *any* of its decisions one iota. Whatever values of its decision variables it will find most profitable in the one case will also maximize profits in the other.[10]

There is another way that this conclusion has been described in the literature. The subsidy program (1) has been interpreted as equivalent to a tax on pollution, vs (with v being the per-unit tax rate), plus a lump-sum

[8] We should note that the profit function (4) for the firm receiving a subsidy for the reduction of emissions can be taken to represent the profit function in the general case encompassing all three of the relevant possibilities: a subsidy program, a tax program, or the absence of either. The function, as it stands, is the subsidy relationship. By setting $v = 0$, we at once obtain the case with neither taxes nor subsidies. Finally, setting $s^* = 0$, we are left with the pure tax case, with the firm having vs deducted from its profits and thus paying the tax rate v per unit of emission. This observation about the generality of (4) will prove useful to us in Section 4 of this chapter.

[9] For an illuminating discussion of the subject of this section, see Kneese and Bower, *Managing Water Quality,* pp. 98–109. See also A. P. Lerner, "Pollution Abatement Subsidies," *American Economic Review* LXII (December, 1972), 1009–10.

[10] In an unpublished note, Yakov Amihud has argued that in the presence of risk the lump-sum payment, vs^*, may reduce the marginal risk of the subsidized firm and may therefore induce it to maintain an output level larger than that of the taxed firm. On this see, for example, A. Sandmo, "On the Theory of the Competitive Firm Under Price Uncertainty," *American Economic Review* LXI (March, 1971), 65–73.

subsidy given by the constant vs^*. Because, by definition, a lump-sum subsidy does not affect behavior, it should hardly come as a surprise that the choice between a tax and a subsidy policy does not influence any of the firm's decisions. This, then, is the basic argument rationalizing the intuitive notion suggested at the beginning of this chapter that a tax and a subsidy, like the carrot and the stick, should be able to achieve the same result.[11]

Strictly speaking, this conclusion is, however, incorrect. For suppose that, in the absence of taxes and subsidies, our firm's maximum profits are zero. Then the imposition of a tax would ultimately force it to close its doors, but the subsidy program could end the precariousness of its existence. Put another way, it is not quite legitimate to describe the component vs^* in the subsidy (1) as a lump-sum payment, for it may influence the firm's decision between continuation and cessation of operations.

This suggests immediately the provision that is required for the subsidy program to establish a set of incentives identical to those of the tax: The lump-sum payment (vs^*) must not be contingent upon the firm's decision to stay in business.[12] In principle, this payment must be made to the polluter, whether potential or actual, so that it has no direct influence on any choice that confronts him.[13] Note that once this stipulation is introduced, the choice of the benchmark level of emissions becomes wholly arbitrary in terms of any implications for optimal resource use; the selection of a value for s^* affects only the magnitude of the subsidy payment.

The administrative infeasibility of such a system of payments is evident. The lump-sum subsidy must be paid not only to those who continue polluting activities, but also to any *potential* polluters. For example, a firm that chooses to cease its operations altogether must continue to receive the subsidy payment *indefinitely* (otherwise the subsidy program might have induced the firm to remain in business). Similarly, potential entrants into the polluting activity must be eligible for the subsidy to prevent them from initiating waste generation simply to qualify for the lump-sum payment. The difficulty of identifying these economic units (along with the obvious political obstacles to such a system of payments) imply that we must restrict our consideration of this form of subsidy program to the conceptual realm, as it does not represent a real policy alternative.

[11] There is a different argument whose invalidity is shown in Section 5. Suppose there are two industries, A and B, and that a tax rate of t on A's output will achieve the desired reallocation of resources from A to B. Then surely the same thing can be accomplished by an r dollar subsidy to A if a sufficiently greater subsidy is provided to B and (fiscal and monetary) policy keeps the levels of employment of resources from changing. As will be shown later, this argument is, in fact, incorrect so long as the relative prices corresponding to a given optimum for the economy are unique, *and* the absolute prices are fixed by some normalization rule or otherwise.

[12] Kneese and Bower note this condition (*Managing Water Quality,* p. 104).

[13] We must say no "direct" influence here, because a set of lump-sum taxes or subsidies will have income effects leading, in general, to a new general equilibrium set of relative prices. The point is that such a program has no direct price effects in the sense of altering the terms of choice in the initial equilibrium situation.

Throughout this chapter, it is therefore assumed that subsidy payments in any period t are limited to firms that are actively in business during this period. The equivalence of the incentives under the tax and subsidy programs then vanishes, and we conclude

Proposition One. For the individual firm, the choice between a tax and a subsidy program to induce a decrease in pollution emissions may determine whether or not the firm continues its operations. However, other things being equal, no other decision of the profit-maximizing firm will be influenced by the choice between the two fiscal measures provided the marginal tax and subsidy rates are equal.

Note that Proposition One does not enable us to reach any unambiguous conclusions about the relative desirability of taxes and subsidies in practice. *If* the firm stays in business, its level of output will be identical under the two fiscal programs. However, we know (ignoring any external effects) that monopoly outputs are normally less than optimal.[14] It is thus conceivable that a subsidy, if it permits a monopoly to continue its operations, may be a second-best solution superior to a tax that leads to the cessation of production. However, when we turn next to the case of pure competition, the conclusions are unambiguous. As we have already shown in Chapter 4, the appropriate taxes imposed on detrimental externalities are indeed capable of yielding a Pareto optimum. In the next section, we will see, however, that, for the competitive *industry*, subsidies may be expected to produce pollution levels very different from those corresponding to a Pigouvian tax program. We find that subsidies must unavoidably violate the necessary conditions for Pareto optimality (Table 1 of Chapter 4).[15,16]

[14] As we noted in Section 1 of Chapter 6, Buchanan and others have pointed out that the imposition of effluent charges on monopoly firms may actually reduce welfare, because they will induce a fall in the level of an output that is, perhaps, already less than optimal. See his "External Diseconomies, Corrective Taxes, and Market Structure," *American Economic Review* LIX (March, 1969), 174–77.

[15] In most of this chapter, we will take the utilization of resources achieved by the Pigouvian tax as the standard of optimality against which to measure the subsidy program. It is easy to argue the propriety of this procedure intuitively. After all, the tax merely makes the individual pay *all* of the social costs of his activity. The optimality of a system of pure competition in the absence of externalities follows in part from this characteristic

Before turning to the behavior of the industry in the next section, the reader should note that Proposition One refers explicitly to the *individual firm* and applies only with "other things being equal." This means that, *if* the tax or subsidy has no effect on the price of the firm's output, then the firm (if it stays in business) will operate at the same level of output with the same level of waste emissions under both fiscal programs. However, as we shall see in the next section, a system of taxes in a competitive industry will generate a different industry supply curve (and hence a different price) than a subsidy program. As a result, the new equilibrium output and emissions level for the competitive firm will differ under the two sets of fiscal incentives.

3 The case of the competitive industry

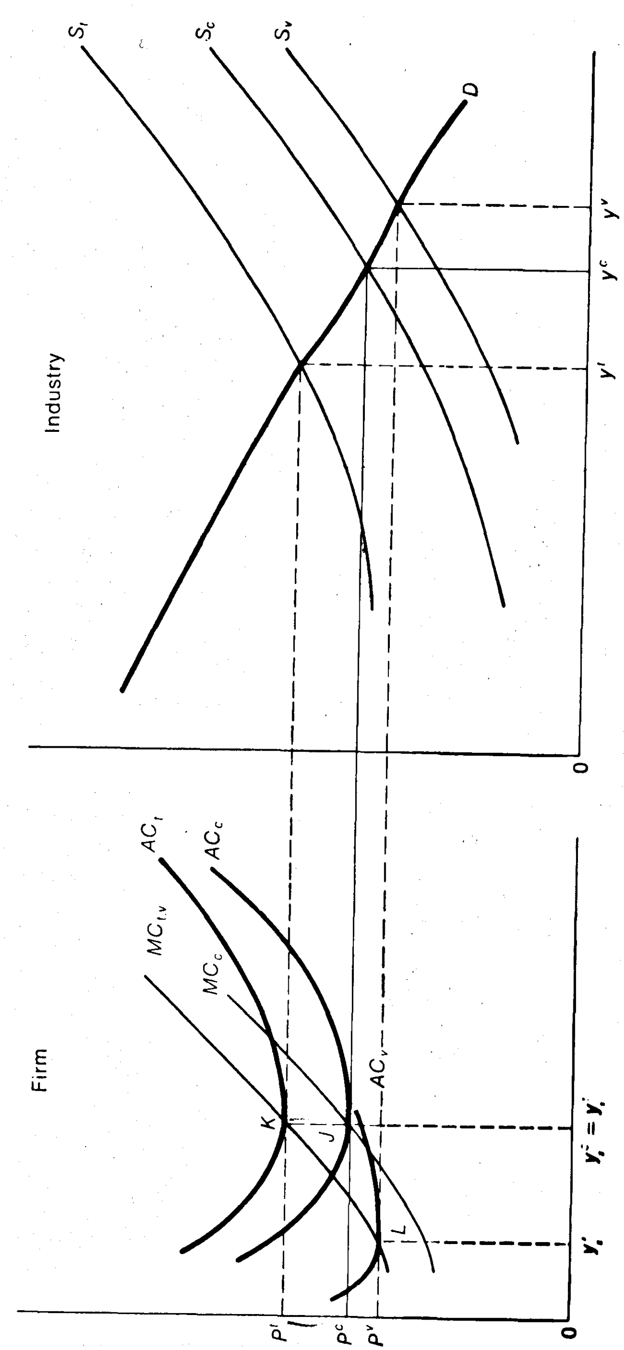
Matters turn out quite differently in the competitive industry, because exit and entry are an integral element in the determination of total output. Here we can expect the choice between a tax and a subsidy to have a significant effect on total output. In fact, the results of a subsidy may well prove surprisingly unsatisfactory, as we will now show. In this section the argument will proceed on the simplifying premise that emissions are a single-valued function of industry output, and in the next section it will be generalized to take account of the possibility of changing emissions independently of output (abatement).

It may be helpful to consider the argument first in diagrammatic terms. In Figures 14.1a and 14.1b, we depict the equilibrium positions of a rep-

Footnote 15 *(cont.)*
of its operation. The tax program, in effect, internalizes all externalities and makes a competitive system operate as if no externalities were present. That is why the tax system always yields optimal results and why, if a subsidy program leads to a different pattern of resources utilization, it is likely not to be optimal.

However, we must be careful in using this argument. Because a Pareto optimum is normally not unique, one cannot be certain from the observation that the allocation of resources under the subsidy program differs from that under taxes that the former is not itself Pareto-optimal. This point will be examined further in Section 5.

[16] Note that Table 1 of Chapter 4 shows that Pigouvian taxes will sustain Pareto-optimal exit and entry decisions by all the firms in a competitive economy and not just optimal decisions on nonzero activity levels. The exit-entry decisions relating to emissions of pollution are represented by conditions 5° and 5ᶜ in Chapter 4, which show that the equilibrium emissions of the firm will be zero under a Pigouvian tax regime if, and only if, that is true in the corresponding Pareto optimum. However, we recall that these results depend on competitive behavior and on each polluter being a "small" source of emissions. As we saw in Chapter 4, if the marginal damages from the firm's emissions are not (approximately) constant over the range of its discharges, then the firm's Pigouvian tax bill will not equal the total damages that its emissions impose on society. In such cases, the Pigouvian tax will not provide the correct incentive for the firm's entry-exit decision.



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resentative competitive firm (firm i) and the corresponding competitive industry under three different sets of circumstances: the equilibrium point, (y^c, p^c), when there is no public environmental program; point (y^t, p^t) with a unit tax on pollution emissions; and point (y^v, p^v) when there is a unit subsidy, v (equal to t), for reductions of emissions below some benchmark level. Starting from the no-program solution, we note that the unit pollution tax produces an upward shift in the firm's marginal and average cost curves (to $MC_{t,v}$ and AC_t).

If, instead of having no environmental program, a system of subsidies is instituted (under which we assume there are no negative subsidy payments), the firm's marginal cost shifts up to $MC_{t,v}$, but its average cost is now reduced to AC_v. From our earlier results, we know that the tax and subsidy programs have identical effects on the firm's marginal costs. Consequently, in Figure 14.1a, the sole difference in the firm's cost relationships under the two programs is that its average cost under the system of subsidies (AC_v) will be less than its average costs (AC_t) under the pollution tax or in its absence (AC_c). However, entry and exit can be depended upon to drive price down to the firm's minimum level of average cost.

The result may actually be no change or even an increase in the equilibrium emissions of the individual firm under an emissions tax. For example, if emissions are strictly proportionate to output, the equilibrium output of the representative competitive firm must be exactly the same with and without the tax, for a fixed tax per unit will then shift its average cost curve directly upward by a uniform vertical distance (it will not be increased by full amount of the unit tax because rent will also be affected by the accompanying change in industry output) and so the firm's cost minimizing output and emissions levels will remain completely unaffected by the tax.[17]

However, a subsidy program will generally decrease the equilibrium emissions of the competitive firm. Geometrically, we see this by noting that the new marginal cost curve, $MC_{t,v}$, must now cut the original (no-program) cost curve, AC_c, at a point that lies to the left of the old equilibrium point, J. But, AC_v, the average cost curve with subsidy, must lie

[17] Robert Kohn has demonstrated recently that although this result holds in a partial-equilibrium competitive model, it does not, in general, hold in a general-equilibrium analysis. In a full general-equilibrium setting, Kohn demonstrates that this proposition is valid only if firms' production functions are homothetic. See his, "A General Equilibrium Analysis of the Optimal Number of Firms in a Polluting Industry," *Canadian Journal of Economics* XVIII (May, 1985), 347–54. Note, however, that the result must hold for a perfectly competitive equilibrium, where at the equilibrium point production functions must always be linearly homogeneous locally.

below AC_c, and so, given a positive slope of the marginal cost curve, the new equilibrium point, L, must lie still further to the left of J.[18]

Turning now to the emissions of the industry, which are, of course, the primary concern of policy, we note that the tax program, because it raises every firm's average and marginal costs, must result in a leftward shift of the industry supply curve, from S_c to S_t; price rises from p^c to p^t and *industry* output falls from y^c to y^t with a consequent decline in the *industry's* emission of pollutants. This happens though each firm that continues to operate produces the same output in both cases, because the tax will drive some firms from the industry. Similarly, the subsidy will induce the entry of firms (producing the rightward shift of the industry supply curve from S_c to S_v); the result is a fall in price (to p^v) and an increase in industry output (to y^v) and in industry emissions. Note that, although the individual firm produces less under the subsidy than it would under *either* the tax or in the absence of any program, the industry output under the subsidy (y^v) exceeds both y^t and y^c; thus, the entry of new firms more than offsets the reduction in emissions by the individual firm.

More specifically, if waste emissions are a fixed and rising function of the volume of industry output (no abatement technology available), Figures 14.1a and 14.1b suggest the disturbing conclusion that, although a subsidy program may reduce the emissions of each firm by itself, the subsidies, far from yielding a reduction in total industry emissions like a pollution tax, may, in fact, increase emissions from their unregulated level! It is easy to show that this paradox *must* result if emissions increase with output, and if the slopes of the industry supply and demand curves are respectively positive and negative, as we normally assume. For, on the premise that the subsidy program as described by (1) never involves a negative subsidy payment (that is, a payment by the firm to the government), some reduction in average cost to the industry must result. Hence, with a subsidy, the long-run competitive supply curve must shift downward and so, with a negatively sloping demand curve, equilibrium output *and pollution* must be increased above the levels they would have reached in the absence of government intervention. In sum:

[18] If emissions are strictly proportionate to output, so that we may write s [illegible] this result is trivial if the average curve has a single minimum and a continuous [illegible] For if $g(y)$ represents the firm's average cost in the absence of a tax or [illegible], with minimum point given by $dg(y)/dy=0$, at that point the slope of the average cost curve with subsidy is

$$d[g(y)-vb(y^*-y)/y]/dy = dg(y)dy - d[vby^*/y]/dy = vby^*/y^2 > 0,$$

so that the average cost minimizing output in the absence of subsidy must be greater than that under subsidy.

Proposition Two. In a competitive industry, where polluting emissions are a fixed and rising function of the level of industry output, equal tax and subsidy rates will normally *not* lead to the same output levels or to the same reductions in total industry emissions. Other things being equal, the subsidy will yield an output and emission level not only greater than those that would occur under the tax, but greater even than they would be in the absence of either tax or subsidy.[19]

As already noted, the explanation of our paradox is straightforward. The subsidy does indeed reduce the level of emissions per firm. But it necessarily attracts into the industry enough additional firms to offset this reduction and more. Thus, we can hardly expect the effect of the subsidy on the decision of the firm to continue or discontinue operations to be an insignificant matter.

A further examination of the case in which emissions depend exclusively on output can sharpen these results and offer some additional insights. Let us simplify still further by assuming emissions to be strictly proportionate to output. Then we may write $s = by$ (b some constant) as the emissions-output relation and let

$s^* =$ the base pollution level for calculation of the subsidy,

$y^* =$ the corresponding output level where $s^* = by^*$,

$s^v =$ the emissions of the representative firm after imposition of subsidy rate, v, per unit of emissions, and

$y^v =$ the output of the representative firm under a subsidy program with a pollution benchmark, s^*, and a subsidy rate $v = t$ per unit of reductions in emissions, $s^v = by^v$.

With subsidy rate v, the total subsidy payment to the representative firm must be

$$v(by^* - by^v)$$

so that the subsidy per unit of output will be

$$vb(y^* - y^v)/y^v = vb[(y^*/y^v) - 1]. \tag{5}$$

This will be positive if, and only if, $y^* > y^v$ (that is, so long as the benchmark emission level at which zero subsidy is paid is set higher than the firm's level of emissions under the subsidy program). Thus, so long as $y^* > y^v$, the subsidy program must produce a uniform downward shift in the industry supply curve by the amount indicated by (5), though one that is not generally equal to the upward shift that results from a tax program. This, incidentally, points up the importance of the value of the second parameter in a subsidy program: the benchmark pollution level (s^*). The larger s^*, the more the industry supply curve shifts down and the larger will be the industry's output (and emissions). This is in contrast to our earlier conceptual subsidy that was made equivalent to a tax by paying the subsidy to all "potential" polluters; there, the benchmark pollution level had no direct effect on the industry supply curve.

[19] We note that our proof of this proposition employs a partial-equilibrium framework. Mestelman has shown that in a general-equilibrium setting, it is possible that a subsidy will not result in an increase in industry output and emissions. This result, although presumably unlikely, could occur in response to relative factor price adjustments within a general-equilibrium system. See S. Mestelman, "Production Externalities and Corrective Subsidies: A General Equilibrium Analysis," *Journal of Environmental Economics and Management* IX (June, 1982), 186–93.

Now from (5), we can immediately derive a second paradoxical conclusion:

Proposition Three. If emissions rise monotonically with industry output, the more effective the subsidy program is in inducing the individual firm to reduce its emissions, the larger is the *increase* in total industry emissions that can be expected to result from the subsidy.

This follows at once, for the smaller the value of y^v relative to y^*, the larger will be the unit subsidy payment (5) and so the larger will be the resulting downward shift in the industry supply curve. In other words, the more effective the subsidy program is in inducing the desired behavior on the part of the individual firm, the worse for society the corresponding subsidy program will be![20]

To summarize, we see that in a competitive industry the consequences of a given tax and subsidy rate are far from similar; a subsidy intended to curb pollution may produce exactly the opposite outcome by inducing increases in total emissions. Note also that the problem need not be limited to competitive industries. Under oligopoly, for example, a subsidy

[20] A moment's thought shows that this proposition must hold where the output emissions function for the industry takes the more general form $g = G(y)$ where $G' > 0$. The result is in no way dependent on our simplifying proportionality premise $s = by$. It does, however, depend upon our assumption that there is no pollution-abatement technology so that the firm is unable to reduce emissions per unit of output. We will relax this condition in the next section.

One way to get around the difficulty of Proposition Three is to reduce the unit subsidy with the number of firms so that, with n firms in operation, the individual firm will receive $(v^*/n)(s^* - s^r)$ instead of $v(s^* - s^r)$ where v^* is a constant. There would appear to be serious practical difficulties to such a variable-subsidy arrangement. In any event, it does not help in the more fundamental difficulty described in Proposition Two: for any positive subsidy payment must, in the conditions we are discussing, increase rather than decrease the pollution emissions of a competitive industry.

program may induce the entry of new firms or the opening of additional plants that can produce precisely the same sort of result.[21]

4 Industry equilibrium with abatement technology

As was shown in Chapter 4, appropriate taxes will always lead to optimal industry outputs even when the emissions of the firm depend not only on its outputs but also on the resources it devotes to their abatement. However, we have seen in Section 6 of Chapter 7 that, where emissions depend on the levels of both of these types of activities by the firm, the level of the polluting output may very well be *increased* by the imposition of a tax simply because the corresponding Pareto-optimal level of that output is greater than it would be in a competitive market equilibrium. Indeed, if several industries produce the pollutant or if the community has several different pollutants to contend with, the optimal tax may conceivably result in an increase in the industry's emissions of the pollutant.

However, such anomalies generally arise only in cases that violate the concavity-convexity conditions that are usually assumed to hold. The issue before us here, rather, is the effect in the "normal case" of a tax or a subsidy upon outputs and emissions of the industry in long-run equilibrium, when abatement techniques (whose effectiveness can be increased by increased abatement expenditures) are available.

We will prove the following result:[22]

Proposition Four. Under "normal" concavity-convexity conditions, where the competitive industry adjusts both outputs and abatement outlays and all inputs are purchased on competitive markets so that cost functions are fixed, then a marginal addition to a tax on emissions will always reduce the total industry output of the pollution-generating commodity and reduce total industry emissions, On the other hand, a marginal addition to a subsidy for reduction of emissions will increase output of the commodity in question, but its effect on total industry emissions cannot in general be predicted from the maximization conditions, and may go in either direction.

