Delhi School of Economics Winter School

Epidemics, growth and economic behavior:
Traditional approaches and new covid-driven research

1. Epidemics and development

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December 17th, 2022

A tsunami of papers, special issues...

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INTRODUCTION

JOURNAL OF REGIONAL SCIENCE WILEY

COVID-19 and regional economies: An introduction to the special issue

Editors of Journal of Regional Science

A tsunami of papers, special issues...

Call for Papers

Special Issue on

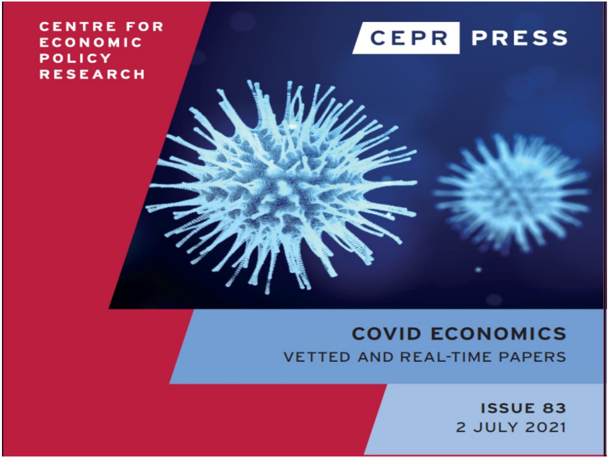
Mathematical Economic Epidemiology Models

Guest editors:

Raouf Boucekkine (Rennes School of Business & Aix-Marseille School of Economics)

Ted Loch-Temzelides (Rice University)

...and even a new form of academic publishing in economics...



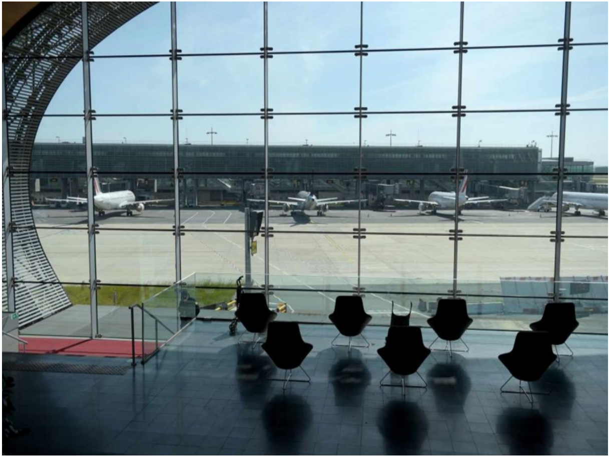
Emergency of a new **epi-econ** literature

- **Surprise/terror effect**: most epidemiologists thought that the new respiratory virus (SARS COV 2) will have the same kind of local (and relatively weak) impact as those of the two past decades. Example: bird flu (H5 N1 virus) first detected in Guangdong in 1996.
- Quickly however, Covid-19 started challenging (and is still so) science, health systems and socio-economic systems despite relatively low and heavily age concentrated letality.
- Unprecedented use of non-phamaceutical interventions (NPIs), unprecedented scale...
- Massive macroeconomic impact (vs quite low aggregate fatality rates), unique macroeconomic consequences
- Concomitant (and closely related to) with current ecological crisis

Mur de la peste, Vaucluse mountains, 1721

Collapse of transport facilities , before first lockdown (here Italy)

Collapse of the global supply chain- Roissy, first lockdown



Outlines of this lecture

1. Introduction
2. The disaster approach to epidemics: the growth theory of imbalance effects
3. The historical perspective: insights from unified growth theory
4. AIDS and the emergence of the theories of enduring epidemics
5. Concluding remarks

L'enfance de l'art

MEMORANDUM

RM-4700-TAB

FEBRUARY 1966

DISASTER AND RECOVERY:

THE BLACK DEATH IN WESTERN EUROPE

Jack Hirshleifer

Through the lens of disaster theory/analysis

- This famous 1966 Hirscheleifer report has had a long-lasting influence on how economists have been initially studying epidemics: mostly as any other disaster, thus a quite perduring parallelism with wars (even in the most popular modern textbooks)...
- ... though the explanatory power of this frame was quite questionable from the beginnning: *Direct inferences can hardly be drawn from this 14-th century catastrophe as to possible consequences of thermonuclear war...* (J. Hirschleifer, 1966)
- Initial conditions shocks leading to the so-called imbalance effects analysis, popularized by Barro (and Sala-i-Martin). Applicable to short-lived epidemics (Spanish flu, Black Death,...), not to enduring epidemics (AIDS, Malaria,...).
- However, **only with the Covid shock, the epi-econ stream has emerged as a strong research program with a distinctive methodology and research questions**.