To derive this result, we use the same basic notation as before in writing our subsidy-profit relationships. Abatement outlays will be dealt with

[21] We are grateful to Lionel Robbins for this observation.

[22] We are deeply indebted to Eytan Sheshinski, who provided the following proofs and to Peter Coughlin for his helpful comments. We must also thank Michael Braulke and Alfred Endres, "On the Economics of Effluent Charges," *Canadian Journal of Economics* VIII (November 1985), 891–4, for pointing out some errors in our earlier formulation in the first edition of this book.

only implicitly, taking them to be a function, $a=G(y,s)$, of output, y, and emissions, s, with $G_y>0$ and $G_s<0$ (i.e., if emissions are to be held constant, more money must be spent on abatement as output increases, etc.).

We use the same expression, $v(s^*-s)$, to represent both the subsidy and the tax payment, where v is the subsidy (tax) rate and s^* is the base from which reduced emissions are calculated. Thus, if $s^*>s$, the expression represents a subsidy payment, but if $s^*=0$, it becomes an emissions tax payment of vs.

We must begin the proof of the proposition by deriving some results about the behavior of the representative firm. Then we will turn in succession to an examination of $\partial y/\partial v$ and $\partial s/\partial v$, where y and s are the output and emissions rate of the representative firm. Finally, we will examine the effect of a rise in v on industry output and emissions, $\partial ny/\partial v$ and $\partial ns/\partial v$, where n is the number of firms in the industry.

We may now express the firm's cost function as the result of its selection of an emissions level that minimizes its total cost, given the level of its output. Thus, letting C and c, respectively, be the firm's cost function with and without the subsidy (tax), we have

$$C(y,v)=\mathrm{Min}[c(y,s)-v(s^*-s)].$$

This immediately yields the maximum conditions

$$c_s+v=0, \qquad c_{ss}>0. \tag{6}$$

$c_{ss}\,ds + c_{ys}\,dy = 0$

Using the usual comparative statics approach to determine the effects of a change in v and the interrelations of the other variables in equilibrium, we differentiate the equation in (6) totally with respect to y and s, and then, in turn, with respect to s and v and set the total differentials equal to zero to obtain

$$\frac{\partial s}{\partial y}=-\frac{c_{ys}}{c_{ss}}, \qquad \frac{\partial s}{\partial v}=-\frac{1}{c_{ss}}<0 \tag{7}$$

and, by (6), (7), and the second-order conditions

c_y

$$C_y=c_y+\underbrace{(c_s+v)}_{=0}\frac{\partial s}{\partial y}=c_y$$

$$C_{yy}=c_{yy}+c_{ys}\frac{\partial s}{\partial y}=\frac{c_{yy}c_{ss}-c_{ys}^2}{c_{ss}}>0 \tag{8}$$

which imply, by (7), that

$$D=c_{yy}c_{ss}-c_{ys}^2>0. \tag{9}$$

We turn next to long-run competitive equilibrium with the zero profit condition for the firm

$$yp(ny)-C(y,v)=0. \tag{10}$$

Because in competitive equilibrium the firm selects its output to maximize its total profit at the (fixed) equilibrium price, we obtain, differentiating (10) with respect to y,

$p' \cdot dy -$

$$p(ny)-C_y(y,v)=0. \tag{11}$$

?

Again taking total differentials of the first-order conditions in equilibrium conditions (10) and (11) in the standard comparative statics procedures, we obtain

$$\begin{bmatrix} nyp' & y^2p' \\ np'-C_{yy} & yp' \end{bmatrix}\begin{bmatrix} dy \\ dn \end{bmatrix}=\begin{bmatrix} C_v \\ C_{yv} \end{bmatrix}dv \tag{12}$$

where the determinant of the system, Δ, satisfies

$$\Delta=y^2p'C_{yy}<0$$

by the second-order conditions. Next, solving (12) as a pair of linear equations in dy, dn, and dv, we get

$$\frac{dy}{dv}=\frac{1}{\Delta}[yp'C_v-y^2p'C_{yv}]=\frac{1}{yC_{yy}}[C_v-yC_{yv}]. \tag{13}$$

From the definition of $C(\cdot)$ and (6), we obtain

$$C_v=-(s^*-s)+(c_s+v)\frac{\partial s}{\partial v}=-(s^*-s)<0 \tag{14}$$

and, by (14) and (7),

$$C_{yv}=\frac{\partial s}{\partial y}=-\frac{c_{ys}}{c_{ss}}.$$

Substituting the two preceding expressions into (13) gives

$$\frac{dy}{dv}=\frac{1}{yC_{yy}}\left[s-s^*+y\frac{c_{ys}}{c_{ss}}\right]=\frac{1}{yD}((s-s^*)c_{ss}+yc_{ys}), \tag{15}$$

where by (8) and (9) $D=C_{yy}c_{ss}$. From (12), we also obtain

$$\begin{aligned}\frac{dn}{dv}&=\frac{np'}{y^2p'C_{yy}}[C_{yv}y-C_v]+\frac{C_vC_{yy}}{y^2p'C_{yy}}\\&=-\frac{n}{y^2C_{yy}}\left[\frac{c_{ys}}{c_{ss}}y+s-s^*\right]+\frac{s-s^*}{y^2p'}\\&=-\frac{n}{y^2D}(c_{ys}y+(s-s^*)c_{ss})+\frac{s-s^*}{y^2p'}.\end{aligned} \tag{16}$$

Then we obtain the effect upon industry output, ny, from (15) and (16) as

$$\begin{aligned}\frac{dny}{dv}&=n\frac{dy}{dv}+y\frac{dn}{dv}\\&=\frac{s-s^*}{yp'}>0 \quad \text{if } s^*-s>0, \text{ so that } v(s^*-s) \text{ is a subsidy;}\\&\qquad\quad <0 \quad \text{if } s^*=0, \text{ so that } v(s^*-s)=-vs, \text{ an emissions tax.}\end{aligned}$$

To determine the effect upon emissions, we get, by (7),

$$\frac{ds}{dv}=\frac{\partial s}{\partial y}\frac{dy}{dv}+\frac{\partial s}{\partial v}=-\frac{c_{ys}}{c_{ss}}\frac{dy}{dv}-\frac{1}{c_{ss}},$$

which, by (15),

$$=-\frac{1}{c_{ss}}\left[c_{ys}\frac{1}{yD}((s-s^*)c_{ss}+yc_{ys})+1\right],$$

which, by the definition of D in (9),

$$=-\frac{1}{yD}((s-s^*)c_{ys}+yc_{yy}).$$

Finally, we determine the effect of a change in v on the industry's total emissions, ns:

$$\begin{aligned}\frac{dns}{dv}&=n\frac{ds}{dv}+s\frac{dn}{dv}\\&=-\frac{n}{yD}((s-s^*)c_{ys}+yc_{yy})-\frac{ns}{y^2D}(c_{ys}y+(s-s^*)c_{ss})+\frac{s(s-s^*)}{y^2p'}\\&=-\frac{n}{y^2D}[y(s-s^*)c_{ys}+y^2c_{yy}+ysc_{ys}+s(s-s^*)c_{ss}]+\frac{s(s-s^*)}{y^2p'}\\&=-\frac{n}{y^2D}[2y(s-s^*)c_{ys}+y^2c_{yy}+(s-s^*)^2c_{ss}]\\&\quad-\frac{s^*n}{y^2D}(yc_{ys}+(s-s^*)c_{ss})+\frac{s(s-s^*)}{y^2p'}.\end{aligned} \tag{17}$$

Now it is readily shown that the first term in (17) is negative, because the bracketed quadratic form

$$\begin{aligned}&y^2c_{yy}+2y(s-s^*)c_{ys}+(s-s^*)^2c_{ss}\\&=c_{ss}\left((s-s^*)+\frac{c_{ys}}{c_{ss}}y\right)^2+\left(\frac{c_{ss}c_{yy}-c_{ys}^2}{c_{ss}}\right)y^2>0 \quad \text{by (8).}\end{aligned}$$

We see at once that

$$\frac{dns}{dv} < 0 \quad \text{if } s^* = 0, \text{ the emissions tax case,}$$

but that its sign is indeterminate if $s^* > 0$ and $s^* - s > 0$, the subsidy case, because then the last term in (17) must be positive.[23] Q.E.D.

5 Uniqueness of the tax solution for Pareto optimality

The argument that a subsidy is not usually an adequate substitute for a tax, because the former will generally not satisfy the conditions for a Pareto optimum, may at first leave the reader uncomfortable because of the nonuniqueness of the Paretian solution that is inherent in the concept. We know that there will usually be a substantial set of Pareto optima with each optimum corresponding to a different distribution of benefits among the affected parties. Must it not be true then that one can get from one such solution to another with a suitable redistribution (that is, with different combinations of unit taxes and subsidies of the activities of the affected parties)? Will not all such tax and subsidy programs be Pareto-optimal?

There is an element of validity to this argument. Either by changes in the initial income distribution or through *lump-sum* taxes or subsidies, one can get from one of the optimal solutions to any other. But *any* Pareto optimum achieved in this manner must always end up satisfying the necessary optimality conditions derived in Chapter 4. If those necessary conditions call for a tax per unit of output, then a per-unit subsidy on just that item simply will not do; it will generally prevent the attainment of optimality. That is, of course, the nature of a necessary condition.

That the move from one Pareto optimum to another will not change the Pigouvian taxes into subsidies follows immediately from one highly plausible assumption: that the change from one optimum to another does not transform any activity from a generator of external benefits into one that yields detrimental externalities, or *vice versa*. The product whose manufacture yields noxious fumes does not begin to emit Arpege. Our result follows at once, for we have demonstrated in Chapter 4 that optimality always requires taxation of activities that produce detrimental externalities and subsidization of those that yield external benefits in accord with the standard Pigouvian formula.

23 To show that the sign is indeterminate, it is necessary, strictly speaking, to provide consistent examples that go both ways. To avoid further lengthening of the argument, we have made no attempt to do so.

Similarly, if the victims of a detrimental externality continue to suffer from it when one shifts from one optimum to another, but in both cases generate no externalities themselves, they will be required in both cases to receive zero compensation for the damage they suffer (neglecting lump-sum payments). Thus, a shift between Pareto optima can*not* introduce compensation of the victims of externalities.

In sum, we have

Proposition Five. If every activity that yields detrimental externalities in one Pareto optimal solution also does so in some other solution, both solutions will call for Pigouvian taxation of these activities. Moreover, there will always be zero compensation and zero taxation of the victims of the externality. The analogous proposition (with unit subsidies instead of taxes) applies to external benefits.

However, as we will see now, for any particular Pareto optimum, there is a formal sense in which a complex system of subsidies can generally be substituted for a simple Pigouvian tax. For the choice of unit of account does offer a degree of freedom in the selection of the price, tax, and subsidy values called for by the solution in Chapter 4. It is easy to show that the solution summarized in Table 1 of Chapter 4 is unique except for the factor of proportionality permitted by our price normalization convention.[24]

This is, of course, what we would expect: For a particular competitive equilibrium, *relative* prices will be determined uniquely, with taxes serving as prices for the generation of externalities. Thus, we can multiply all prices, taxes, and subsidies by the same constant, call it $(1-k)$, without violating the optimality requirements. Now it is true that in a formal sense, by using some appropriate value of k, we do get a system in which taxes and subsidies replace one another.

As an illustration, assume for simplicity that any increase in taxes produces an equal increase in price and that, as in Chapter 4, only commodity 1 produces externalities, requiring the imposition on that good alone of a tax at rate t. Then the price of that item is changed from p_1 to (p_1+t_1).

Now, if all prices and taxes are reduced by the factor $(1-k)$ this becomes

$$(1-k)(p_1+t_1) = p_1 + [t_1 - k(p_1+t_1)] = p_1 + t_1^* \tag{18}$$

24 Recall the condition $p_{i^*} = \omega_{i^*}$ (9) of Chapter 4, where ω_{i^*} is the Lagrange multiplier corresponding to the labor constraint. This condition may be interpreted as setting the price of labor (leisure) equal to the marginal utility derivable by consumers from a unit addition to society's labor supply. Comparison of optimality relationships (3°)–(5°) of Chapter 4 with market equilibrium conditions (3^c)–(5^c) indicates immediately that all optimal prices and taxes can simply be multiplied by the same factor, q.

which is tantamount to the original price plus a subsidy t_1^*, if $t_1^* < 0$, that is, if

$$t_1^* = t_1 - k(p_1 + t_1) < 0 \quad \text{or} \quad 1 > k > t_1/(p_1 + t_1) > 0. \tag{19}$$

However, any other good, $i \neq 1$, that was previously untaxed will now have its price changed from p_i to

$$p_i(1-k) = p_i - kp_i = p_i + t_i^*, \quad t_i^* = -kp_i < 0. \tag{20}$$

Thus, for k sufficiently large to satisfy (19) (that is, to permit a subsidy to the production of commodity 1), (20) must represent a set of universal subsidies that together with (18) will yield exactly the same Pareto optimum as the simple Pigouvian tax, t_1, on commodity 1 alone. Of course, the subsidy option is extremely cumbersome because it requires one subsidy value to be determined for each activity in the economy in place of the one tax on the externality-generating output. Nevertheless, it is true that

Proposition Six. If the necessary conditions for any specific Pareto optimum can be satisfied by a set of Pigouvian taxes, it is generally possible to satisfy those conditions also with a subsidy to the externality-generating activity, counterbalanced by subsidies to other activities. However this substitution, in effect, amounts only to a variation in the unit of account that leaves all relative prices and taxes unchanged.[25]

Of course, this sort of substitution can hardly be considered a practical proposal, and it certainly is not what the advocates of subsidy proposals have in mind. Yet it is perhaps useful to recognize to what (very limited) extent there is, theoretically, a choice in the matter.

6 Subsidies to polluters and compensation of victims: an important qualification

In Chapter 4, we found that in a competitive setting, a Pigouvian tax on polluters with no compensation to victims can correct the allocative distortions resulting from a detrimental externality. Subsidies, as we have seen in this chapter, are not, in general, a satisfactory substitute for taxes; they can themselves be a source of excessive entry with consequent resource misallocation. Similarly, compensation of victims can distort choices involving defensive activities by such victims to reduce the damages they

[25] In reality, this is complicated by cash balance effects, fixed contractual relations, and so on, which makes it extremely difficult to institute a pure change in the unit of account, particularly through a clumsy system of universal subsidies that must vary from commodity to commodity by just the right amount after allowance for differences in shifting.

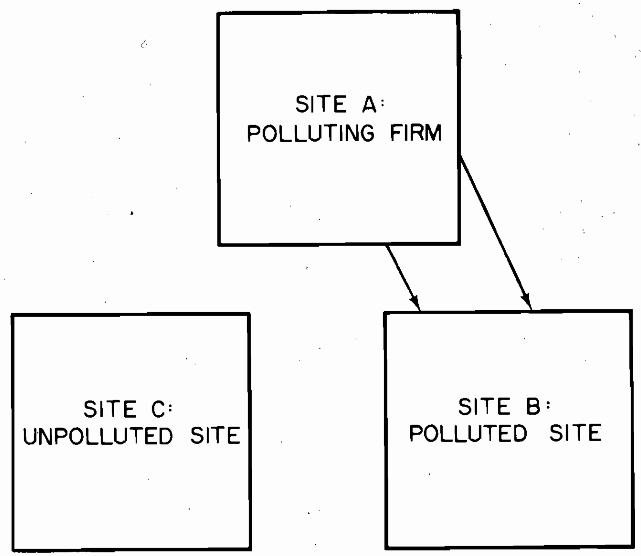

Figure 14.2

suffer. Subsidies to polluters and compensation of victims are both suspect measures.

However, Martin J. Bailey has recently shown that there is an important class of cases in which subsidies and compensation will not introduce inefficiencies.[26] The Bailey case involves the capitalization of any benefits or damages into site rents. In such instances of capitalization, subsidies and/or compensation have no direct effects on individual decisions (including the entry-exit choice). This is so because, if the supply of land is fixed, a tax upon pure rents (or a subsidy to them) is, in effect, just a lump-sum transfer.[27]

The Bailey argument is straightforward and is easily understood in terms of a simple example. Consider Figure 14.2, which depicts the configuration of sites and the flow of pollution for our illustrative case. We assume that a polluting firm is located at site A from which the prevailing

[26] "Externalities, Rents, and Optimal Rules," *Sloan Working Paper in Urban Public Economics 16–82* (University of Maryland, College Park, Md., 1982).

[27] Robert Dorfman made this point some years ago in conversation with one of us. See also D. M. G. Newberry, "Externalities: The Theory of Environmental Policy," in G. Hughes and G. Heal, Eds., *Public Policy and the Tax System* (London: Allen & Unwin, 1980), p. 132.

Table 14.1. *Maximum annual rents bid by competing tenant firms*[a]

Potential firms	(1) Site *C* (no pollution)	(2) Site *B* (no compensation)	(3) Site *B* (uniform compensation to tenants)	(4) Site *B* (firm-specific compensation)
X	60	60	80	60
Y	100	70	90	100
Z	90	80	100	90

[a]This table comes from Bailey, "Externalities, Rents, and Optimal Rules," p. 8.

winds transport its smoke emissions to site *B*. Site *B* is thus polluted, but site *C* is unpolluted. Assume initially that the polluting firm is subject to the appropriate Pigouvian tax so that it is emitting the socially optimal quantity of smoke. Firms from three different competitive industries, *X*, *Y*, and *Z*, compete for sites *B* and *C* on which to locate their plants. Firms in industry *X* suffer no damage from the pollution; in contrast, those in industries *Y* and *Z* experience damage in the form of higher costs of operation, and this will be reflected in their relative bids for the two sites.

Table 14.1 describes the competitive bids (in terms of annual rents) by the three types of firms. We assume here that for all firms, sites *B* and *C* would be equivalent were *B* unpolluted. Column (1) indicates the bids for site *C*, the unpolluted site. A firm from industry *Y* will obviously occupy site *C*; this is as it should be since the productive value of the site is, in this way, maximized. The figures in column (2) reveal the extent of the potential smoke damages to each type of firm. Firms from industry *X* suffer no damage from the smoke, *Y*-firms suffer damages of 30, and *A*-firms incur damages of 10. These figures, incidentally, must be understood to reflect the damages after the victims have undertaken the optimal level of defensive activities; as we saw in Chapter 4, optimal levels of defensive measures will result from standard profit-maximizing (or utility-maximizing) behavior. From column (2), we see that a firm from industry *Z* will make the highest rental bid, namely 80, and will occupy site *B* in the absence of any compensation.

The discussion thus far makes one important point. The real victim of the pollution is not the tenant firm – it is the owner of site *B*. Potential tenants reduce the level of their rental bids by the amount of the damages that they absorb. So it is the owner of site *B* who is the damaged party.

If there were to be direct compensation for damages, it should consist of a payment of 20 to the owner of site *B*.

Suppose, however, that compensation is rendered, not to the landowner, but to the tenant firm. The proper payment would be a sum of 20 paid to the tenant, where this payment is independent of the particular identity of the tenant or his behavior. Note that such a payment is effectively a lump-sum transfer to the tenant on site *B*. As indicated in column (3) of Table 14.1, competitive forces will, in response to such a payment, induce all potential tenant firms to raise their bids for site *B* by 20. So compensation, in the end, is effectively channeled to the owner of *B*, irrespective of whether the compensation is rendered directly or is routed through the tenant firm. Note that in either case, a firm from industry *Z* will make the highest bid and become the occupant of site *B*. This is the efficient outcome because it maximizes the productive value of the site. We thus find that with the capitalization of benefits and costs into site rents, compensation (of the appropriate form) is consistent with efficient resource use. Such compensation payments have no direct effects on allocative outcomes.

There is, however, a perverse form of compensation that can be the source of distortions. Suppose that instead of a lump-sum payment of 20 to the tenant (whoever it is), compensation is firm-specific. In this instance, each potential tenant understands that he will receive full compensation for whatever smoke damages he suffers. In this case, the *ordering* of bids will be influenced by compensation, as is indicated in column (4) of Table 14.1. A firm from industry *Y* will now be the highest bidder, with an inefficient pattern of economic activity as the consequence. The problem here is essentially that which we discussed in Chapters 3 and 4. The payment of compensation induces the victim to ignore the proper pricing signals. But if compensation is provided correctly, it need not cause misallocations, even if it is paid to the tenant instead of the landowner.

We turn next to the treatment of the polluting firm at site *A*. Once again suppose that there are a number of competitive firms seeking the use of this site. We have shown in Chapter 4 that a Pigouvian fee equal to marginal social damage will lead to an optimal outcome. In the presence of such a fee, firms will adjust their bids for site *A* to equal the productive value of the site minus the payment of the tax. Thus, these bids will properly reflect the value of the site net of any damages from a potential tenant's smoke emissions. Suppose, however, that the environmental authority adopts a unit subsidy for abatement rather than a Pigouvian tax. We have seen earlier in this chapter that such a subsidy is formally equivalent to a unit tax plus a lump-sum subsidy [equal to vs^* in Equation (1)].

Without working through another numerical example (see Bailey on this), it is not hard to see that the bids of potential tenants will differ from their bids under the tax scheme by precisely the amount of this lump-sum element. All prospective tenants will thus raise their bids by vs^* (relative to the Pigouvian tax), so the high bidder under the subsidy program will coincide with the high bidder under the tax regime. We thus find that the substitution of the subsidy program will have direct allocative effects that are no different from the tax scheme.[28] Note also that, like compensation, the subsidy payment under competitive conditions will accrue, in the end, not to the tenant but to the landowner. Because this does not affect the supply of the input, the payment is, once again, lump sum.

7 Concluding comment

This chapter has shown that, although there is some degree of symmetry in the effects of taxes and subsidies on the generation of externalities, the two are far from perfect substitutes. Since the opportunity cost of the failure to collect a subsidy payment is the same at the margin as a tax of equal magnitude, the effects of the two upon behavior bear some resemblance. Yet we have found that in equilibrium they can lead to striking differences in the behavioral patterns of firms and their industry. For example, we examined one pertinent model – that of perfect competition with a fixed ratio of emissions to outputs – in which the following somewhat paradoxical results emerged: (1) An emissions tax does *not* reduce the emissions of the individual firm. (2) An abatement subsidy does reduce the firm's emissions. (3) The tax reduces the aggregate emissions of the industry. (4) The subsidy increases the industry's emissions.