Short-lived epidemics and long-term growth

In line with Hirsheleifer, the classical analysis of epidemic shocks has focused on short-lived epidemics (few months to a few years), with two superstars: Black Death (1348-1353, for the first wave) and the Spanish flu (2018-2019). With two main questions:

1. What are the short-term consequences of initial conditions shocks (on the size of population/human capital, for epidemics, and on the stock of physical capital for wars)? Transition?
2. Could these initial conditions shocks have a long-term effect *ceteris paribus*?

While the first question has been deeply explored in growth theory under the general topic of imbalance effects, the second is totally nontrivial in the **endogenous growth** framework. By construction, long-term (balanced) growth paths do depend on initial conditions: not the long-term growth rate, but the long-term levels (or the variables in detrended form). However, balanced (long-terme) growth paths are typically undetermined in levels in these models. So, the literature has barely provided with an answer to our basic question!

Indeterminacy in level in endogenous growth

• consider a growth model represented by the system (including optimality conditions):
$\dot{X} = F(x)$ with $X \in R^n$, $F(.)$ mapping from R^n to R^n, given boundary conditions.

• A BGP is a particular solution $X = \bar{X}e^{gt}$,

• After substitution in the original dynamic system: $f(\bar{X}, g) = 0$ ($f(.)$ has the same dimension as $F(.)$)

Endogenous growth models

- $f(\bar{X}, g) = 0$ has more variables than equations
- The Dimension reduction strategy: Define new variables as ratios between the variables of the original system: typically in the Lucas-uzawa mode, we choose ($\frac{k}{h}$, $\frac{c}{k}$)
- Indeterminacy of the variables in levels $\rightarrow$ It is not possible to deal with long run comparative statics analysis on the original variables.

Benchmark: the one-sector model with physical and human capital

- One good, Y produced, consumed and invested ex-ante in physical vs human capital:

$$Y = AK^{\alpha}\, H^{1-\alpha} = C + I_K + I_H$$

- Irreversibility: $I_K \geq 0$, $I_H \geq 0$
- At equilibrium, marginal products of K and H equalized, yielding an equilibrium value for the ratio (if depreciation rates equalized):

$$\left(\frac{K}{H}\right)^{\star} = \frac{\alpha}{1-\alpha}$$

- What happens of $\frac{K(0)}{H(0)} \neq \left(\frac{K}{H}\right)^{\star}$?

The optimal control problem

$$max \int_0^\infty \frac{c\left(t\right)^{1-\sigma}-1}{1-\sigma} N\left(t\right) e^{-\rho t} dt$$

subject to

$$\overset{\bullet}{K}\left(t\right) = I_K - \pi K,$$

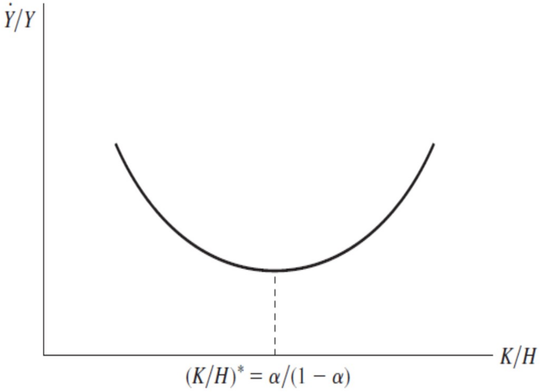
$$\overset{\bullet}{H}\left(t\right) = I_H - \pi H,$$

$$Y = AK^{\alpha}\ H^{1-\alpha} = C + I_K + I_H$$

$$K\left(0\right) = K_0, \quad h\left(0\right) = h_0, \quad N\left(0\right) = N_0,$$

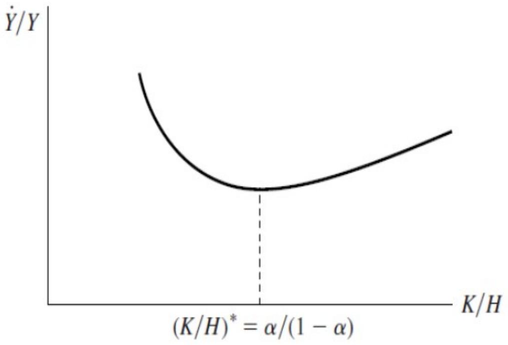
$$I_K \geq 0, \quad I_H \geq 0, \quad c\left(t\right) \geqslant 0, \quad K\left(t\right) \geqslant 0, \quad H\left(t\right) \geqslant 0.$$

Benchmark imbalance effect result



But epidemics are hardly followed by growth miracles!