Only in the case analyzed by Martin J. Bailey, in which subsidies constitute solely a contribution to pure economic rent, do subsidies produce the same results as a set of optimal taxes, and then, incidentally, compensation of the victims of externalities is likewise not a source of inefficiency. We note in conclusion that the Bailey case – that in which the detrimental effects of externalities affect only particular sites – may be an extremely important one in practice.

[28] As is clear from the discussion, this assumes that all prospective tenants are assigned the same s^*. Otherwise, the lump-sum element would vary among potential tenants.

CHAPTER 15

Environmental protection and the distribution of income

At least from a reading of the newspapers, one gets the impression that environmental policies are an issue in which income class plays a significant role. The poor and the wealthy seem to assign different degrees of priority to environmental protection: the proposed construction of an oil refinery is likely to produce anguished cries from middle- and upper-income inhabitants of a potential site and yet be welcomed as a source of more remunerative jobs by residents whose earnings are low. Similarly, proposals to ban DDT have been received with somewhat less enthusiasm in underdeveloped countries than they have encountered in the wealthier nations. This should, of course, come as little surprise to an economist. Assuming environmental quality to be a normal good, we would expect that wealthier individuals would want to "buy" more of it.

In addition to these differences in the demand for environmental quality, distributive elements also enter when we consider how the costs of a policy of environmental protection are likely to be distributed among individuals with differing incomes. To reach firm conclusions on so broad a subject is difficult, because the methods that are used to finance such policies vary widely. Nevertheless, by making some reasonable assumptions and exploring the available evidence, environmental economists have made some estimates of the incidence of these costs.

Obviously, the distributive side of externalities policy is of interest in and of itself in a world in which inequality and poverty have assumed high priority among social issues. In addition, without adequate consideration of this aspect of the matter, we may not be able to design policies that can obtain the support they require for adoption. Thus, by ignoring the redistributive effects of an environmental policy, we may either unintentionally harm certain groups in society or, alternatively, undermine the program politically.

In the first section of this chapter, we consider the relation between Pareto optimality and equity in environmental programs. In particular, we will present a theorem that shows that, under certain conditions *all* users of common-property resources who impose external costs upon one another may actually be made worse off by the introduction of the Pareto-optimal tax! This suggests a possible source of conflict between objectives in the design of environmental measures.

In the next two sections, we construct two polar models describing the consumption of environmental quality; with these, we explore the extent to which individuals with differing incomes will succeed in obtaining their desired level of consumption of environmental services. From this background, we then use these models along with some statistical evidence to examine the incidence, first, of the benefits of environmental programs, and, second, of their costs.

The results suggest that strong measures to improve environmental quality may indeed have a very uneven pattern of incidence, particularly during the period of adjustment to a new composition of output and employment. Moreover, the evidence suggests that we can typically expect a somewhat regressive pattern of distribution of the benefits and costs from environmental programs; we find some basis for the contention that environmental concern "is not the poor man's game."

Yet, because there is strong evidence that health and longevity are affected substantially by pollution and by other types of environmental damage, we continue to believe that the interests of society, including those of its less-affluent members, require a relatively efficient environmental program even taking account of its distributive consequences. But the pious hope that the "distributive branch" of the fiscal authority can be trusted to compensate for the regressive effects of environmental programs carries little conviction. This suggests that programs to improve the quality of the environment should incorporate provisions specifically designed to help offset any distributive consequences; we discuss some provisions of this kind in the concluding section.

1 Efficiency and equity in the provision of environmental quality

The efficiency conditions we have derived in earlier chapters of this book are all founded on the criterion of Pareto optimality. That is, in each case, we determined a state, or set of conditions, necessary for maximization of the welfare of any one individual, selected arbitrarily, without reducing the level of welfare (also selected arbitrarily) of any other member of the community. This may appear to avoid entirely the issue of income distribution, for if the proposal harms no one, it would seem, almost by definition, to be unobjectionable to everyone.

The matter can be put another way. It is tempting to argue that, whatever the distribution of income that is desired or with which one starts, an allocation of resources that is not Pareto-optimal must be unsatisfactory. For, given any such allocation, there must exist some reshuffling of resources that benefits some individuals and harms no one. This *is* true by definition, for if no such alternative were available, the initial allocation would have satisfied the conditions of Pareto optimality. It is all too easy to conclude from this that it is irrational to oppose a policy measure necessary or, perhaps, sufficient for the achievement of Pareto optimality, for with a supplementary program capable of achieving whatever distribution is desired, the policy maker can always increase social welfare by combining the socially desired distributive measure with one that achieves a Pareto-optimal allocation of resources.

Although all this is unimpeachable at a formal level, the difficulty of implementing such policy packages in practice is well-known. Nevertheless, it is often ignored by economists who advocate concrete policies derived directly from welfare theory. This section offers a specific example that illustrates dramatically how dangerous it can be to disregard the redistributive consequences of environmental policies.

In general terms, the issue is a simple one. Given any initial resource allocation, *A*, that is not Pareto-optimal, it is of course true that there must exist at least one other allocation, say *B*, that leaves everyone unharmed in comparison with *A* and makes some individuals better off. But now select randomly some other Pareto-optimal allocation, *C*. There is no way of knowing from this whether or not some persons will be harmed by the move from the nonoptimal point, *A*, to the optimal point, *C*. The distinction here is between a *state* of Pareto optimality and a *move* that can be described as a *Paretian improvement*. Any point on the utility-possibilities frontier obviously represents a Pareto-optimal state; no one can increase his level of welfare without reducing that of someone else. However, a *move* from some position in the interior of utility-possibilities space to a point on the frontier may not itself be Pareto optimal, for it can make someone worse off. Thus, somewhat paradoxically, a *move* to a *state* of Pareto optimality may not itself be a Paretian improvement.

Martin Weitzman and Uwe Reinhardt have independently constructed striking examples of this point with direct implications for environmental policies.[1] We describe Reinhardt's simpler, but less-formal, analysis because it is easier to follow and its rigor is sufficient for our purposes.

A standard illustration of the effects of externalities is road crowding. An additional car that enters an overcrowded highway adds to the congestion and imposes a time loss on everyone else. The driver's entry thus generates a marginal social cost that exceeds the marginal private costs.

[1] M. Weitzman, "Free Access vs. Private Ownership as Alternative Systems for Managing Common Property," *Journal of Economic Theory* VIII (June, 1974), 225–34; U. Reinhardt, "Efficiency Tolls and the Problem of Equity" (Working Draft, 1973).

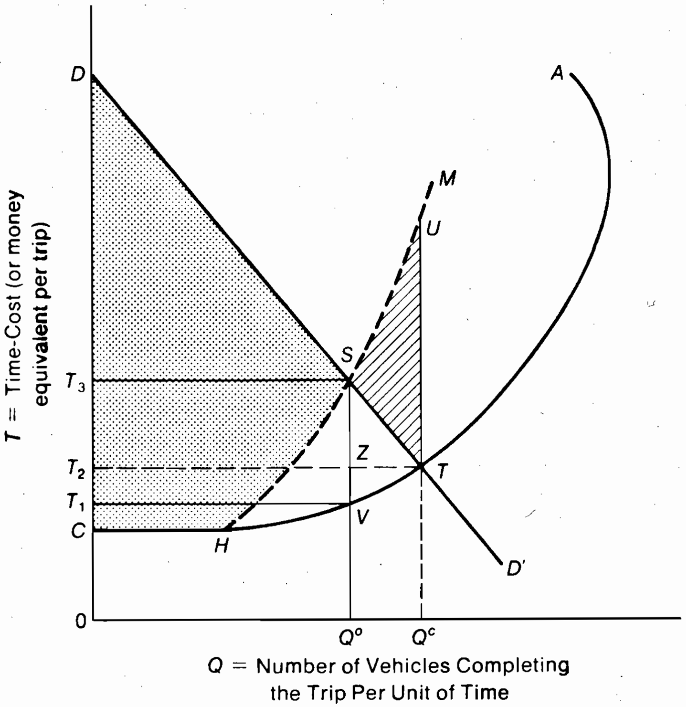

Figure 15.1

In this case, every driver is both a generator of these externalities and a victim of the same externalities produced by other drivers. The drivers constitute a self-contained group engaged in inefficient levels of driving activity. In accord with the conclusions of Chapter 4, optimality requires the imposition upon each driver of a toll equal to the marginal social damage resulting from his presence, *with no compensation to him for the damage he suffers from the presence of others.*

So far there is nothing new in our discussion. But the novel and rather startling observation offered by Weitzman and Reinhardt is that this optimal Pigouvian tax, far from benefiting some drivers without harming anyone, may, on the contrary, result in a loss in welfare to each and every one of the road users.

The proof is easily provided with the aid of a supply-demand diagram, Figure 15.1. For simplicity, we assume that there is a fixed rate of exchange between time spent on the journey and money. That is, we take

one hour to be worth some specified number of dollars to all individuals.[2] We deal with the demand for and cost of travel along some specified stretch of road. *DD'* is the analogue of the ordinary market demand curve that we interpret, subject to the usual qualifications, as an approximation to a curve of marginal social benefits.

Curve *CA* indicates the money value of the amount of time spent per vehicle on the journey (that is, it is a curve of average social time cost per vehicle trip).[3] We asume that *CA* is increasing over some range, which simply implies that the presence of additional vehicles can slow traffic.

The curve labelled *CHM* is the marginal social cost of an additional vehicle.[4] The net benefit to this group of drivers is given by the area between the marginal social cost curve, *CHM*, and the marginal benefit (demand) curve, *DD'*. This is at a maximum (dotted area) at traffic volume OQ^o. However, left to itself, traffic will settle at the "competitive" level, OQ^c, at which the demand curve crosses the average cost curve. This must be so because, at any smaller volume of traffic, marginal private benefit exceeds marginal private cost so that traffic will expand (and conversely). Relative to the optimal level of usage, OQ^o, the competitive level, OQ^c, involves a net loss to the drivers equal to the cross-hatched area, *STU*.

Our theory tells us that society can eliminate this loss by imposing a road tax, T_1T_3 equal to *VS*, the marginal social damage at the optimal level of usage, OQ^o. However, it is easy to see that this must leave every driver worse off. For as compared with the unregulated usage, the individual saves T_1T_2 in time-cost per trip, but for this saving he pays the

[2] For a notion of time-price that is justified more rigorously, see Gary Becker, "A Theory of the Allocation of Time," *Economic Journal* LXXV (September, 1965), 493-517. Becker's treatment is much more complex than ours: time-price varies from individual to individual according to each person's opportunity cost. We assume here that the cost of time is the same for everyone. Weitzman's approach, incidentally, does not require this simplification.

[3] The shape of *CA* may require a bit of comment. It is horizontal over the stretch *CH*, which indicates that up to some level of utilization, the road is completely uncongested so that additional vehicles do not slow anyone down. The later backward bend in the curve represents a phenomenon that has been substantiated empirically: after some point, a further increase in the number of vehicles attempting to enter the road increases the time-costs so severely that the number of vehicles able to traverse it in a given period of time is actually reduced. The analysis, however, does not depend in any way on the two properties of the average cost curve discussed in this note; it requires only that the marginal costs of congestion be increasing at least over some range.

[4] Note that *CA*, not *CM*, is the curve of marginal *private* costs. Consider an individual traversing the stretch of road we are examining. If traffic is at level OQ^o, the individual who embarks on the road can anticipate a time-cost for his journey of Q^oV. That is, if the total time-cost of his day's activities would otherwise be x, the decision to add this trip to his other activities will increase his total time-cost to $(x + Q^oV)$.

additional amount T_1T_3 per trip. Because with a negatively sloping demand curve, the latter *must* be greater than the former by the amount $ZS = T_2T_3$, he will inevitably suffer a net loss in welfare.

The result seems paradoxical, for here we have a move to a Pareto optimum that appears to be detrimental to *everyone* involved. But this is, of course, not so. Assuming that the level of employment remains the same, *some* members of the economy must gain in the process. The taxes must either finance the supply of additional public goods or, by decreasing prices or taxes paid by others, it must add to the private-goods consumption of other persons. The point is that, so long as the users of the road do not share in the proceeds made possible by the additional public revenues,[5] they will actually suffer a loss in welfare from the imposition of the "optimal" tax.[6] There is thus a net gain to the community, but it is associated with a loss to drivers on the taxed road.

Although we have used the case of highway congestion to illustrate the theorem, it should be clear that this proposition also applies to at least some other sorts of envirionmental usage. More specifically, the argument shows that, ~~wherever a~~ common-property resource is subject to rising costs of congestion, the imposition of the optimal Pigouvian tax will reduce the welfare of the users of that resource so long as they are excluded from the benefits accruing from the tax revenues. We may see here why opposition to "optimal" taxes is to be expected, unless special provisions are made to assist the losers.

2 The demand for environmental quality by income class

In later sections of this chapter, we will offer some empirical evidence and tentative conclusions on the probable pattern of incidence of the benefits and costs of programs to enhance the quality of the environment. However, to examine the issue theoretically, it is necessary first to consider in this and the next two sections how the demand for environmental quality is likely to vary with income and how these variations in demand can, to some extent, be accommodated through the individual's choice of location.

[5] Because compensation of the victims was shown, in Chapter 4, to be incompatible with Pareto optimality, the road users *cannot* share in the proceeds of an optimal tax program if that share depends to any extent on their own use of the road.

[6] This suggests, incidentally, that the argument will not hold if every member of the community uses the road. In this case, the welfare gain arising from the move to a Pareto-optimal pattern of resource use must get back to (at least some of) the road users. Indeed, as the preceding footnote argues, in this case, no tax program may even be able to achieve Pareto optimality. However, if the real tax proceeds are channeled back in a manner that is sufficiently indirect, they may not cause significant deviations from Pareto optimality.

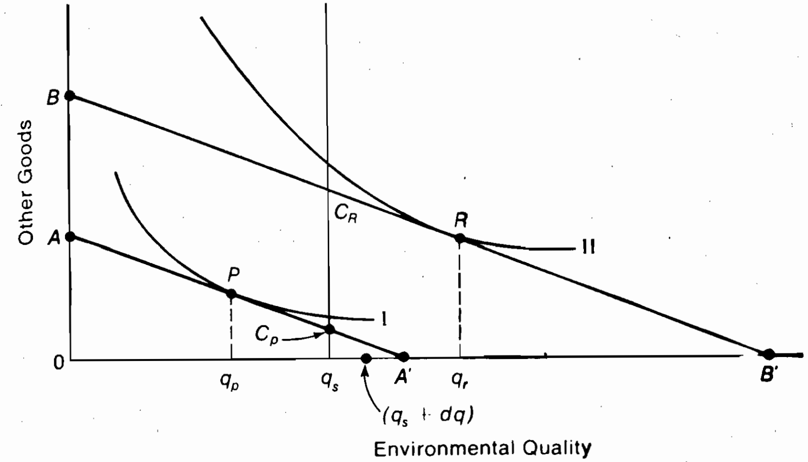

Figure 15.2

As suggested earlier, there is good reason to believe that the demand for environmental quality will rise with income. Such a case is illustrated in Figure 15.2, where we see that a rise in the individual's budget constraint from AA' to BB' leads to an increase in his desired level of environmental quality from q_p to q_r. We might therefore expect higher-income groups to have a greater demand than poorer individuals for such things as clean air and water.

This conclusion depends upon three assumptions implicit in Figure 15.2. The first is that, for a typical individual, environmental quality is a normal good, so that his desired degree of, say, air cleanliness rises with income, an assumption that seems quite reasonable. Second, this proposition assumes at least roughly similar preference *functions* for rich and poor; or, more accurately, it presumes that lower-income groups do not possess systematically stronger preferences for environmental quality than the more wealthy. Otherwise, the poor, because of their more intense preferences for clean air, might, in spite of their lower incomes, still be willing to pay more than the rich for a given level of environmental quality. This second assumption also seems to us a valid one. In fact, if preferences themselves diverge significantly among income groups, it would be our guess that the stronger predilection for environmental protection is to be found among those with higher incomes. The dangers, both in health and aesthetic terms, of environmental deterioration are frequently complex and sometimes apparently remote and so are more likely to be

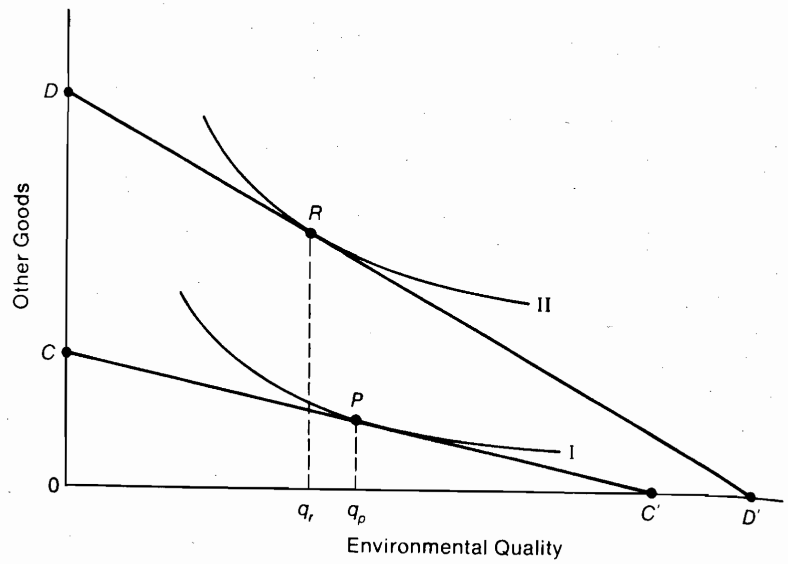

Figure 15.3

recognized by those reached regularly by the media that offer extensive discussions of the issues. Some have actually characterized the growing concern with environmental protection as an "upper-class" movement.[7]

The third, and most problematic, of the conditions implicit in Figure 15.2 is that there is a fixed price for environmental quality, a price that is invariant with respect to income. It is certainly conceivable that, with a progressive tax system, the price of environmental programs will be higher for the rich than for the poor. In fact, we can even have a situation like that illustrated in Figure 15.3, where the effect of the price differential outweighs that of income, so that the poorer individual actually demands a higher level of environmental quality (q_p) than that (q_r) desired by the wealthier person. We will have more to say about this later, when we examine the various ways in which individuals can "buy" varying degrees of environmental quality. Let us say here that we frankly doubt that the situation depicted in Figure 15.3 is plausible as a typical

[7] See, for example, J. Harry, R. Gale, and J. Hendee, "Conservation: An Upper Class Social Movement," *Journal of Leisure Research* I (Summer, 1969), 246. This, of course, does not prove that there exist systematic disparities in the preference maps of rich and poor for environmental quality; the apparently greater concern of the wealthy for environmental protection may result simply from a positive income effect like that illustrated in Figure 15.2. Our point here is simply that there seems to be no persuasive evidence that the poor exhibit stronger preferences for environmental quality than do the rich.

case. For one thing, what is relevant here is not the progressivity of the initial tax structure, but rather that of the *incremental* taxes needed to finance increased outlays on environmental protection. Progressivity of current taxes by no means implies that the tax-price of a given *increase* in environmental protection need be greater to the rich than to the poor. Moreover, as we shall see shortly, the evidence suggests that private-sector costs of pollution control are distributed in a regressive manner. Outcomes like that depicted in Figure 15.3 seem very unlikely.

3 A public-good model of the provision of environmental quality

In this section and the next, we want to consider two polar cases of the consumption of environmental quality. In this first model, we take environmental quality to be a pure, Samuelsonian public good; this is a world in which all individuals in society consume exactly the same quality of air, water, and other environmental goods. Returning to Figure 15.2, let indifference curve I and budget constraint AA' represent the situation of our typical poor individual, while curve II and budget constraint BB' are associated with a rich person. As noted earlier, the wealthier individual will, in this case, demand a level of environmental quality, q_r, higher than q_p, the amount desired by his poorer counterpart. If, however, environmental quality is a pure public good, all persons must, by definition, consume the same set of environmental services. This means that a single level of environmental quality (or vector of environmental characteristics) must be settled upon by society. If this decision is made through democratic processes, let us say by simple majority rule, we might expect to obtain (roughly) the level of environmental quality most preferred by Duncan Black's median voter.[8] The point here is that a likely outcome is a compromise in which the quality of the environment will be less than that desired by the wealthy and more than that preferred by the poor, say q_s in Figure 15.2. To the extent, therefore, that environmental quality is a relatively pure public good, we should find upper-income groups pushing for greater outlays on environmental programs in opposition to the wishes of the poor, who want more income to devote to the consumption of other goods. We will return to this point later.

4 The model of perfect adaptation by choice of location

As many writers have pointed out, environmental quality is, at least under most circumstances, far from a pure public good. The quality of air,

[8] D. Black, "On the Rationale of Group Decision Making," *Journal of Political Economy* LVI (February, 1948), 23–34.

for example, varies substantially even within the confines of a single metropolitan area. This means that an individual does have some choice as to his environment: he can determine to some extent his environmental surroundings by his selection of location.[9] We can envision, at the opposite pole from our pure public-good case, a Tiebout type of world in which a continuum of environmental quality is available at differing points in space.[10] Individuals choose, in accordance with their demands, a location that provides the most desired quality of the environment. Locations offering superior environmental quality obviously rent for a higher price and thus command an economic rent. Moreover, in line with our earlier discussion, we can expect higher-income groups to satisfy their relatively high demands for environmental quality by selecting sites with comparatively little air pollution, noise, and so on. In contrast, the poor can be expected to occupy the less-attractive parts of the metropolitan area in exchange for lower rents. In fact, if differentials in environmental quality are perfectly capitalized into differentials in property values and rents, we can visualize a locational pattern that is economically efficient in that the marginal rate of substitution (MRS) between environmental quality and other goods of each individual would, in equilibrium, equal the opportunity cost of a "unit" of environmental quality; equality of MRSs among individuals would then hold. Although poorer individuals would consume an inferior quality of environment (as depicted in Figure 15.2), their marginal valuation, as measured by their willingness to sacrifice other goods for another unit of environmental quality, would be identical with that of wealthier persons if the (marginal) costs of environmental improvement were the same for everyone.

Although the Tiebout polar case, like that of pure public good, is surely an oversimplification, it contains more than a little truth. Empirical studies have verified that, within metropolitan areas, property values do indeed reflect differences in environmental quality. In one such study (and there are others with similar results), Ridker and Henning found, in the St. Louis metropolitan area, that property values displayed a significant inverse relationship with a measure of the extent of air pollution (specifically, a measure of atmospheric sulfation levels).[11] Moreover, Freeman,

[9] Even in the same locality within a particular city, environmental quality may vary. The rich, for instance, can insulate themselves from such annoyances as noise and the discomforts of hot and dirty air through the purchase of appropriately constructed apartments, air conditioners, and so on.

[10] See the classic article by Charles Tiebout, "A Pure Theory of Local Expenditures," *Journal of Political Economy* LXIV (October, 1956), 416–24.

[11] Ronald Ridker and John Henning, "The Determinants of Residential Property Values with Special Reference to Air Pollution," *Review of Economics and Statistics* XLIX (May, 1967), 246–57. This is a multiple-regression study that attempts to hold constant the other determinants of property values.

in a study of three metropolitan areas, determined that exposure to air pollution varies inversely with income; he concludes that, "Air quality is distributed in a pro-rich manner."[12] It is thus clear that geographical location has, to some degree, permitted individuals to purchase different environmental qualities in accord with the differences in their effective demands and, as is to be expected, this bears a strong relationship to income. The poor live in the most heavily polluted sections of metropolitan areas, while the wealthier seek out the more attractive sites.

Reality, of course, lies somewhere between the two worlds that we have dealt with: the community in which public goods are supplied to everyone in equal quality and the range of geographic areas offering a wide variety of levels of public outputs. The rich and the poor cannot afford to live too far apart; the latter offer jobs to the poor, and the former offer services to the rich. Geographic separation imposes heavy time and money costs of commuting on one or both parties. For this and other reasons, one often finds slum neighborhoods cheek by jowl with the homes of the wealthy. If the air is foul, neither of them escapes it completely, and purification of the atmosphere affects both neighborhoods directly. Most environmental programs thus have strong elements of "publicness."

5 The distribution of benefits of environmental programs

We turn now to the issue of central concern: the incidence by income class of the costs and benefits of environmental programs. We will consider, first, the distribution of the benefits from these programs, and, second, the pattern of incidence of their costs. At the outset, we stress that it is difficult to reach firm conclusions on these matters; in some cases, a single program has both pro-poor and pro-rich elements. Nevertheless, the available evidence on these programs, along with some reasonable conjectures, suggest to us (as it has to others) that, without specific redistributive measures as part of an environmental policy, we can expect programs of environmental improvement to be typically pro rich in their redistributive effects.

Let us first consider the distribution of benefits of a program of environmental improvement in the pure public-goods case; we will then reexamine the issue in the model of geographic specialization. Suppose, for example, that the public authority undertakes to reduce the level of air pollution in a metropolitan area. Where the improvement is a pure public good, it must, by definition, be available to everyone on equal terms. Thus, it will not be provided preponderantly either to the rich or to the

[12] A. Myrick Freeman, "The Distribution of Environmental Quality," in A. Kneese and B. Bower, Eds., *Environmental Quality Analysis: Theory and Method in the Social Sciences* (Baltimore: The Johns Hopkins Press, 1972), p. 264.

poor. Nevertheless, the public-goods model suggests that the dollar value placed on these *benefits* will be greater among higher-income recipients. We recall that our public-goods solution (q_s in Figure 15.2) was one in which the marginal valuation of a unit of environmental quality is higher for a rich man than for a poor man. This implies that an incremental increase in the quality of the environment will be worth more (as measured by willingness to pay) to those with higher incomes than to the poorer members of the community. In this model, therefore, an environmental program must be more favorable to the rich than to the poor providing there is no offsetting differential in the apportionment of the cost burden.[13]

However, in a Tiebout world we can reach no such simple and categorical conclusion. Because there the poor and the rich inhabit separate areas, it is possible to devise (a) programs whose benefits flow to both parties, (b) programs that exclusively, or at least primarily, affect the poor alone or (c) programs directed mainly to localities inhabited by the wealthy.

In fact, one encounters each of these three types of measures in practice. A general tax on emissions, for example, is likely to improve air and water quality everywhere to some extent and thus is a measure of type (a). A set of minimum standards for air and water quality (for example, a regulation limiting emissions in different communities sufficiently to achieve an acceptable level of sulphur dioxide in the atmosphere in all localities) may have its primary impact on poorer neighborhoods, because the wealthy may inhabit areas in which the standards were already met prior to the adoption of the regulation. Finally, a program designed to protect the more unspoiled areas, and so to preserve "sanctuaries of cleanliness," is likely to focus on the areas inhabited by the wealthy rather than the localities in which the poor live and in which deterioration may be well under way. We want to consider next somewhat more systematically the effects of each of these three types of policies. Because in our Tiebout world pollution is likely to be most serious in poorer neighborhoods, we might suppose that a program of type (a) that improves environmental quality (for example, reduces levels of air pollution) in all localities generates benefits of more critical importance to the poor than to the rich.

However, this conclusion requires several important qualifications. First, although such programs may bring greater improvement *measured in physical terms* to areas of poorer residents, it cannot be stated unequivocally that the *value* of these increases in environmental quality will be greater to the poor than to the rich. Depending on the geographical pattern of the improvements, the income elasticity of demand for environmental quality, and current income differentials, the value *in money terms* of a lesser increase in, say, air quality may still be greater in rich, than in poor, areas. Our formal analysis is consistent with this conclusion.

As Figure 15.2 suggests, in a Tiebout equilibrium there *need not* be a significant difference in the rich and poor individual's MRS between environmental quality and private goods, even though this quality is far more abundantly supplied to the former. True, the equal MRSs displayed in the figure depend on the highly questionable premise that the marginal cost of environmental improvements are the same in the two types of area. However, there seems to be no clear presumption that the relative costs will differ systematically in such a way that the relative marginal value of a given improvement will tend to be higher for the poor than it is for the rich.

Second, suppose that our cleansing of the atmosphere effected a dramatic improvement in, say, the air quality in what has been a low-income area. In our Tiebout world, this should make these sites more attractive, and thereby lead to a bidding up of rents in the area. To the extent that they are renters, the poor may well find that much of the benefit of living in a cleaner environment is largely offset by the higher rents they must pay. The force of this argument at a practical level is difficult to evaluate. As Freeman points out, the sunk investment in housing and other neighborhood configurations generally make changes in local land-use patterns a relatively slow process.[14] It *may* thus be a long period before the improvements in environmental quality become capitalized into higher rents. However, over the longer run, alterations in locational patterns and levels of rents may reduce significantly the net benefits realized by the poor.

Programs of type (b), requiring, for example, the attainment of certain minimum environmental standards in all localities, obviously have the greatest potential for a pro-poor incidence of benefits. Even here, however, the extent of this pro-poor pattern of benefits may be eroded by one response noted above: the bidding up of rents in areas inhabited by the poor as a result of the improvement in environmental quality in these neighborhoods.

We turn finally to the apparently pro-rich [type (c)] environmental programs. Because of the heavy costs of maintaining high levels of environmental quality in all areas, the environmental authority may decide to

[13] Note that we cannot say that the program is strictly regressive. Although the marginal benefits to the rich are greater than those to the poor, it still remains possible that the incremental benefits would be larger *as a proportion of income* for the poor than for the rich.

[14] "Distribution of Environmental Quality," pp. 268–69.

Ind. ffere... curve.

confine polluting activities to specific locations so as to preserve other localities from environmental degradation.[15] Such a result can be obtained in a rather inefficient manner by zoning devices, or more efficiently by some variety of tax measure (for example, one in which taxes on emissions of fumes vary *directly* with the initial purity of the atmosphere in the area).

There is, clearly, a strong presumption that such an environmental policy will work counter to the interests of the poor in a Tiebout economy.[16] Because they may be assumed to inhabit the dirty areas to begin with, the imposition of these policies is likely to make their communities dirtier still, as polluting activities are driven there from the protected areas. Moreover, rents in the unprotected regions may be expected to increase as well, as more polluters are induced to locate there![17] Thus the poor

[15] As we saw in Chapter 8, this may be an optimal strategy in the presence of nonconvexities caused by the presence of externalities. For then there may be virtue in a corner solution in which polluting activities are segregated.

[16] The Samuleson model is not relevant to this case, which requires, as one of its premises, differentiation in the environmental quality of different communities.

[17] Actually, this is not inevitable. For example, a tax that varies directly with initial air cleanliness will to some extent discourage pollution in *both* areas. If the tax on the *relatively* unprotected area is still not too far below that in the other, it may offset the resulting migration of polluting activities from the more protected areas.

To show this, assume that a firm produces in two areas: A, which is unprotected, and B, which is protected, and let x_a and x_b be its outputs in the two locations, which are produced at respective costs $c_a(x_a)$ and $c_b(x_b)$; its total revenue is $r(x_a+x_b)$; and assume that the tax rates on polluting production in the two locations are, respectively, kt and t where $0 \le k < 1$. Then if the firm's objective is to maximize profits, its problem is to

$$\text{Max } \pi = r(x_a+x_b) - c_a(x_a) - c_b(x_b) - ktx_a - tx_b,$$

yielding the first-order conditions

$$r' - c_a' - kt = 0$$

$$r' - c_b' - t = 0.$$

Differentiating totally with respect to t, x_a, and x_b, we obtain

$$(r'' - c_a'')\,dx_a + r''\,dx_b = k\,dt$$

$$r''\,dx_a + (r'' - c_b'')\,dx_b = dt.$$

Solving and letting D represent the determinant of the system (where $D > 0$ by the second-order conditions), we have

$$\frac{dx_a}{dt} = [k(r'' - c_b'') - r'']/D.$$

Thus, if as we might expect, $r'' < 0$ and $c'' > 0$, then dx_a/dt will be negative if k is sufficiently close to unity (that is, if the tax differential is not great enough, x_a, the firm's output in the unprotected area may actually be reduced by the tax), and so its demand for land there may fall, with rents following suit. A very similar argument holds for a competitive *industry*.

will find themselves living in less-attractive areas and receiving less of a rent advantage relative to the cleaner areas than they would in the absence of the program.

So far, we have largely followed our intention of dealing exclusively with the distribution of the benefits of an environmental program. But in the Tiebout model, this procedure forces us to ignore a particularly critical issue. Suppose that the programs we have been considering require the individual communities to pay the bulk of the costs of their environmental improvements. Then, from the point of view of the members of each individual locality, its own environmental program is, *on net*, detrimental to their interests. For in the pure Tiebout case, everyone will have achieved precisely the level of environmental quality that he desires, given the cost of improvement. Consequently, any measure that forces further improvement on a community must impose on its inhabitants something they do not want. In terms of our figures, it forces them to the right of their preferred positions.

Thus in this case, programs of type (b) (the setting of uniform standards), rather than benefiting the poor, will be disadvantageous to them and to them alone, and programs of type (a) that affect the environment in every type of community will be somewhat less anti-poor because they will be disadvantageous to rich and poor alike![18]

When we bring the analysis to a lower level of abstraction, the pro-rich orientation of the benefits from environmental programs seems even more likely. For example, substantial funds have been directed into the provision of outdoor recreation facilities: national parks, the preservation of surface waters for recreational purposes, and so on. We might guess that the use of such facilities would be related directly to income, particularly in view of their significant distance from densely populated areas. Empirical studies confirm this. In a comprehensive study of the economics of outdoor recreation, Cicchetti, Seneca, and Davidson have found (using multiple-regression analysis) that level of income was a significant determinant of the probability and frequency of usage by an individual of a wide variety of outdoor recreational activities.[19] Expenditures on such facilities thus appear to have a pro-rich orientation. This result is of particular significance since it has been estimated that "70

[18] To the extent that community environmental programs have beneficial external effects on environmental quality in other jurisdictions, they may of course benefit everyone if all communities undertake measures, say, to achieve certain standards of environmental quality. In a Tiebout world, the case for additional incentives to communities for environmental improvement appears to rest primarily on such external effects.

[19] C. J. Cicchetti, J. J. Seneca, and P. Davidson, *The Demand and Supply of Outdoor Recreation* (Washington, D.C.: U.S. Department of the Interior, 1969).

percent of the benefits of improved water quality will be in the nature of improved recreational opportunities."[20]

For air quality, the distribution of the benefits of pollution control by income class seems somewhat uncertain. Gianessi, Peskin, and Wolff, in a study of the U.S. Clean Air Act, find striking locational differentials in benefits; not surprisingly, most of the benefits from efforts to improve air quality are concentrated in the heavily industrialized cities of the East.[21] The benefits (and costs) accrue primarily to urban rather than rural residents. Within urban areas, they find that the benefits may be slightly pro-poor in their pattern of incidence, but this is, in all likelihood, more than offset by a regressive pattern of costs (as we shall see shortly).

6 The distribution of transitional costs

In our public-goods model, we used the simplifying assumption that the cost per unit of environmental quality was the same for rich and poor. This is admittedly rather unlikely: the incidence of the costs of an environmental program will obviously depend on the means adopted to implement the program, be they effluent charges, government subsidies, or direct controls that, in turn, influence the structure of prices. In examining this issue, we will consider two kinds of costs: the *transitional* costs involved in a program of improving the environment and the *continuing* costs of maintaining a given state of environmental quality. By transitional costs, we mean the costs of the process of adjustment from one state of environmental quality to another; continuing costs then become the costs of maintaining, over time, the newly achieved quality of the environment.

The most striking feature of the transitional costs of environmental programs is the likelihood of a highly uneven pattern of incidence. Whether the improvement of the environment (involving, say, reduced emissions into the atmosphere and waterways) is achieved by effluent charges or by direct regulation, the effects will hit some industries much harder than others. Heavy polluters, such as those chemical and paper plants that are located in populous areas, may be forced to curtail their operations significantly and perhaps even to stop them completely. This suggests, as testified to by frequent opposition in industrial towns, that one of the

[20] Henry M. Peskin, "Environmental Policy and the Distribution of Benefits and Costs," in Paul R. Portney, Ed., *Current Issues in U.S. Environmental Policy* (Baltimore: Johns Hopkins University Press, 1978), 163.

[21] Leonard P. Gianessi, Henry M. Peskin, and Edward Wolff, "The Distributional Effects of Uniform Air Pollution Policy in the United States," *Quarterly Journal of Economics* XCIII (May, 1979), 281–301.

most significant transitional costs of environmental programs will be a loss of jobs.

The employment-restricting effects of environmental measures may be increased by the fact that such policies are not instituted in all regions simultaneously. The area that imposes them unilaterally or in concert with only a few other jurisdictions will find itself at a competitive disadvantage in the production of the polluting items. Whether or not this will reduce the level of employment in the region as a whole, it will certainly make for a decrease in the demand for labor in the industries directly affected.

There are some obvious automatic offsets to these employment effects and some that are optional. Measures that penalize the emission of pollutants will stimulate the manufacture of recycling and purification equipment. Moreover, appropriate monetary and fiscal programs can be used to minimize any loss in employment entailed in an environmental protection policy. However, it is difficult, as we have learned, for conventional stabilization policy to cope effectively and promptly with highly localized unemployment resulting from cutbacks in particular lines of activity. The short-run costs for the newly unemployed are thus likely to be heavy.

In principle, this burden need not inevitably fall more heavily on the poor. A new refining plant, for example, may offer an unusually high proportion of jobs to executives and technicians. The pattern of transitional costs by income class will thus depend on the relative change in demand for high- and low-income employees. It is difficult to generalize on the matter; however, where environmental protection does restrict job opportunities, it is our conjecture that the costs are likely to fall most heavily on those in the lowest-income stratum. Professional personnel frequently have a greater occupational and geographical mobility than lower-wage employees; as a result, lower-income workers may well have more to lose than higher-salaried employees. This at least appears to be how workers themselves view the matter. When one reads newspaper accounts of local opposition to the curtailing of activities of some plant, the invariable rallying cry of its proponents (who are usually reported to be drawn largely from the community's lower-income groups) is that restriction of the enterprise will mean a loss of jobs that are "badly needed."[22]

This discussion has a direct bearing on the diagrammatic analysis of earlier sections. It suggests that, at least in the eyes of the poor themselves,

[22] Even if employment is not hurt by environmental protection measures, real output, conventionally measured, will tend to be reduced because a given set of inputs will yield a smaller bundle of outputs than before. In many cases, this cost, too, will probably fall most heavily on the poor. If a ban on DDT undermines the "green revolution" with its spectacular contribution to grain outputs in less-developed areas, can there be any serious doubt about the income group that will suffer the resulting malnutrition or starvation?

and, very likely, in fact as well, the transitional costs of environmental measures may be much higher for the poor than they are for the wealthy. The slope of the price line in Figure 15.3, interpreted as a curve of total real cost per unit of environmental quality, rather than being less steep for the poor, may actually be steeper for those whose jobs are jeopardized by programs for environmental improvement. In such cases, income as well as transitional "price" effects will make environmental measures more attractive to higher- than to lower-income groups.

7 The distribution of continuing costs

The continuing costs of programs to sustain a given level of environmental quality relate more to the change in the structure of prices of goods and services. If we assume that, following a transitional period of temporarily unemployed resources, full (or approximately full) employment is reestablished, the incidence of the steady-state environmental programs becomes a matter of the equilibrium set of prices (including levels of wages). Our expectation here is that there will be a rise in the relative price of those goods whose production involves substantial external costs (at least where techniques of production that reduce destructive emissions are significantly more costly than "free" dumping of wastes into the atmosphere or local waterways).

Suppose, for example, that we were to impose a set of effluent charges on emissions of the sort discussed in Chapter 11; the level of charges would be adjusted to achieve desired targets of environmental quality. What can we say about the pattern of incidence of such a set of charges? In principle, the approach to this problem is a straightforward one. Effluent fees simply amount to excise taxes on certain activities of the industry; the problem thus becomes one of determining, first, the effect of the tax on the cost and price of each commodity (including inputs) and, second, of establishing the incidence of the price changes by income class. Although all this may be straightforward in principle, the empirical evaluation of such general-equilibrium consequences is a very complex undertaking.

Although there are no studies that perform this kind of exercise for a system of effluent charges, there have been some attempts to estimate the incidence of the costs of existing pollution-control programs. Using various assumptions, these studies estimate how the costs of pollution abatement have affected the prices of various classes of products and how, in turn, these price increases have influenced the real incomes of different income classes. Some of the early studies of this type found the pattern of costs to be regressive. Gianessi, Peskin, and Wolff, for example, examined the distributive pattern of the costs of the Clean Air Act and found that lower-income groups bear costs that constitute a larger fraction of their incomes than do higher-income classes.[23] In a more recent study, H. David Robison has examined the distribution of the costs of industrial pollution abatement in a full general-equilibrium model.[24] Using a highly disaggregated input-output model, Robison assumed that the control costs in each industry were passed forward in the form of higher prices. He was then able to trace these price increases through a general-equilibrium system to determine their effect on the pattern of consumer prices. Robison's model divides individuals into twenty income classes, and for each class he has data describing the pattern of consumption. With this information, he is able to estimate for each of his income classes the increase in the costs of the items that they purchase. He finds that the pattern of incidence of control costs is quite regressive. Costs as a fraction of income fall over the entire range of his income classes, and they range from 0.76 percent of income for his lowest-income class to 0.16 percent of income for the highest-income classes. All these studies thus suggest that the costs of current programs are regressive in their incidence. This, we conjecture, would also be true for a system of effluent fees.

8 Distributive considerations in environmental policy

In sum, our models and the available evidence lend support to the view that, on balance, programs for environmental improvement promote the interests of higher-income groups more than those of the poor; they may well increase the degree of inequality in the distribution of real income. Low-income families are more likely to feel that basic needs, such as better food and housing, constitute more pressing concerns than cleaner air and water. Moreover, where new environmental programs threaten jobs, including higher-paying as well as lower-wage work, redistributive effects may weigh particularly heavily on certain individuals.

In fact, the rich and the poor seem often to have realized instinctively the difference in what they stand to gain from environmental programs.

[23] "The Distributional Effects of Uniform Air Pollution Policy in the United States." For other studies with similar findings, see Nancy Dorfman and Arthur Snow, "Who Will Pay for Pollution Control?" *National Tax Journal* XXVIII (March, 1975), 101–15, and Leonard P. Gianessi and Henry M. Peskin, "The Distribution of the Costs of Federal Water Pollution Control Policy," *Land Economics* LVI (February, 1980), 85–102.

[24] "Who Pays for Industrial Pollution Abatement?" *Review of Economics and Statistics* LXVII (November, 1985), 702–6.

In a case study in California, Perry Shapiro examined voting patterns in a referendum in Santa Barbara Country.[25]

> At issue was the development of a large ranch (El Capitan) fronting on the sea in the rural part of the county. The voters were to decide whether or not a private developer should be allowed a zoning variance to develop homesites in an established agricultural open space area. The project promised to generate an increase in local economic activity at the expense of environmental quality. The issue, as related in pre-election press reports, was one of environmental quality versus income, and there is good reason to believe this was the alternative between which voters chose in the polling booth.[26]

Using probit analysis to study the election results by wealthier and poorer districts, Shapiro found a clear, direct relationship between mean income and the proportion of voters opposing the project; only in the lowest income class was there substantial support for the grant of a variance for increased housing density.

In a similar kind of study, William Fischel examined voting behavior in eight New Hampshire towns in a local referendum on the proposed construction of a new wood-processing pulp mill.[27] Here again, the issue clearly involved a choice between new jobs and avoidance of detrimental environmental effects such as air and water pollution as well as congestion. From a statistical analysis of data from interviews with 359 voters, Fischel found (much like Shapiro) that the probability of a resident voting in favor of the pulp mill was significantly increased if the individual was in a "blue collar" occupation and was reduced if he or she was a "professional," had a relatively high income, or had a college degree. These and other studies indicate that higher-income groups give higher priority to programs for improved environmental quality than do those with lower incomes.

There are two obvious polar reactions to these observations. An oversimplification of the reaction of the pure economist might assert that resource allocation and income distribution are two separate issues and that one should not be permitted to interfere with a rational resolution of the

[25] Perry Shapiro, "Voting and the Incidence of Public Policy: An Operations Model and an Example of an Environment Referendum," Working Paper in Economics #8, University of California at Santa Barbara (May, 1972). In several subsequent studies of voting patterns on other environmental issues, Professor Shapiro and his colleagues have obtained very similar results. See, for example, Robert Deacon and Perry Shapiro, "Private Preference for Collective Goods Revealed Through Voting on Referenda," *American Economic Review* LXV (December 1975), 943–55.

[26] *Ibid.*, pp. 1-2.

[27] "Determinants of Voting on Environmental Quality: A Study of a New Hampshire Pulp Mill Referendum," *Journal of Environmental Economics and Management* VI (June, 1979), 107–18.

other. No matter what their distributive implications, one should seek to institute policies that make for efficiency in resource utilization, leaving it to some other (unclearly identified) branch of government to take the steps required to achieve a more just distribution of income.

The other extreme view, again one that is probably rarely held in its strongest form, asserts that the elimination of poverty is a matter of much higher priority than the (primarily aesthetic) issue of environmental protection. If the latter interferes with the former, so much the worse for it; it is a luxury whose attainment must at the very least be postponed until the more pressing problem of inequality is reduced to reasonable proportions.

We find neither of these views acceptable. The past performance of redistributive policy does not make us confident that the undesired redistributive consequences of environmental programs will somehow be offset. Moreover, at a more pragmatic level, the failure to redress at least the most glaring redistributive insults will generate strong opposition to the adoption of appropriate environmental programs.

On the other hand, postponement of environmental measures is not an appealing option. If these are vital matters of public health and perhaps ultimately of survival, even the poorest citizen may not have much reason to thank the legislator who resists effective action, even if it apparently is resisted for his sake. The issues of allocation raised by the literature on externalities cannot be brushed aside lightly on distributive grounds.

What this suggests to us is the need to incorporate sensible redistributive provisions into environmental programs, both as a matter of justice and as a means to enhance their political feasibility. We should not, however, lose sight of the fact *that the primary purpose of environmental programs is allocative:* their basic rationale is the direction of resource use to achieve desired levels of environmental quality.[28] We are inclined to agree with Freeman's contention that environmental programs are generally not very well suited to the achievement of distributional objectives.[29] The goal should rather be to neutralize the more serious of the objectionable redistributive consequences of our environmental policies. Two promising lines of strategy have been suggested. First, as we noted earlier, the most drastic redistributive effects are likely to occur during periods of transition with individuals displaced from jobs in badly located,

[28] This is admittedly a tricky issue. As Henry Aaron and Martin McGuire show at a formal level, the appropriate level of provision of a public good can, under certain circumstances, become, largely, an ethical decision. See their "Efficiency and Equity in the Optimal Supply of a Public Good," *Review of Economics and Statistics* LI (February, 1969), 31–39.

[29] Freeman, "Distribution of Environmental Quality," pp. 274–78.

heavily polluting plants. Such transition problems can be met, at least in part, by the use of *adjustment assistance*, outlays common under legislation to reduce tariffs; such provisions typically offer unemployment compensation, retraining programs, and relocation assistance to minimize the costs to those displaced by the altered patterns of output and employment resulting from the legislation. Adjustment assistance can be an important component that would spread the transition costs of the program more evenly across society.

Second, we have suggested that the continuing costs of environmental measures are likely to have a somewhat regressive pattern of incidence. Two kinds of measures can be employed to offset this. First, as Gianessi, Peskin, and Wolff suggest, subsidies rather than taxes can be employed to reduce somewhat the increases in costs in polluting industries.[30] Although this has some appeal on distributive grounds, it is a proposal that must be considered cautiously, for (as we saw in Chapter 14) subsidies to firms that reduce their emissions can lead to allocative distortions and can actually result in increased pollution by inducing the entry of new polluting firms. The use of subsidies instead of taxes requires compelling evidence that the subsidy payments will not have such undesirable consequences. Second, the finance of public environmental projects is likely to be less regressive if the funds come from federal, rather than state and local, revenues. Since the federal tax system is more progressive than most state and local taxes, this would serve to distribute the burden of this part of the cost of environmental programs in a way that is less regressive. As we mentioned earlier, it is the progressiveness of incremental revenue collections that is important here; we may expect, however, that at the margin (as well as on average) federal revenues are likely to be collected in a more progressive manner than state and local funds.

[30] "The Distributional Effects of Uniform Air Pollution Policy in the United States."

CHAPTER 16

International environmental issues

Almost invariably, public discussion of programs for the protection of the environment has emphasized their international implications. Two central issues have emerged from the debates. First, questions have been raised about the effects upon the competitive position in international trade of the country undertaking the program. It has been suggested, particularly by representatives of industries likely to bear the costs, that the proposed measures would impose on exporters a severe handicap in world markets that is certain to have an adverse effect on the nation's balance of payments, its employment levels, and its GNP. This problem has proved particularly frightening to the less-affluent nations, but even in wealthy countries it has been a persistent concern.

The second issue in this area is quite a different matter; it involves the transportation across national boundaries, not of commodities desired by the recipient nation, but of pollutants whose influx it seems powerless to prevent. Although there is a good deal of talk of international cooperation in the control of transnational pollution, joint programs like those we have already discussed will undoubtedly prove difficult to institute. Therefore, it is important to consider whether the victim nation can do anything to protect itself in the absence of something better in the form of effective collective measures. Obviously, where international cooperation *can* be achieved, the theoretical analysis that has been described in earlier chapters applies equally to international and domestic policy. It is only in the absence of joint action that an analysis of special measures for an effective international policy is required.

International trade theory offers some illumination on both these issues. Accordingly, this chapter is divided into two largely unrelated parts. The first examines the effects of a domestic pollution-control program on the initiating country's balance of payments and on international patterns of specialization; the second part concerns itself with transnational pollution issues. To avoid unnecessary complications, we will assume

Much of this chapter is taken from the 1971 Wicksell Lectures, W. Baumol, "Environmental Protection, Spillovers and International Trade" (Stockholm: Almqvist and Wiksell, 1971).

away each problem in turn when discussing the other. That is, when examining the balance of payments and related issues, we will assume that the pollution in question remains within the borders of the country that generates it, and in discussing transnational pollution problems, we will ignore the issues relating to specialization and trade considered in the first part of the chapter.

1 Domestic externalities and trade objectives

Just as the management of an individual firm may feel that it cannot undertake unilateral measures to reduce its emission of pollutants for fear of being priced out of the market by its competitors, as a matter of national policy, a government may be reluctant to institute significant pollution-control measures for fear of the effects on its production costs and hence on its balance of trade.[1] Our objective in this section is to examine what theoretical analysis can tell us about the validity of such fears.

Let us then consider a world composed of two countries, *i* and *w*, which it may be suggestive to think of as a more impecunious and a wealthier country, respectively, though that interpretation plays no role in our formal analysis. In our model each country produces, among other goods, a commodity, *D*, whose production can, *but need not,* be dirty. Suppose for example that, unless preventive measures are taken, *D* generates smoke, all of which falls in the vicinity of the factory. We assume that there exists a method of producing *D* that is smokeless but more expensive than the alternative production method. Assume that country *w* has already chosen its environmental policy, say it prohibits the production of *D* by the smoky method. Our central concern is the effect of the decision of the other country, *i*, between a policy of controls and no controls. In the next two sections we examine the (short-run) consequences of this unilateral choice for the balance of payments in *i* and for the demand for

[1] Some very preliminary calculations by Ralph C. d'Arge and Allen V. Kneese suggest that the trade and income consequences of the imposition of strong environmental controls would, in some cases, be very substantial though they would differ from country to country. On the basis of data consisting partly of available statistics and partly of very rough guesses, they estimate that each of the countries examined would experience about the same relative increase in export prices, something on the order of a 3.5 to a 9 percent rise. However, assuming that a country were to impose environmental protection measures unilaterally, the effect on gross national income varied considerably from country to country. In several cases, the effects were negligible, but in others, the loss in income exceeded 25 percent. See Allen V. Kneese, "The Economics of Environmental Management in the United States," in *Managing the Environment: International Economic Cooperation for Pollution Control,* Allen V. Kneese, Sidney E. Rolfe, and Joseph W. Harned, Eds. (New York: Praeger Publishers, 1971), pp. 3-52.

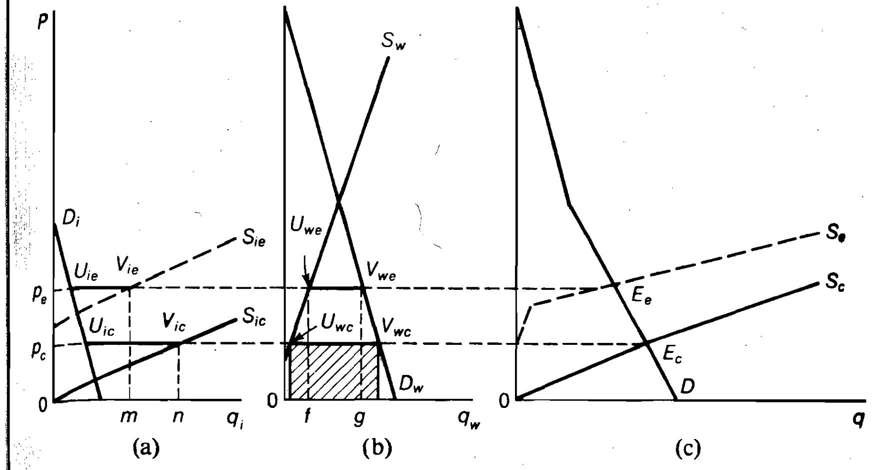

Figure 16.1

employment of its labor. Then, a later section considers the more permanent effects on international patterns of specialization (that is, on the types of industry located in the two countries).

We are concerned, then, with a comparative-statics question: the difference in its foreign exchange earnings and employment levels that will result if *i* decides to continue its cheap but smoky production methods as against the smokeless alternative. The shorter-run effects on balance of payments and employment have attracted the bulk of public attention, and they also happen to lend themselves to formal analysis. Consequently, they will occupy most of our discussion. However, it is the longer-run consequences for specialization patterns that, we believe, will have the more profound consequences for the welfare of the nations concerned, and they deserve more attention than they seem to have received.

2 Shorter-run effects

Figures 16.1a and 16.1b are the standard supply-demand diagrams used to examine such issues in a partial analysis. In the case of country *i*, two alternative supply curves are considered: the lower curve, S_{ic}, corresponds to the cheap, dirty method of production, and S_{ie}, the higher broken curve, corresponds to the choice of the expensive production process in which pollution is eliminated.

Ignoring differences introduced by transportation costs, tariffs, and the like, we shall assume in our discussion that *p*, the price of *D*, is the same in both countries. This premise simplifies the analysis but does not really alter its substance. Figure 16.1c then represents total supply and demand in the two countries together, corresponding to each alternative price. There are two total supply curves, one corresponding to each of the alternatives available to i. The solid combined supply curve, S_c, corresponds to the case where i decides to keep its costs low by not prohibiting pollution. The corresponding international equilibrium point is E_c, and it yields equilibrium price p_c. In the diagrams as drawn, at this price, i is a net exporter of D, shipping out quantity $U_{ic}V_{ic}$ (with w, clearly, importing the same amount). Similar magnitudes correspond to the expensive production case. We obtain the following conclusions whose derivation will be examined in the following section.

1. In general, we may expect that a decision by i to use the less expensive (dirty) production process will keep down the world price of the commodity (p_c lower than p_e). This will be true so long as the supply curves have positive slopes or, if those slopes are negative, so long as they are less steep than the demand curves.[2]

2. World demand for the commodity, and the demand for it in each country, will be higher as a result of the lower price. The higher world demand when the cheaper production method is employed is indicated in Figure 16.1c by the position of E_c, which lies to the right of E_e. Similarly, the rise in quantity demanded in country w is indicated by the comparative position of V_{wc} and V_{we}, and so on.

3. Country i will certainly produce more of the commodity if it refrains from adoption of the more expensive process, because the lower price will increase both domestic demand (from U_{ie} to U_{ic} in Figure 16.1a) and foreign import demand (from $U_{we}V_{we}$ to $U_{wc}V_{wc}$ in Figure 16.1b). As a corollary of items 2 and 3, we have the not very surprising result that the total world emission of pollutants is likely to be increased as a result of country i's failure to undertake the pollution control program, for with greater world demand for commodity D and more of it produced by the dirty process in country i, the output of pollutant can be expected to be increased.

4. However, employment in industry D of country i may fall as a result. Although more of the commodity will be produced, less labor (and other inputs) will very likely be required per unit of output and so it is conceivable, at least in principle, that the net consequence will be a decline in employment.[3] In Figure 16.1a, the total cost of i's production of D with

may be

[2] To be a bit more precise, we will show in the next section that this result requires the sum of the slopes of the supply curves to exceed the sum of the slopes of the two demand curves.

[3] This is not meant to suggest that environmental policy is the appropriate means to deal with employment issues. But complete disregard of its employment consequences is equally inappropriate.

the cheaper polluting process is represented by the rectangle $OnV_{ic}p_c$. Similarly, with the more-expensive process, the corresponding rectangle is $OmV_{ie}p_e$. The relative magnitude of the rectangles depends on the slopes of the alternative supply curves for country i and the distance between them, and one cannot generalize about their relative sizes. The effects on country i's wage bill will therefore also be indeterminate. Specifically, we know that total expenditures on output in i will fall when its price is lowered if domestic demand for D and foreign import demand for D are both price inelastic, so we may expect that, in the absence of other measures to keep up the level of employment, in these circumstances, demand for labor will also fall.[4]

5. Whether i's foreign currency earnings are increased by failure to introduce pollution control must be considered separately for the case where it is a net importer and that where it is a net exporter of the item.

(a) If i is a net importer of D, the fact that its domestic cost of production has been kept down means that the cost of its imports must have been held down as well. This reduced cost results in the production of more D in i and less in w. Note that the marginal costs of producing D in the two countries will (neglecting transport costs) remain equal despite the more costly production process used by w. By keeping down both the amount of its imports and the price of what it does continue to import, it follows that i will gain in terms of its foreign exchange position.[5]

(b) If i is a net exporter of D, it is no longer clear that the adoption of the dirty method of production will increase its net foreign exchange earnings.[6] True, it will now export more than if it had banned smoky production processes within its borders. But it also receives a lower price for its product. Hence, its exchange position will have improved only if w's price elasticity of demand for imports of D is greater than unity. Otherwise, i may actually earn a smaller quantity of foreign exchange for its exports.[7] We see, in Figure 16.1b, that receipts of foreign

[4] Of course, this need not be the case if the clean method of production is less labor-intensive than the dirty technique.

[5] This abstracts from side effects on exports and imports of the other good, C. If, for example, pollution control raises the world price of D, demand may shift to C. If i is the exporter of C, then this could conceivably swamp the worsening of its import position described in the text.

[6] It is noteworthy that the d'Arge–Kneese estimates of the trade effects of environmental protection measures, which were mentioned earlier, suggest that for virtually all of the countries studied, the result of their unilateral adoption would be an *improvement* in the trade balance! That is, the country that refused to institute such measures would very likely *lose* in terms of its exchange position. Of course, the calculations were very rough, as the authors are careful to stress.

[7] There is an obvious difference here between the price set by competitive export and import industries and the administered price set by a firm with monopoly power. Ordinarily, the

exchange will be less under the smoky production technique if the shaded area, representing the total import expenditure on D by w at the lower price, is smaller than the area of the corresponding rectangle at the higher price, the rectangle $U_{we}V_{we}gf$.

In sum, what appear to be obvious consequences of pollution controls by our poorer country are by no means as certain as widely supposed. A decision by its government that leads to elimination of the polluting production process *may* produce a deterioration in its balance of payments and an increase in domestic unemployment, but neither of these is a forgone conclusion. Without examining the relevant elasticities, it is never safe to argue that a rise in production cost and price will lead to a reduction in revenues and input demand.[8]

3 Formalization of the shorter-run analysis

We will now generalize somewhat the arguments of the preceding section, though we continue to utilize a partial analysis in the sense that we will ignore the effects of changes in the price of the polluting commodity on the exports, imports, and price of the other commodity. We use the following notation:

$$p = \text{price}$$
$$D^i(p), D^w(p) = \text{demand for the commodity in } i \text{ and } w\text{, respectively}$$
$$S^i(p,a), S^w(p) = \text{the supply functions in } i \text{ and } w\text{, respectively,}$$

where a is a shift parameter representing the cost of pollution control. We may assume:

$$S_a^i = \frac{\partial S^i(p,a)}{\partial a} < 0. \tag{1}$$

That is, all other things being equal, the higher the cost of pollution control, the lower will be the quantity of product supplied by i at any given product price.

International equilibrium obviously requires equality of total supply and demand for the product in question:

Footnote 7 *(cont.)*
latter will not end up in the inelastic range of the demand curve for his product, but it is perfectly possible for the equilibrium output of the former to fall within the inelastic portion of the industry demand curve. That is why we have the paradoxical result that a country may be able to improve its financial position by "reducing its cost efficiency," as one reader put the issue.

8 Though it should be noted that those "obvious" conclusions do hold for the classical small country case, the elasticity of demand for whose exports is infinite.

$$S^i(p,a) + S^w(p) = D^i(p) + D^w(p). \tag{2}$$

To determine the effect of a change in the cost of i's production process, assuming that equilibrium is then reestablished, we change the value of a and investigate the equilibrating change in p. Thus, we differentiate (2) totally with respect to a and p to obtain

$$S_a^i\,da - (D_p^i + D_p^w - S_p^i - S_p^w)\,dp = 0$$

where S_p^i represents $\partial S^i(p,a)/\partial p$, and so on, or

$$dp/da = S_a^i/(D_p^i + D_p^w - S_p^i - S_p^w). \tag{3}$$

With negatively sloping demand curves, we have $D_p^i < 0$, $D_p^w < 0$ and, by (1), $S_a^i < 0$. Hence, if the supply curves are upward sloping, dp/da will certainly be positive. More generally,

$$\frac{dp}{da} > 0 \quad \text{if} \quad S_p^i + S_p^w > D_p^i + D_p^w. \tag{4}$$

We conclude from (4),

Proposition One. If i selects a less expensive process, so that $da < 0$, then the world price of the commodity may be expected to decline. It follows as a corollary that with D_p^i and D_p^w both negative, demand for the item in each of the countries must rise.

It is usually assumed that

$$D_p^w - S_p^w < 0. \tag{5}$$

That is, a rise in price will lead to a decline in w's imports (i's exports) of the item.

Because i's export quantity is $D^w - S^w$, its foreign exchange receipts from its sales of the good will be

$$R^i = p(D^w - S^w). \tag{6}$$

Differentiating, we have

$$\frac{dR^i}{da} = [p(D_p^w - S_p^w) + (D^w - S^w)]\,\frac{dp}{da}.$$

By (4) and (5), dR^i/da will be negative if $(D^w - S^w)$ is negative (if i is a net importer of the commodity). That is,

Proposition Two(a). If i is a net importer of the commodity, i will always improve its balance of trade by reducing unit costs and price.

However, if $(D^w - S^w) > 0$ so that i is a net exporter of the item, its trade balance may or may not improve from the resulting reduction in the world price of the commodity because dR^i/da may then be either positive or negative. Thus:

Proposition Two(b). If it is a net exporter of the item, country i will gain in its foreign exchange receipts when it keeps down its costs of producing the commodity if and only if w's import demand is elastic, so that a decline in price increases i's receipts as given by expression (6).

We also have

Proposition Three. Output of the commodity in country i can be expected to be higher if it selects the lower cost process of production.

For, in equilibrium, by (2),

$$\frac{dS^i}{da} = [D_p^i + (D_p^w - S_p^w)] \frac{dp}{da} < 0, \tag{7}$$

whose sign follows from (4), (5), and the negative slope of i's demand curve, $D^i(p)$. By (7), a fall in cost in country i ($da < 0$) will lead to an increase in its equilibrium output, S^i, as asserted.

Finally, we show that

Proposition Four. A decrease in country i's costs of producing output D may not produce a net increase in employment.[9]

If, for example, wages in i remain unchanged, and a constant proportion of expenditure on commodity i is spent on labor, employment in i devoted to commodity D is given by kpS^i for some constant, k. In equilibrium, this employment is equal to

$$kpS^i(p,a) = k[pD^i + p(D^w - S^w)], \tag{8}$$

where the first term inside the brackets is total revenue from domestic sales of the item, and the remaining expression inside the brackets represents total revenue from exports. Obviously, if both demands are price inelastic, these will both decline in value when p is reduced as the result of a decrease in a; in that case, employment in this industry in i will decline.

This result is consistent with (7) which requires output to increase when a declines, for the less-expensive (more polluting) process may well require less labor (as well as other inputs) per unit of output. Specifically, if we define $L(a)$ as the number of labor hours used per unit of output, our

[9] The decrease in employment will, of course, be accounted for by the decreased use of labor for pollution control, which means that there will be an indirect decline in the quantity of labor utilized per unit of output of D.

employment demand becomes $L(a)S^i(p,a)$, and $d[L(a)S^i(p,a)]/da = L(a)\,dS^i/da + S^iL_a$. Because L_a may plausibly be taken to be positive, the sign of this expression is indeterminate for, by (7), the first term is negative,[10] but the second will then be positive.

4 Longer-run consequences for specialization patterns

The choice of technique of production also has longer-run implications for the international pattern of specialization. We recall that implicit in our model is the production of other goods, some of which presumably are not sources of significant damage to the environment. Let C be the collective designation of such items whose production generates no external costs. By not eliminating its smoke, i will affect the private comparative costs in the two countries: at any given levels of output, w will have less of a comparative cost advantage in the supply of D than it would otherwise. Unless the additional marginal cost of producing D by low pollution methods is completely covered by subsidy, w will be led permanently to produce more of the clean commodity, C, and less of D, than it would[11] if i were to adopt pollution controls for the manufacture of D, and the reverse will be true in country i.

Thus, we have the obvious but very important

Proposition Five. A country that fails to undertake an environmental protection program when other countries do so increases its comparative advantage (decreases its comparative disadvantage) in the production of items that damage its environment; in the absence of offsetting subsidies, this will encourage greater specialization in the production of these polluting outputs.

In sum, as a result of its failure to limit pollution, country i will tend to become specialized more than it would have otherwise in the production of items that generate pollutants. In particular, less-developed countries that choose uncontrolled domestic pollution as a means to improve their economic position will voluntarily become the repository of the world's dirty industries. This means that they will undertake to provide benefits to everyone else by taking on the world's dirty work. The willingness of the poorer nations to bear the social costs produces effects analogous to those that would result from an increase in productivity in the manufacture

[10] Note that the first term contains dS^i/da, not $S_a^i = \partial S^i/\partial a$. It thus includes the indirect effect of a on price, as taken into account in (7).

[11] This is, of course, just a special case of the general proposition on comparative costs and international patterns of specialization.

of polluting outputs. However, this apparent increase in productivity is more accurately described as a peculiar export subsidy, one that conceals, more effectively than most, what the exporting country is giving away to its customers.

5 Tariff policy for externalities that cross a nation's borders

We turn now to the second major issue considered in this chapter: the problem of transnational pollution. In international trade, a tariff plays somewhat the same role as an excise tax for domestic outputs. It would thus seem that, where some import generates costs that are external to the exporting country and that fall on persons in the country in which the good is imported, a tariff on the offending commodity may, at least in principle, become an appropriate instrument to deal with the problem.

It will be argued that such a second-best tariff usually exists, provided the country that is the victim of the externality is also an importer of the commodity whose production process generates it, and that the victim nation has market power sufficient to influence, through its tariffs, the prices (output) in the generating country.

As we will see, the tariff that best protects the interests of the importing country is not necessarily the one that yields an (second-best) optimal allocation of resources for the world as a whole. In part, this is just an extension of the observation that, in the absence of externalities, a tariff may be beneficial to the country that imposes it even if it should be undesirable when considered from a more cosmopolitan point of view. We turn consequently to an examination, first, of the tariff level that best protects the victim of a transnational externality, and, second, to the tariff levels that can help to sustain a (second-best) Pareto optimum when the polluting country does not attempt to regulate its emissions or at least does not take adequate account of the effects on the victim nation.

We begin by observing that although a tariff can play somewhat the same role for transnational externalities that a Pigouvian tax performs within a single political jurisdiction, the former will generally not be a perfectly satisfactory substitute for the latter. Thus, suppose that the polluting country enacts an emissions tax based on marginal damage within its borders, and each other affected country imposes a tariff equal to the marginal damage suffered by its own nationals. The resulting set of taxes and tariffs will not generally yield the prices and the allocation of resources that would have resulted if the polluting country had imposed an internationally optimal Pigouvian tax on its emissions – a tax equal to marginal damage in all countries together.

There are several reasons why the two will not be equivalent. First, in the emitting country, prices will not be affected *directly* by duties in countries that import the product.[12] Hence, domestic prices in the producing nation will be different (usually lower) than if producers had been taxed for damage they impose anywhere in the world.[13] Second, the duty in any importing nation will also reflect only those detrimental effects of the externality that fall within its borders, so that its nationals, too, will pay less than the full social costs of their consumption. An extreme case is that in which country *A* produces the externality, country *B* suffers from the externality but imports none of the item whose manufacture generates it, and country *C* imports the item from *A* but receives none of the damage. In that case, there will be no tariff levied on the item in response to its emissions, despite the transnational character of its effects.

Thus, our analysis of appropriate tariff policy will generally be a discussion falling within the theory of the second-best, for no set of tariffs will be capable of sustaining the Pareto optimum that would be yielded by the optimal Pigouvian taxes.

For the treatment of this problem, we have found a diagrammatic approach to the issue more fruitful than a more formal analysis. For we are dealing with a second-best problem in which resource allocation is constrained by the nonoptimal behavior of one of the countries, and so any maximization calculation will be complicated considerably by the behavioral relations that must consequently be included among its constraints.

Even the diagrammatic construction is not completely elementary, because the problem is one in which consumption in one country increases *production* in another, and that, in turn, raises the transnational flow of pollutants. As a result, we cannot use an Edgeworth-Bowley box diagram that takes the total quantities of commodities produced to be given. After all, the purpose of the tariff is to control the flow of pollutants via its effect on the polluting output, and so an analysis of the problem cannot assume away the possibility of output changes. Fortunately, Meade has provided an ingenious modification of the box diagram that permits production changes to be taken into account.[14] For this purpose, he transforms the

12 Of course, the tariff will affect excess demand in the world as a whole and so it will influence prices in other countries, but although this effect can be important, it is an indirect consequence of the duty, differing fundamentally from that of an equal tax imposed on all consumers.

13 Put in a different way, with optimal Pigouvian taxes, relative commodity prices are the same for all consumers, but with any tariff, relative prices will differ in the exporting and the importing country and that is clearly inconsistent with Pareto optimality.

14 See James E. Meade, *A Geometry of International Trade* (London: Allen and Unwin, 1952), Chapters i–iv.

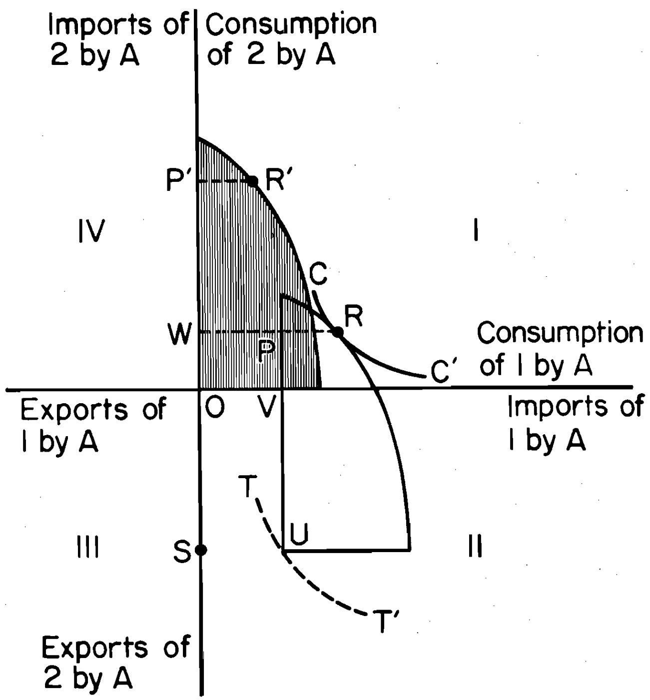

Figure 16.2

social consumption indifference curves into what have been described as *trade indifference curves* corresponding to the possible exchange positions of the two countries after both their exchange and their production decisions have been made.

Because the device is not as widely known as the ordinary box diagram, it will perhaps be useful to summarize its construction briefly. In Figure 16.2, let the points in quadrant I represent the consumption of the two goods in country A, and let the shaded area represent A's production-possibility set. Now consider any point in this quadrant, such as R. If R is to be an equilibrium point, the ratio of prices of the two goods must be given by the slope at that point of CC', the consumption indifference curve of A through R. Similarly, the equilibrium outputs of the two commodities in A will be given by R', the point with the same slope on A's possibility locus. To determine what exports and imports will be required to permit the consumption represented by R when production is represented by R', we now interpret the axes of the diagram to represent imports and

exports (negative imports) of the items. Next, we shift the axes of the production-possibility set until the set is tangent to CC' at R. We see at once that, because at the equilibrium corresponding to R, quantity $P'R' = PR$ of item 1 is produced while WR is consumed, the difference $WP = SU$ of item 1 must be imported.

In exactly the same way, it follows at once that in these circumstances A can export VU of item 2. Hence point U, the shifted origin of the production-possibility set, indicates the export-import combination corresponding to consumption at point R in country A. Repeating this construction for other points on the consumption indifference curve CC', we obtain the locus TT', which is the corresponding trade indifference curve that we wanted to construct. That is, any point on TT' represents a combination of imports and exports that permits A to consume a combination of goods represented by a corresponding point on CC'.

6 Alternative tariff policies for transnational pollution[15]

In the following discussion, it will be assumed that item 1 is a good whose output produces transnational pollution affecting A, and that A is an importer of good 1 and an exporter of 2. Hence, the following diagrams will correspond to quadrant II of Figure 16.2.

[15] A simplified formalization of the issue may help to clarify the nature of the discussion that follows. We have two commodities, 1 and 2, and two countries, A and B, and we let

x_{1a} = consumption of good 1 in country A, and so on,
$z = z(x_{1a}, x_{1b})$ = the output of pollutant,
$U^a = U^a(x_{1a}, x_{2a}, z)$ and
$U^b = U^b(x_{1b}, x_{2b}, z)$ be social utility functions for countries A and B, respectively.

We will examine, at least cursorily, each of the following three maximization problems for country A acting alone:

(i) Maximization of A's welfare with no consideration of effects on B; this involves the choice of a tariff level by A by simply maximizing U^a;

(ii) Imposition of a "Pareto-optimal" tariff. This is the second-best tariff that

maximizes $U^a(\cdot)$

subject to $U^b(x_{1b}, x_{2b}, z) \geq U^{*b}$ (some constant);

(iii) Imposition of a *quasi*-Pareto-optimal tariff that takes no account of the social cost of the externality in B, on the grounds that, by adopting no externality control measures, B has, in effect, chosen politically the utility function $U^b(x_{1b}, x_{2b}, 0)$, which assumes away emissions damage. This then calls for

maximization of $U^a(\cdot)$

subject to $U^b(x_{1b}, x_{2b}, 0) \geq U^{*b}$ (constant)

For reasons that will be indicated later, most of our discussions will deal with cases (i) and (iii) because there is relatively little we are able to say about case (ii).

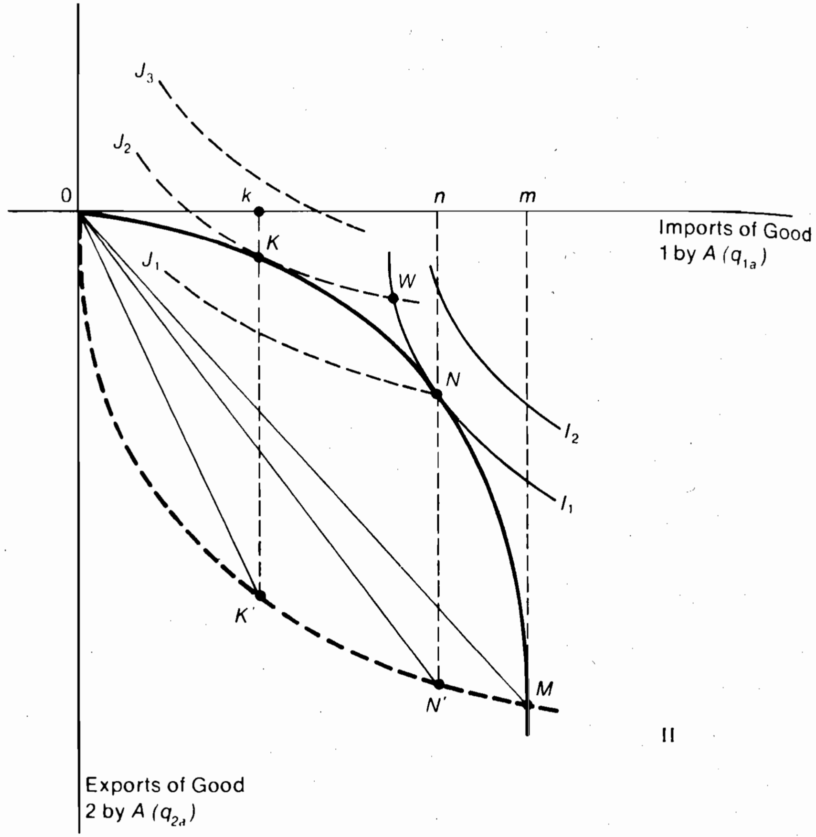

Figure 16.3

In Figure 16.3, an abscissa, q_{1a}, represents A's imports of 1, the externality-generating good,[16] and q_{2a} represents its exports of good 2. The initial (zero trade) point is, of course, the origin. The lower, broken offer curve, $OK'N'M$, is that of A, the importer[17] of 1, and the solid upper

[16] We deliberately change our notation from that used in earlier sections in this chapter to emphasize that 1 is an output that generates *transnational* pollution: in contrast, the effects of D, the polluting good of Sections 1–4, were taken to remain entirely within the boundaries of the country that produces it.

[17] The importing country's offer curve, of course, represents what it *would* be willing to exchange if its international trade were carried out under conditions of pure competition without governmental interference. Because the remainder of the discussion examines the effects of a tariff by the importing country, its offer curve is relevant largely as a

offer curve, $OKNM$, is that of the exporting country. Point M is, as usual, the free-trade equilibrium point, and m is then the quantity of item 1 imported.

First, suppose that A decides to levy a tariff that is designed to exploit B but that does not take pollution into account. Let the curves labelled I_i represent the family of A's trade indifference curves relating exclusively to the private benefits of the imports to A's consumers of 1. Given the shape of B's offer curve, and assuming, as is usual in such models, that the exporting country is passive and does nothing to protect itself from exploitation by the importing nation, it follows that country A maximizes its own welfare at N, the point of tangency between the exporting country's offer curve and one of A's indifference curves. This point can be attained by A's imposing an import duty sufficient to restrict the import demand to n. This involves a change in relative prices from that given by the slope of price line OM to that given by ON', where N' is the point on A's offer curve corresponding to import level n.

So far, this is all review of the standard analysis of the "optimum"[18] tariff. Now let us see what happens if the pollution (say, smoke) arising from the externalities is taken into account. We can construct a new family of community indifference curves taking cognizance of *all* of the costs imposed by q_{1a}. The external cost (indirectly) generated by q_{1a} can be interpreted to mean that the relative social marginal utility of 1 is smaller

standard of comparison to show how the free-trade solution differs from that in which a tariff is imposed. Assuming that industry in A is competitive, however, the offer curve continues to indicate the internal prices (after payment of duty) necessary to restrict the import demand for 1 to any given level.

[18] In the literature, the tariff level that maximizes a country's monopolistic gains from trade is often referred to as *the optimum tariff*. Obviously, this does not correspond to a universal welfare maximum of any sort. In the remainder of the chapter, when we refer to a tariff as optimal we will mean that it can sustain a Pareto-optimal position for the affected countries, or at least one that is second-best.

One advantage in using the standard *optimum tariff* as a starting point for our discussion of the second-best tariff level in the presence of externalities is that it does suggest an important relationship between the two. Both of them require a degree of influence on international prices by the country that imposes them. If that country is so small that its actions do not affect the prices of the countries that export to it, then both the optimum and the second-best tariff levels will be zero.

The method of analysis adopted here, comparing levels of optimal protection, is the method employed by Bhagwati and others to examine a variety of problems in trade theory. There is, indeed, a large class of problems that can best be explored by starting with an optimum tariff rather than free trade, in order to avoid confusing the consequences of departing from free trade with the consequences of the particular problem under study. See Jagdish N. Bhagwati, "Optimal Policies and Immiserizing Growth," *American Economic Review* LIX, no. 5 (December, 1969), 967–70.

than its relative private utility,[19] because an increase in q_{1a} induces greater *production* of good 1 by the exporter, B, and hence increases the transnational pollution suffered in A.

Because the slope of an indifference curve for two commodities 1 and 2 at any point is equal in absolute value to mu_1/mu_2, the ratio of the marginal utilities of the two commodities at that point, it follows that through any point W in Figure 16.3, there will be what we may call the *social* indifference curve J_i (the curve that takes externalities into account), which will be flatter[20] than the *private* community indifference curve, I_i, through that point. Figure 16.3 depicts a family of such social indifference curves, the curves labelled J_i $(i=1,2,3)$. The exporter's offer curve, $OKNM$, has, on the usual assumptions, been drawn concave downward. This implies that the point of tangency, K, between this offer curve and one of the social indifference curves must lie to the left of N, the point of tangency with a private community indifference curve. Curve J_1, the J curve through point N, lies below the offer curve to the left of point N, and so better points from the importer's point of view must also lie to the left of N. The tariff corresponding to K is, as before, indicated by the relative slope of OK', the price line through K'. Because OK' is steeper than ON', the tariff for A now generates an even greater departure from the price ratio than would emerge under free trade. That is,

Proposition Six. The tariff that maximizes the importing nation's net gain in the presence of external costs imposed by the imports is higher than that which would do so in the absence of externalities, all other things being equal.

So much for the interests of the country that levies the tariff. We turn now to a somewhat less parochial view of the matter. Figure 16.4 depicts two contract curves – the locus of what may be called "quasi-Pareto-optimal points" corresponding to the cases where the transnational externalities are not, and that in which they are, taken into account. The curves labelled E are the community indifference curves of the exporting

[19] Here it seems easier to take the pollution resulting from increased output of item 1 to affect the indifference curves through the disutility it imposes on consumers rather than the production of other goods. Of course, the externalities may also affect the production-possibility locus by increasing the resources cost of some (or all) outputs.

[20] Reverting to the notation of an earlier footnote, $U^a[x_{1a}, x_{2a}, z(x_{1a}, x_{1b})]$ is A's utility function. Then the absolute value of the slope of the indifference curves II' that ignore the externality is U_1^a/U_2^a. That of the JJ' indifference curves is $(U_1^a + U_z^a \partial z/\partial x_{1a})/U_2^a$, which takes into account the smoke damage resulting from increased production of good 1. Because smoke creates a disutility, $U_z^a < 0$, so we may expect the second fraction to be smaller than the first; that is, the JJ' curves can be expected to be flatter than the II'.

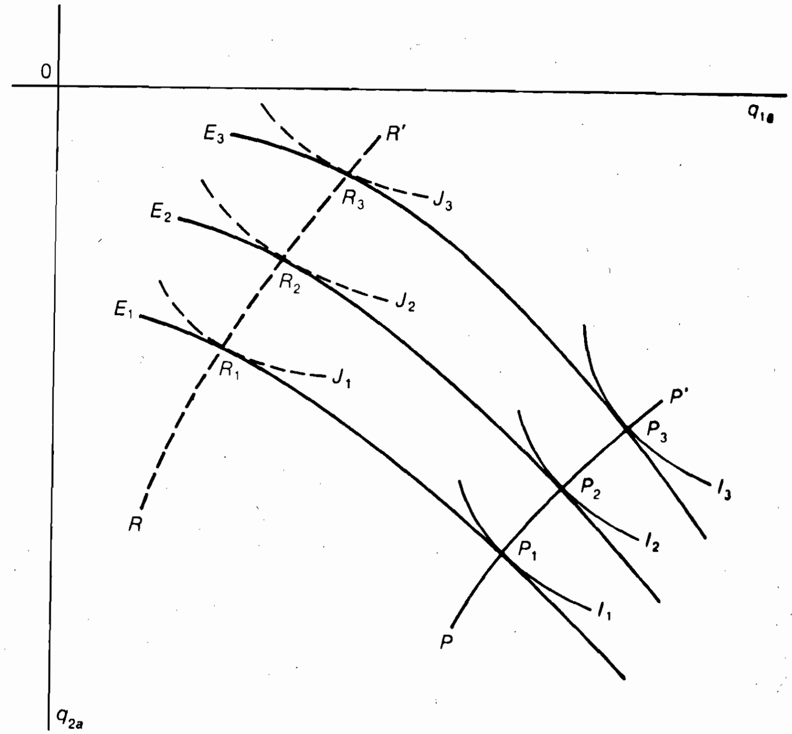

Figure 16.4

country, which are taken to be based on private preferences in B and to ignore external damage in that country.[21] Once again, the I and the J curves are the community indifference curves of A, the importing country, corresponding respectively to the cases where externalities are not, and are, included in A's welfare calculations. Because the former are steeper than the latter, the tangency point, P_i, of one of the I curves with an E curve will lie to the right of R_i, the point of tangency of a J curve with the same E curve. Hence, contract curve RR', the locus of all the R_i tangency points that take externalities into account, will be entirely to the left of PP', the contract curve that ignores the externalities.[22]

[21] In terms of the first footnote of this section, we are dealing with case (iii) in which B's (implicit?) political decision to ignore domestic external effects is respected.

[22] As we have noted, this argument takes into account only the externalities that fall on the importing country, A. By showing the effects of the externalities on the E curves, we can also take account of effects on B. It follows by the same argument as before that the

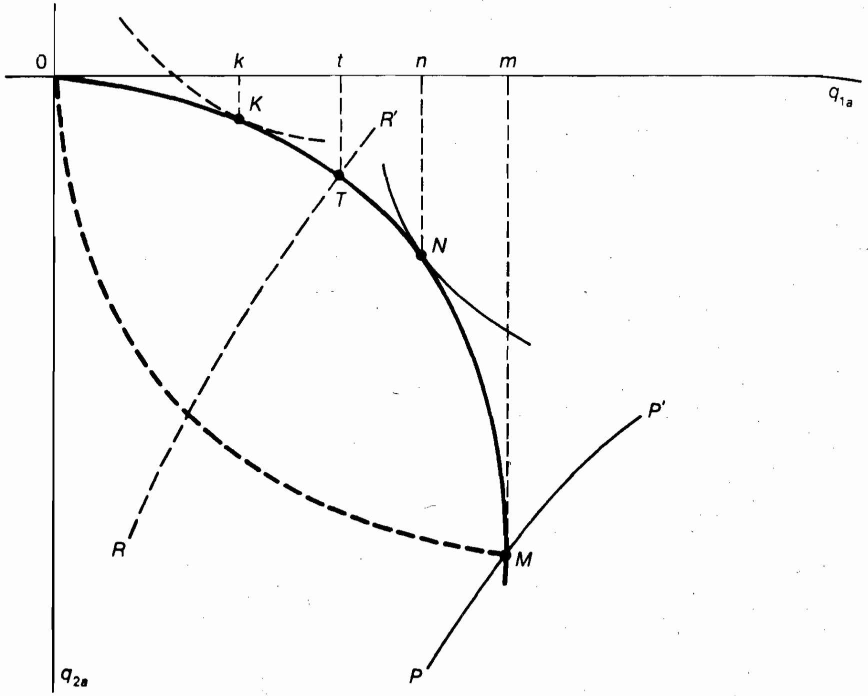

Figure 16.5

In Figure 16.5, these two contract curves are brought together with the two offer curves. In accord with the usual argument, the free-market equilibrium point, M, at which the two offer curves intersect, lies on the zero externalities contract curve, PP'. But because externalities *are* in fact present, there is nothing optimal or necessarily desirable about points on this pseudocontract locus. The optimal point on the exporting country's offer curve (which we continue to take as given) is T, the intersection point of that offer curve with RR', the true locus of Pareto-optimal points. Clearly, this must lie to the left of the market-equilibrium point, M.

Footnote 22 *(cont.)*
external damage yielded by production of item 1 will flatten B's as well as A's indifference curves, so that it becomes very difficult to say much about the position of RR'. The argument of Chapter 7 shows that, with appropriate convexity assumptions, RR' will still lie *somewhere* to the left of PP' (that is, some reduction in use of commodity 1 will be required for Pareto optimality). Hence, some positive tariff will still be appropriate.

As a final step in our diagrammatic discussion of tariffs and externalities, we can now relate these two points, M and T, to the points N and K of Figure 16.3 that ignored the interests of country B. As we know, point N must lie to the left of M. For exactly the same reason, K must lie to the left of T. For T is simply the market-equilibrium point that would prevail (with an appropriate distribution of income) if market prices were adjusted to reflect the full values of the social costs of goods 1 and 2, and K is the point that corresponds to N in these circumstances.[23] It follows that k, the level of importation that best serves the importing country's interests, will be smaller than t, the internationally optimal level of imports. Thus we obtain

Proposition Seven. If the external effects fall entirely on the importing country, the internationally quasi-optimal tariff (corresponding to T) will be smaller than that (associated with point K) which maximizes the importing country's total gain from exploitation of its monopoly position.

We see from this rather lengthy diagrammatic discussion that the presence of external costs can, at least in principle, affect the role of tariffs. We have the basic result

Proposition Eight. In the presence of transnational pollution with no collective regulation, zero tariff levels are generally not optimal.

In the presence of external costs, a tariff sufficient to reduce imports from m to t in Figure 16.5 will be required for the purpose.[24] Moreover, the narrow self-interests of the importing country will also call for a tariff higher than that which would be appropriate in the absence of externalities. In Figure 16.5, the tariff level must exceed that which would apply in the absence of externalities by an amount sufficient to reduce the imports of good 1 from n to k. In general, if the externalities generated by the imports affect only the importing country, the tariff that is best from the point of view of both countries together will be less than that which maximizes the returns to the importing country alone.[25]

[23] Incidentally, there seems to be no general statement that we can offer about the relative positions of points N and T. Both must lie on $MNKO$ between points M and K, but which will lie to the right of the other depends upon the comparative shapes of the families of indifference curves I and J in a manner that is not generally predictable. In brief, we cannot say whether the tariff that maximizes A's welfare (with externalities ignored) by manipulation of the terms of trade is greater or less than the internationally optimal tariff with external effects accounted for.

[24] This suggests also that where external benefits are present, a negative tariff may be appropriate.

[25] However, even this conclusion can no longer be taken for granted if the exports also impose unregulated pollution costs in the exporting country (for reasons indicated in note 23).

It should be noted once again, in concluding, that even the Pareto-optimal tariff, that corresponding to point T in our discussion, will only sustain a second-best optimum, not the optimum that could have been achieved by a set of internationally optimal Pigouvian taxes in the country where the externality is generated. For the tariff restricts consumption of the externality-generating good in the importing country, but it does not restrict corresponding consumption of the item within the country that exports both the good and the pollution. Consequently, such a duty must inevitably distort international consumption patterns. It is a desirable policy measure only if a more direct attack on the problem is not possible.

7 Transnational pollution tariffs as instruments of practical policy[26]

We have seen that the adoption of a second-best duty, in principle, will be useful for a country whose transnational pollution problems are in part generated by its own imports, and whose market power is substantial. However, refined optimality calculations, such as those just discussed, are likely to have little bearing in practice on the use of import duties as a means to control transnational environmental damage. But all this does not mean that the approach itself has little relevance in application. Where an exchange process has a relatively small number of participants, as in international trade or in oligopoly situations, prices can affect resource allocation in at least two different ways. First, they influence the pattern of excess demands and, hence, relative outputs in the usual way. Second, pricing policy can serve as part of a strategy in which one participant threatens to undertake price-influencing measures that would be damaging to some other participant in order to force the latter to modify his behavior. This section considers tariffs both in the role normally assigned to taxes in the externalities literature, and as part of a threat strategy designed to induce the generator of transnational pollution to modify its behavior.

Because the record of international cooperation on other critical matters hardly inspires confidence in the prospects for efficacious multilateral measures for the protection of the environment, it may be essential to design instruments whose effectiveness does not require the unanimous consent of those involved. Suppose half the nations bordering a body of water were to agree on some set of emission standards. Without unanimous consent, the remaining countries in the group might well continue

[26] We are grateful to Bertil Ohlin for suggesting to us the general ideas of this section.

to pour their wastes into the waterway as before, unless someone were to produce some device to induce a change in their behavior.

The pollution tariff (which may give less offense if called something like "a transnational resources charge") is such a device. It does not require the consent of the polluting country. Indeed, if several countries decide (jointly or independently) to adopt such a measure, they need not agree to use a similar schedule of charges or on uniformity of other provisions. Thus, the danger that the process of negotiation will preclude any effective program is minimized because little or no negotiation or coordination is required.

This approach also has several characteristics that distinguish it from protective tariffs of the classic beggar-thy-neighbor variety. First, although the usual tariff is likely to lead to a misallocation of resources and reduced economic efficiency, a well-designed transnational resources charge can be expected to improve them.

But there are other significant differences. The ordinary tariff depends for its effectiveness on the absence of similar action by other countries. If everyone builds a system of protective tariffs against everyone else, all countries are likely to lose in the process. In the case of the transnational resources charge, the more widely it is adopted the more salutary it is likely to be. If polluting country *B* finds its exports subject to an environmental charge only by (small) country *A*, then it need not give the matter much attention. But if a large number of importers of its products adopt such a measure, the costs of its damage to the international environment will effectively come home to roost.[27]

Suddenly, its exporters will find their financial interests reversed. In the absence of a widely accepted resources charge, they can be depended upon to resist any substantial program for the protection of the environment for fear that its cost will reduce their ability to compete on the international market. But with duties levied on their products in many of the world's markets so long as they *fail* to adopt an appropriate program, they will recognize soon enough that promotion of their foreign sales in fact requires environmental protection measures at home.

Of course, one hesitates to provide any argument to the opponents of free trade and to open the doors to new rounds of restrictive measures brought in under the banner of environmental protection. Perhaps the threat of such measures may help to facilitate the process of direct negotiation and may lead to cooperative steps that will be effective in controlling transnational pollution. Thus the notion of transnational resources

[27] Of course, if the prime objective of the tariff is to coerce the transnational polluter to take remedial action, there is no reason to levy it only on the commodity that generates it. Any exports of the offending country may be fair game for the purpose.

charges may help in one of two ways: either as a threat that helps to stimulate effective cooperation, or by serving as an instrument of second resort in the event some countries, by refusing cooperation, continue to pose a threat to health and welfare in other nations.

As a final point, one should be under no illusion that any transnational pollution charges adopted in practice will bear a marked resemblance to the quasi-optimal levies emerging from the theoretical models of the preceding sections. They will presumably work in the right direction, and serve primarily as a stimulus for a change in practices by a polluting country, not as an instrument for the fine tuning of international resource allocation. This suggests that other economic penalties, such as quotas and outright import prohibitions, may be able to do the job as well and that they will perhaps run into fewer practical difficulties. That may be so, though it is unlikely that they will have the sanction of theoretical analysis, for whatever it may be worth.

8 The potential role of effluent fees and marketable permits for the control of transnational pollution

Up to this point, we have considered only a single policy instrument, tariffs, for the regulation of pollution crossing national borders. We have found a potential, second-best role for such tariffs. At the same time, however, we have concluded that they are not a fully satisfactory substitute for the kinds of charges and permits that have been the central subject of most of this book and that can efficiently internalize the externalities that are the source of most pollution problems. This leads us to ask whether there may not be some way in an international setting to make use of these preferred policy instruments for the management of environmental quality.

In principle, the analysis of the preceding chapters is fully applicable to the regulation of transnational pollution. As Ruff has noted, "If we regard individual nations as sovereign, with power to control their own citizens in any way they choose, then the transfrontier pollution problem is no different from an ordinary problem of externalities among a small group of individuals."[28] Although this is, of course, true, the problem is that national sovereignty does, in effect, impose a further constraint on the problem. As Ralph d'Arge and others have emphasized, we can hardly expect a polluting nation to place a tax on its own polluting industries in order to reduce the damages accruing outside its borders.[29] A sovereign nation will have little incentive to impose costs on itself for the benefit of its neighbors. Obviously, this is also true of an individual, but here some government is in a position to impose the required fees. There is, however, no "world government" with taxing prerogatives.

[28] Larry E. Ruff, "The Economics of Transnational Pollution," in Organization for Economic Co-operation and Development, *Economics of Transfrontier Pollution* (Paris: OECD, 1976), p. 8.

The presence of transnational externalities implies that gains can be realized from cooperative behavior. There must exist some reordering of activities (perhaps including side payments) that will make all national parties to the externality better off. The problem is that of finding some institutional structure that will facilitate the appropriate agreements. One thing the discussion does make clear: Such a structure must be one that, in fact, makes all parties better off. Otherwise, any agreement is unlikely. In short, political feasibility requires us to introduce a further constraint on any policy prescriptions for the control of transnational pollution: Such policies must constitute a Pareto improvement for all nations concerned. We thus seek structures that promise both a Pareto efficient outcome *and* (as discussed in the preceding chapter) a *move* representing a Pareto-improvement.

Transnational pollution can take any of several forms. In the simplest case, the polluting emissions of one nation can flow across its borders and damage its neighbors. This kind of unidirectional transnational pollution encompasses important cases like sulphur deposits in the form of 1.
acid-rain (or solid particles) or the emission of various wastes into a river that pollute the downstream waters flowing into a neighboring country. Alternatively, transnational pollution may be bidirectional in character: 2.
Countries that both border on a lake, for example, may pollute waters that they share in common. Obviously, the form of the transnational pollution in question has implications for the most promising approach to environmental management. In one sense, the bidirectional case (although in some ways more complex) may be the easier problem to resolve since both parties have a direct incentive to engage in negotiations to reduce the environmental damages; both nations in such cases have something to gain.

To sharpen the issue, we consider only the unidirectional case. Our objective is neither to provide a rigorous analysis nor to propose a full policy prescription. Instead, our more modest goal is simply to indicate some of the implications of the transnational setting for international environmental policy. Suppose that country *A* is the source of polluting emissions

[29] Ralph C. d'Arge, "On the Economics of Transnational Environmental Externalities," in Edwin Mills, Ed., *Economic Analysis of Environmental Problems* (New York: Columbia University Press, 1975), 397–416.

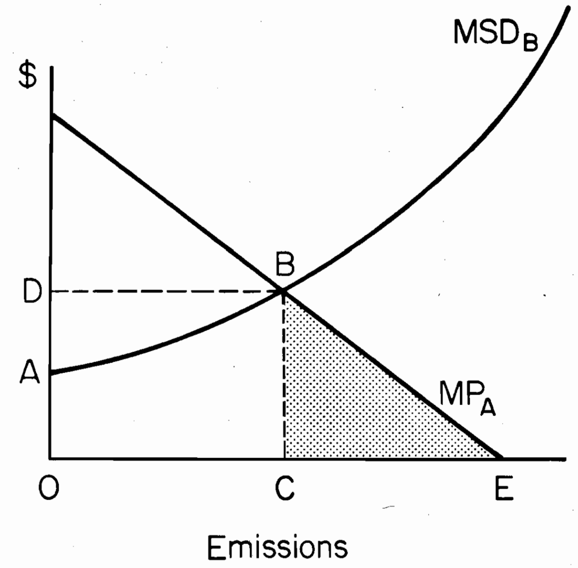

Figure 16.6

that cause environmental damage in country B. Figure 16.6 depicts (in terms of a common numeraire) the marginal social damages (MSD_B) accruing to country B and the marginal product (or marginal abatement cost) function (MP_A) of country A. The globally efficient policy would obviously be one that restricts emissions in country A (in an efficient manner) to the level OC. Our quest is for a procedure that can accomplish this, subject to the constraint that both countries are made better off.

In order to test whether the proposed policy promises a Pareto-improvement, we must first determine the relevant point of departure – a benchmark level of emissions. As Robert Preece has argued, a sensible choice here is the "no-policy" level of emissions, OE.[30] This is the point that would emerge in the absence of any agreements between the two countries. We thus seek a procedure that will lead to a reduction in waste emissions from OE to OC in such a way that social welfare rises in both countries. One point is immediately evident. We cannot simply rely on a program of pollution abatement in country A, for this would impose costs on A with no offsetting benefits to the polluting country. The *OECD's*

[30] Robert S. Preece, *The Economics of Transnational Pollution: An Evaluation of the Role of Bilateral Bargaining in Determining the Efficient Pollution Level,* unpublished Ph.D. dissertation, University of Maryland. 1983.

Polluter-Pays-Principle is thus inconsistent with our insistence on a Pareto-improvement.[31] Mutual gains to the countries necessarily require the victim country B to make some payments to A. More specifically, we see that for country A not to be worse off, country B must pay, at a minimum, the total of abatement costs – that is, the shaded area CBE in Figure 16.6. In fact, the requirement that the process yield a Pareto-improvement implies a Victim-Pays-Principle! Moreover, we see from the figure that if the victim country B pays only for abatement costs, then B realizes all the gains from the agreement. This provides little incentive for country A to engage in such a program. One possible alternative is a subsidy payment from country B to A of OD per unit of abatement; this would serve to divide the gains from the program between the two countries.

Such a side payment from the victim to the polluting country would thus ensure that both countries are made better off overall from A's reduction in waste emissions. Country A must then, of course, adopt the requisite program to curb emissions to the agreed-upon level, OC. This country A could do, for example, by adopting either a program of effluent charges or a system of marketable emissions permits as described in earlier chapters. Such systems can, as we know, achieve the efficient level of emissions at least cost.

A fee regime or a system of marketable permits initiated through an auction would not, however, make polluters in A better off. They would suffer a financial loss from the program with no offsetting gains, and, for this reason, they can be expected to provide political opposition in spite of the payment by the victim nation. Is there some way to eliminate these losses to sources in A? One method is for the public environmental agency in A to subsidize the abatement activities of sources.[32] The government can use the payments from country B to subsidize the control efforts of polluters in A. As we saw in Chapter 14, however, the design of such programs is a difficult matter, for such subsidies can provide undesired incentives for the entry of polluting firms and for various kinds of strategic behavior.

There is an alternative approach that makes use of marketable permits. Suppose that country A were to issue permits to existing polluters equal to the current, "no-policy" level of emissions. These permits would be

[31] The Organization for Economic Co-operation and Development has endorsed the Polluter-Pays-Principle for the regulation of transfrontier pollution. For some collections of papers on this issue sponsored by the OECD, see *Problems in Transfrontier Pollution* (Paris: OECD, 1974) and *Economics of Transfrontier Pollution* (Paris: OECD, 1976).

[32] Preece *op. cit.* proposes a tax-subsidy scheme that would effectively subsidize existing sources for reductions in emissions.

issued free of charge to each source. Thus, if source X had been emitting 100 tons of the pollutant per year, then X would receive permits allowing annual emissions of 100 tons. The new twist is that representatives of the victim country would be allowed to participate in the market. More specifically, they could purchase permits from existing sources and then simply retire them from circulation as a means to reduce levels of waste discharges. In terms of Figure 16.6, the victim country would find it worthwhile to purchase the quantity CE of permits in country A. Over this range, the gain to B in terms of reduced damages would exceed the market-determined price of permits. In principle, then, the equilibrium outcome would coincide with the efficient solution. Moreover, all parties to the trades of permits would be better off, so the outcome would constitute a Pareto-improvement.

An "international" market in emissions permits can thus, in principle, satisfy our two criteria for an efficient mechanism for the control of transnational pollution. Although such a system constitutes a provocative approach to the transnational problem, some serious problems clearly beset its execution. Both countries will be tempted to engage in strategic behavior intended to affect the level of payments; country A, for example, may try to inflate the number of permits that it issues. Such behavior becomes even more likely because of the inevitable uncertainty in the valuation of social damages and abatement costs. Moreover, country B will require assurance that after the initial issue, country A will distribute no additional permits.[33] Safeguards against such behavior would obviously be necessary before one could make such a proposal credible in practice.

Finally, there is the troublesome ethical matter of the Victim-Pays-Principle that is inherent in this approach. As we have seen, this principle follows from our insistence on (1) a Pareto-improvement and (2) the designation, as the benchmark, of the quantity of emissions that would emerge in the absence of agreement. There are, however, extensive precedents in international forums for variants of the Polluter-Pays-Principle. In its 1972 declaration, for example, the U.N. Stockholm Conference on the Human Environment asserted that nations have "the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other States or of areas beyond the limits of national jurisdiction."[34] As the history of international environmental

[33] See, Preece *op. cit.* for an extended treatment of the issues of uncertainty and strategic behavior in bilateral negotiations.

[34] Ralph C. d'Arge and Allen V. Kneese, "State Liability for International Environmental Degradation: An Economic Perspective," *Natural Resources Journal* XX (July, 1980), 430. D'Arge and Kneese provide an excellent discussion of the alternative "principles" that might be used to assign responsibility for transnational pollution.

policy attests, however, this dictum has not been widely followed. In fact, the Polluter-Pays-Principle is more likely to constitute reason for delay and evasion than for an effective program to control transnational pollution. This is admittedly a difficult issue involving ethical as well as economic considerations. But it is our judgment that feasible and effective mechanisms for the control of transnational pollution will require cooperation and cost-sharing on the part of victim nations as well as polluting countries.

CHAPTER 17

National or local standards for environmental quality?

The preceding chapter explored the difficult issues that arise for the design of environmental policy in an international setting, issues whose source is, in part, the absence of an international agency with the authority to make decisions that can internalize the costs that nations impose on one another. This chapter returns to purely domestic issues, concerning itself with the choice of the appropriate authority for environmental decision-making. In particular, we ask whether it is preferable to delegate the determination of standards for environmental quality to regional (or "local") governments or to rely on a national environmental agency to set uniform standards for environmental quality that apply throughout the nation.

Current policy exhibits considerable ambivalence on this matter. In the United States, for example, the Congress, under the Clean Air Act, directed the U.S. Environmental Protection Agency to set national standards for ambient air quality. The EPA responded by defining maximum allowable concentrations for six so-called "criteria" air pollutants applicable to all areas of the country. In contrast, under the Clean Water Act, the individual states have responsibility for setting water quality standards.[1] U.S. policy thus relies on uniform national (minimum) standards for air quality, but state-specific standards for water quality. Which approach, a national or a decentralized determination of environmental standards, is the appropriate one?

The results of this chapter suggest that the answer to this question is not simply one or the other approach. Instead, the analysis points to the need both for centralized and decentralized participation in the setting of environmental standards. There is a real case for tailoring programs to the circumstances of individual jurisdictions, but at the same time there are other considerations that require certain centralized measures for effective environmental management.

[1] The EPA does, however, play a major role in water pollution control through the selection of abatement techniques and the evaluation and approval of state programs.

The most surprising result from this chapter emerges from a model in which different localities compete for jobs (or, more precisely, wage income) for their fixed labor forces through reductions in their local environmental standards. We find that, rather than leading to excessive levels of pollution, such interregional rivalry can be consistent with Pareto-optimal levels of environmental quality. The explanation is that within the model a region is effectively trading off environmental quality for additions to real output. Thus, no region gets something for nothing in this process, but gains only what it offers to society, at least at the margin. Matters can, of course, be quite different where regions engage in rent-seeking measures to attract capital that do not have as their counterpart changes in real output; for such measures the regional trade-off is no longer the same as that for society as a whole and excessive environmental degradation can easily result.

1 The case for "local" determination of environmental standards

On first inspection, basic economic analysis seems to provide an unambiguous answer to the question posed in the introduction to this chapter: standards should vary among jurisdictions in accord with local circumstances.[2] As we showed in Chapter 4, the economically optimal level of environmental quality is that for which the marginal social damages of waste discharges equal marginal abatement cost. Figure 17.1 depicts such an outcome. Suppose that MSD_1 and MAC_1 are, respectively, the marginal social damage and marginal abatement cost functions in jurisdiction one; then the optimal level of waste emissions is E_1. Other jurisdictions, however, will typically have different MSD and MAC functions; if, for instance, MSD_2 and MAC_2 are the curves for jurisdiction two, then the local authorities in two should adopt more restrictive measures on waste emissions to limit them to E_2.

Suppose that, instead of locally determined standards, a central environmental authority adopted a uniform set of standards for both jurisdictions – perhaps a compromise measure that restricts emissions to E_n in both areas (see Figure 17.1). This would involve an aggregate loss in welfare (relative to the decentralized solution) equal to the shaded area in the figure: the excess of damages over abatement costs over the range E_2 to E_n (the loss in jurisdiction two) plus the excess of control costs over damages from E_n to E_1 (the loss in jurisdiction one).

[2] Sam Peltzman and T. Nicolaus Tideman, "Local versus National Pollution Control: Note," *American Economic Review* LXII (December, 1972), 959–63.

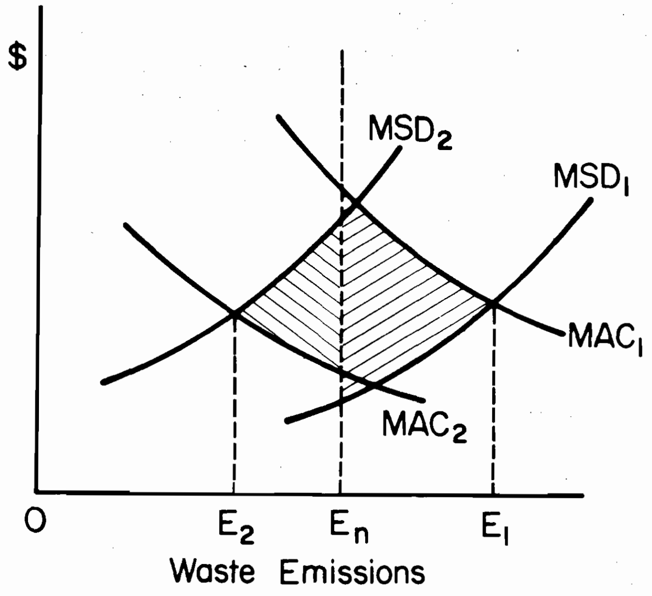

Figure 17.1

The magnitude of this welfare loss will obviously depend on the shapes and locations of the various *MSD* and *MAC* curves. And, in this regard, there are good reasons to believe that these curves will tend to vary significantly among jurisdictions. First, the *MSD* curves in Figure 17.1 represent a vertical summation of the individual curves of willingness-to-pay to avoid the damages associated with the indicated levels of waste emissions. Such a curve will thus depend both upon the number of people in the jurisdiction and on their tastes. We may expect, for example, that the *MSD* curve will be much higher in densely populated urban centers than in more sparsely populated rural areas simply because of the greater concentration of people in the former. Moreover, the geographical configuration of a particular area may translate a given quantity of waste discharge into a higher pollutant concentration (and thus more damage) than elsewhere. For instance, areas subject to frequent air inversions will need to restrict emissions more severely simply to attain the same air quality as jurisdictions with more favorable climatic circumstances. Second, *MAC* curves are likely to differ considerably from one jurisdiction to another. Abatement cost functions will vary, for example, with the industrial com-

position of an area so that it may be significantly more costly for some areas to limit waste discharges than others.

In short, the optimal level of environmental quality in one jurisdiction is unlikely to coincide with that in another. This suggests that the determination of standards for environmental quality should be a local task. However, it must be stressed that the appropriate "locality" is a jurisdiction sufficiently large to encompass the benefits and costs associated with the pollutant and its control. There are some pollutants (like those discussed in the preceding chapter) that can travel across jurisdictional boundaries, leading to troublesome phenomena such as acid-rain. Such pollutants involve interjurisdictional externalities and obviously cannot be managed properly through solely local decisions. However, the effects of many sorts of pollutants are primarily local; for these pollutants the argument in this section favors local determination of environmental standards.

2 The case for national standards

There is, however, a case for national standards. The argument in the preceding section assumed implicitly that localities, if left on their own, would in fact choose the locally optimum level of environmental quality. But John Cumberland (among others) has argued that this is unlikely to be so.[3] More specifically, Cumberland has argued for a set of national minimum standards for environmental quality to avoid "destructive interregional competition." The concern is that, in their eagerness to encourage business investment to create new jobs, state or local authorities are likely to compete with one another by reducing standards for environmental quality to lower the private costs to prospective business firms. This concern parallels the often-cited phenomenon of "tax competition" among jurisdictions to promote state or local economic development.

This argument is hard to evaluate. On the one side, the depreciation of environmental standards will itself impose costs on the local populace – and the extent to which it is in the local authority's interest (even in political terms) to promote economic development at the expense of the local environment is unclear. On the other side, the possibility of some "destructive competition" surely seems plausible and provides a basis for the widespread reluctance to vest responsibility for the setting of environmental

[3] See Cumberland's, "Efficiency and Equity in Interregional Environmental Management," *The Review of Regional Studies* X, No. 2 (1981), 1–9; and his "Interregional Pollution Spillovers and Consistency of Environmental Policy," in H. Siebert et al. (eds.), *Regional Environmental Policy: The Economic Issues* (New York: New York University Press, 1979), 255–81.

standards in states or localities. The difficulty in assessing this position stems, in part, from the paucity of analytical work providing any basis for normative conclusions about the effects of such competition on levels of local environmental quality.[4] Most discussion is typically informal, sometimes anecdotal, and doesn't establish any soundly grounded results. Consequently, we may be genuinely troubled by the potentially detrimental effects of interjurisdictional competition, but have little sense as to its likely frequency or importance. We shall attempt in the next section to set forth the rudiments of a model that can address this issue.

3 A simple model of interjurisdictional competition[5]

We present here a simple model, neoclassical in spirit, in which local jurisdictions compete for a nationally mobile stock of capital with the objective of increasing the local level of wages. In this model, an inflow of capital raises the capital-labor ratio, thereby increasing the marginal product of labor and the wage rate. The policy instrument used in this competition is a parameter that determines the aggregate level of waste emissions in the jurisdiction. The marginal private product of capital depends upon this parameter. If, for example, the community decides to restrict further the level of waste discharges in order to reduce local pollution, then a larger proportion of a given capital stock will have to be devoted to abatement efforts with a consequent reduction in the productivity of capital in the generation of saleable outputs. Such a measure would serve to deflect capital to other jurisdictions where it would earn a higher rate of return. The model thus embodies a straightforward trade-off between local wage income and the level of environmental quality.

Although the analysis will focus on a single jurisdiction and be partial equilibrium in form, this jurisdiction is taken to be one of many. The jurisdiction is, however, assumed to be of sufficient size to encompass within its borders all the pollution it generates. In addition, we assume that individuals who work in the jurisdiction also live in it (i.e., there is no commuting to work across jurisdictional lines).

[4] For an exception, see William A. Fischel, "Fiscal and Environmental Considerations in the Location of Firms in Suburban Communities," in E. Mills and W. Oates, Eds., *Fiscal Zoning and Land Use Controls* (Lexington, Mass.: D.C. Heath, 1975), 119–74. Fischel shows that in a simple model in which firms pay communities an "entrance fee" in compensation for environmental damages, a socially efficient allocation of firms and pattern of environmental quality results.

[5] The model presented in this chapter is a truncated version of an expanded model in a paper by Wallace Oates and Robert Schwab, "Economic Competition among Jurisdictions: Efficiency Enhancing or Distortion Inducing?" Revised draft (June, 1987). The expanded model incorporates both local environmental standard setting and the local taxation of capital.

Within this general framework, we take each jurisdiction to produce a private good, X, with the use of three inputs: labor (L), capital (K), and waste emissions (E). The jurisdiction thus has a production function of the form

$$X = F(K, L, E). \tag{1}$$

We assume further that this production function exhibits constant returns to scale and the other nice curvature properties of a standard neoclassical production function. We noted earlier that environmental policy in the jurisdiction will consist of the choice of the aggregate level of permissible waste discharges, $\sum E$. We will assume, in addition, that this aggregate is divided among firms according to a measure of their level of productive activity – more specifically, according to the quantity of their labor input.[6] Since the stock of labor in each community is, by assumption, fixed, it follows that the choice of environmental policy leads to a particular emissions-labor ratio. With this proviso, we can rewrite (1) in the form

per labor unit

$$X = Lf(k, e) \tag{2}$$

where k is the capital-labor ratio and e is the emissions-labor ratio. Note that, although the production function has the property of constant returns to scale in all three inputs, our assumptions concerning the character of environmental policy imply that firms can behave as though there were constant returns to scale in just the purchased inputs, labor and capital. For if a firm doubles its capital and labor inputs, it may also double its waste discharges and, hence, its output. Using subscripts to denote partial derivatives, we can write the marginal products of capital, waste emissions, and labor as $F_K = f_k$, $F_E = f_e$, and $F_L = (f - kf_k - ef_e)$, since

$$LF_L = F - KF_K - EF_E = Lf - Lkf_k - Lef_e.$$

We also assume that marginal products are diminishing and that a rise in e increases the marginal product of capital; thus, f_{kk} and f_{ee} are negative and f_{ke} is positive.

The local jurisdiction is assumed to be small in the national markets for output and capital in the sense that it is a price-taker both for the output it sells and for the capital that it purchases. We assume that there is a fixed stock of capital in the nation as a whole, but that it is perfectly mobile across jurisdictions. Owners of capital, seeking to maximize their returns, will allocate this stock of capital among jurisdictions so that its

[6] This, as will become evident, turns out to be a very convenient way to characterize local environmental policy. It allows us to describe environmental policy in terms of a single parameter that enters both the production and utility functions.

rate of return (r) will be equal in all locations.[7] As price-takers, local jurisdictions thus treat this rate of return as a parameter; they behave like competitive firms with a fixed stock of labor that choose the amount of capital to employ. Capital thus receives its marginal product, which implies that the stock of capital in the locality will adjust so that $f_k = r$.

In contrast to capital, labor is completely immobile. The residence of workers is taken to be fixed by historical circumstances. Moreover, workers are assumed to be homogeneous and to work a specified number of hours per time period. Local labor markets are assumed to be perfectly competitive; in the model, this implies that the real wage equals the sum of the marginal product of labor and the additional output resulting from the increment in permissible waste discharges that accompanies the hiring of another worker. The real wage, w, is thus equal to $(f - kf_k)$ under constant returns to scale.

The jurisdiction is thus composed of a fixed number of identical worker-residents. Each of these residents possesses a utility function in which the level of utility depends on the level of consumption and the local level of environmental quality:

$$U = U(c, e). \tag{3}$$

Note here that e is a pure public *bad*; higher levels of e correspond to increased levels of pollution so that U_e is negative. Each resident has two sources of income: an exogenous component (y) and wage income (w). This results in the budget constraint

$$c = y + w. \tag{4}$$

The nature of the trade-off is now clear. The residents of a community can increase their wage income and, hence, their level of consumption by relaxing local environmental standards so as to encourage the inflow of capital. Higher levels of consumption are attainable at the expense of local environmental quality.

The issue of concern here is whether residents will tend to select levels of consumption and environmental quality other than those that are socially optimal. To investigate this, we must make some assumptions concerning the mechanism through which local collective choices are made. We will adopt the widely used median-voter model here. Since, however, everyone is identical, the outcome in the median-voter setting will coincide with one in which we simply maximize the utility of an arbitrarily chosen resident. The Lagrangian for our maximization problem is thus:

[7] We take the ownership of capital to be determined exogenously. Capital is traded in a national market so that residents in a particular jurisdiction may own capital that is located elsewhere.

$$\Gamma = U(c, e) + \lambda_1(c - w - y) + \lambda_2(f_k - r). \tag{5}$$

Solving for the stationary values of (5) yields as a first-order condition for our median-voter equilibrium:

$$-U_e/U_c = f_e. \tag{6}$$

We thus find that the jurisdiction will select a level of environmental quality such that the marginal willingness-to-pay (in terms of the numeraire consumption good) is equal to the "marginal product" of the environment (i.e., the increment to output resulting from a marginal increase in pollution).

It is a straightforward matter (which we include as the Appendix to this chapter) to show that social optimality requires that two first-order conditions hold: Equation (6) and a condition requiring the equality of the marginal product of capital among jurisdictions. This latter condition is satisfied in equilibrium by the efforts of capital owners to maximize the return to their capital.

We thus find that in our simple model of identical worker residents, the local setting of standards for environmental quality is Pareto optimal. There is no systematic tendency for jurisdictions to degrade their environments excessively in an effort to increase private income. The rationale for this result is clear: a move to a lower than socially optimal level of environmental quality generates an increment to wage income that is less than the value of the damage to residents from the increased pollution.

We can gain some further insight into this result by exploring the relationship between the incentives for local decisions on environmental quality and the social opportunity costs of these decisions. Local maximizing behavior implies that the incremental loss in wages (the marginal cost) of a marginal improvement in the environment equals the marginal willingness-to-pay (the marginal benefit). Otherwise local residents could increase their level of well-being by further adjustments in local environmental standards. Let us examine more closely the "wage effect" of environmental policy. We noted earlier that the real wage is

$$w = f - kf_k.$$

A change in environmental policy has two effects on the wage: a direct effect on the marginal product of labor associated with an altered emissions-labor ratio, and an indirect effect operating through the induced migration of capital and the consequent change in the capital-labor ratio. If we hold the capital stock constant, we find the direct effect (dw_d) to be

$$dw_d = (f_e - kf_{ke})de.$$

To determine the indirect effect, we recall that equilibrium of the capital stock requires that $f_k - r = 0$. If we take the total differential of this condition, we find that the change in the capital stock associated with a marginal change in e is

$$dk = -(f_{ke}/f_{kk})de.$$

The change in the wage resulting from this alteration in the capital stock will constitute the indirect effect (dw_i) of environmental policy:

$$dw_i = -(kf_{kk})dk = -kf_{kk}(-f_{ke}/f_{kk})de = (kf_{ke})de.$$

The sum of the direct and indirect effects is thus

$$dw = dw_d + dw_i = (f_e - kf_{ke} + kf_{ke})de = f_e de.$$

This is the increment in wages, the wage effect, of a marginal change, de, in environmental policy.

But f_e is also the marginal product of the environment; it is the contribution to output of a marginal change in environmental policy. Thus, the "output effect" (which represents the marginal social cost of another unit of environmental quality) is precisely equal to the marginal loss to the community in the form of decreased wage income (i.e., the wage effect). Social gains and costs at the margin thus coincide with those to the local community. It is this equality of the wage and output effects that results in the social optimality of local decisions. This calls attention to an important caveat: Any sort of imperfection in adjustment processes or in decision procedures that drives a wedge between the wage and output effects will be the source of distortions in local decisions on environmental quality. In the presence of such distortions, local choices will involve externalities consisting of movements of capital into or out of other jurisdictions that are not justified by social costs and benefits.

In sum, in this model localities competing for capital through their decisions on local environmental standards make choices consistent with social optimality, because what they gain in the form of higher wages corresponds at the margin precisely to what the workers contribute to social output. Consequently, a worker's trade-off between wage income and environmental quality is the same as society's trade-off between output and environmental quality. Matters can, however, be quite different where the purpose of interregional rivalry in environmental standards is to increase one region's tax revenues at the expense of another's. Since success in this effort may have no counterpart in increased social output, it may represent a form of rent-seeking behavior that can be expected to lead to less demanding environmental standards than social optimality requires.

4 An extension of the model to heterogeneous jurisdictions

Although the model presented in the preceding section captures the trade-off between wage income and local environmental quality, there is another facet to the local choice problem that is obscured by our assumed homogeneity of jurisdictions. In Chapter 15 on distributive issues, we saw that serious divergences in local environmental preferences have resulted from the varying interests of different local groups. In particular, we described a series of empirical studies that have found systematic differences on local environmental measures between higher-income, professional groups and blue-collar wage earners. In this section, we extend our basic model to encompass such diversity of interests and to determine its implications for local decisions on environmental programs.

To keep matters tractable, we assume that each jurisdiction contains two kinds of residents: wage earners (L) who realize some portion of their income from wages, and non–wage earners (N) whose entire income is exogenously determined. We continue to assume that all residents have identical utility functions. The difference in interests is clear. Wage earners (as before) have an incentive to reduce environmental standards to encourage the inflow of capital as a means of increasing the rate of wages. Non–wage earners, in contrast, have no such incentive; in this model, they will support all measures to improve environmental quality (i.e., to reduce e).

Suppose initially that the group of workers constitutes a majority of residents in the jurisdiction. More precisely, we assume that

$$\gamma = L/(L+N) \quad \text{where } \tfrac{1}{2} < \gamma < 1.$$

Under simple-majority rule, it follows that the median voter will be a member of the worker group so that the local decision on environmental standards will be dictated by worker interests. We thus obtain the first-order condition describing the median-voter equilibrium (as in the preceding section) by simply maximizing the utility of an arbitrarily selected worker-resident. Because the constraints on the problem are unchanged, our first-order condition is identical to that which we obtained earlier in Equation (6): We find that workers will choose a level of environmental quality such that the marginal willingness to pay *on the part of workers* is equal to the marginal product of the environment.

However, in our heterogeneous setting, it is easy to see that this outcome is no longer Pareto-optimal, for it neglects entirely the interests of non–wage earners. More specifically, since non–wage earners have a positive marginal rate of substitution for environmental quality, it follows that an optimal outcome must include their willingness to pay as well as that of workers. The first-order condition for the socially optimal solution now becomes

$$-[L(U_e^l/U_c^l)+N(U_e^n/U_c^n)]=Lf_e, \tag{7}$$

where the superscripts l and n refer to workers and nonworkers, respectively. Equation (7) is simply the Samuelsonian condition for the Pareto-efficient output of a public good – namely, that the sum of the marginal rates of substitution equals marginal cost. However, under the median-voter outcome, the second term in the summation on the left side of (7) will be ignored. In consequence, the worker-dictated solution is one that will involve excessive local pollution relative to the Pareto-optimal outcome.

Were nonworkers to constitute the majority (i.e., were $\gamma<\frac{1}{2}$), they would in the context of this model set waste emissions equal to zero. This extreme result follows from our assumption that nonworkers derive no benefits whatsoever from local economic activity. We can "soften" this result somewhat by giving them some stake in the local economy (perhaps as local landlords), but so long as their interests do not coincide with those of worker-residents, we cannot, in general, expect the median-voter outcome in this case to be Pareto-optimal. Where non-wage earners are in the majority, we may expect as a typical outcome one in which environmental standards are too stringent relative to the optimal solution.

5 Some concluding observations

The attempt to impose rigid, uniform national standards for environmental quality is likely to come at a substantial cost. As we have argued, environmental conditions and local tastes will tend to vary among jurisdictions, and in all likelihood to an extent that produces significant variation in the economically optimal level of local environmental quality. As in the case of local public goods, the prospective welfare gains from adapting programs to local circumstances are no doubt substantial.

The issue is whether the decentralized determination of environmental standards can be expected to realize these gains or if, instead, forces such as interjurisdictional competition for income and jobs will lead to an outcome still worse than that under uniform national standards. This is not an easy question to answer, and we surely cannot conclude much from our admittedly simplistic model of such competition. In one sense, however, the analysis is perhaps encouraging. It suggests that, at least in relatively homogeneous jurisdictions, local choices on environmental standards may not stray too far from the socially desired outcome. This is true at least where local decisions are responsive to the will of the electorate (as under the median-voter model). There are other possibilities, such as cases, for example, where the local public agency has its own objectives. As Oates and Schwab show, for instance, if the local governing unit has a Niskanen-type of objective function involving the maximization of the size of the local public budget, then there will be an incentive to set excessively lax environmental standards as a means to bring in new industry to enlarge the local tax base.[8] This is a matter which needs further, careful study. There may well emerge a case for a set of uniform minimum standards to protect against flagrant deterioration, but it is our judgment that there probably should exist some significant scope for local differentiation in environmental programs.

Finally, we must comment on our rather vague use of the term *local* in this chapter. What is the optimal size of jurisdiction for the setting of environmental standards? This obviously depends critically on the nature of the pollutant. The jurisdiction must be of sufficient size to internalize the great bulk of the pollution. This would suggest, for example, that for certain relatively localized air pollutants and for things like congestion and noise, metropolitan areas or regions may be appropriate decision-making units. The analysis is probably not applicable, at least for most pollutants, to small municipalities within a metropolitan area; for such jurisdictions, the spillovers across boundaries are likely to be too large to ignore. But within a metropolitan area or region, there are a number of pollutants for which "local" control may well represent the appropriate level for environmental management.

However, an important role for the central government is bound to remain. For pollutants that travel over substantial distances (such as acid-rain), it is unlikely that decentralized decision-making can produce satisfactory outcomes. There may, in some instances, be opportunities for Coasian types of bargains among jurisdictions, but the record on such joint efforts for environmental management is not very encouraging.[9] In addition, the central government can serve as an agent to promote and disseminate knowledge on new techniques for the abatement and regulation of pollutants; such information has important public-good properties from the perspectives of the individual jurisdictions. And, finally, as we have seen in this chapter, there may exist circumstances under which localities need to "be saved from themselves" because of the detrimental effects of interjurisdictional competition. This last consideration, however, as suggested by our basic model, is one that needs to be viewed with

[8] Oates and Schwab, *op. cit.*

[9] See, for example, Bruce Ackerman et al., *The Uncertain Search for Environmental Quality* (New York: The Free Press, 1974).

some caution. Local jurisdictions may manage certain forms of pollution reasonably effectively.

Appendix

In this appendix, we derive the necessary first-order conditions for a socially optimal outcome in the model we have presented in this chapter. For purposes of notation, we use superscripts to denote communities; c^i thus indicates the level of consumption of a resident of community i. Efficiency requires that we maximize the utility of a representative consumer in one jurisdiction, say jurisdiction 1, while allowing residents in other jurisdictions to attain some specified level of utility (U_0^i). Further constraints on the problem include the requirements that i) aggregate production in society must equal aggregate consumption, and ii) the national stock of capital (K) must be divided among the n communities. We define s^i as community i's share of the society's labor force. We can then write the social maximization problem as follows:

maximize $U^1(c^1, e^1)$

subject to

$$U^i(c^i, e^i) = U_0^i, \quad i = 2, 3, \ldots, n \tag{1}$$

$$\sum s^i f^i(k^i, e^i) = \sum s^i c^i \tag{2}$$

$$\sum s^i k^i = K / \sum L^i. \tag{3}$$

The solution of this maximization problem yields two first-order conditions:

$$U_e^i / U_c^i = f_e^i, \quad i = 1, 2, \ldots, n \tag{A1}$$

$$f_k^i = f_k^j, \quad i, j = 1, 2, \ldots, n. \tag{A2}$$

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