Refinement with larger costs in adjusting human capital



The two-sector model with physical and human capital: Lucas-Uzawa

$$max \int_0^\infty \frac{c(t)^{1-\sigma}-1}{1-\sigma} N(t)\, e^{-\rho t} dt$$

subject to

$$\overset{\bullet}{K}(t) = AK(t)^\beta \left(u(t) N(t) h(t)\right)^{1-\beta} - \pi K(t) - N(t) c(t),$$

$$\overset{\bullet}{h}(t) = \delta\left(1-u(t)\right) h(t) - \theta h(t),$$

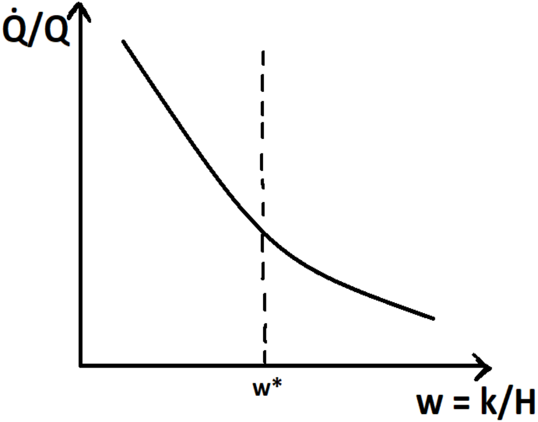
$$K(0) = K_0, \quad h(0) = h_0, \quad N(0) = N_0,$$

$$c(t) \geqslant 0, \quad u(t) \in [0,1], \quad K(t) \geqslant 0, \quad h(t) \geqslant 0.$$

NOTE: GDP is no longer Y as in the one-sector model but broad output Q:

$$Q = Y + pN\dot{h}.$$

Imbalance effects



Imbalance effects in Lucas-Uzawa model

- An economy would recover faster in response to a war that destroyed mainly physical capital than to an epidemic that destroyed mainly human capital.
- The key source of this result is the assumption that the education sector is relatively intensive in human capital. If $\omega > \omega^*$, the marginal product of human capital in the goods sector is high, and growth would be expected to occur mainly because of the high growth rate of human capital.
- The high level of ω implies a high wage rate and therefore a high cost of operation for the sector, education, that is relatively intensive in human capital. This effect tends accordingly to retard the economy's growth rate when $\omega > \omega^*$.
- Can we say more on the long-run impact of an initial shock of population size/human capital on long-term detrended levels of GDP? Yes: Boucekkine et al. (2008, 2013) who solve analytically the model in levels. **Potentially large swings in several detrended long-term trajectories depending on parameters!**

Gauss hypergeometric functions

Properties ${}_2F_1(a, b, c; z)$

- Resolution of non linear dynamics equation systems arising from optimal control problems
- Euler integral representation:

$$
{}_2F_1(a, b, c; z) = \frac{\Gamma(c)}{\Gamma(b)\,\Gamma(c-b)} \int_0^1 t^{b-1}\,(1-t)^{c-b-1}\,(1-tz)^{-a}\,dt,
$$

- Symmetry in the arguments a and b:

  ${}_2F_1(a, b, c; z) = {}_2F_1(b, a, c; z)$

- ${}_2F_1(a, 0, c; z) = 1$

Population size and long-run average human capital level

$$\bar{h} = \frac{h_0}{{}_2F_1(0)}$$

where:

${}_2F_1(0) = {}_2F_1(a, b, c; z(0))$

$a = -\frac{(\delta+n+\pi-\theta)\beta(1-\sigma)-\beta(\rho+\pi-n\sigma-\pi\sigma)}{\sigma(\delta+n+\pi-\theta)(1-\beta)}$ $\quad c = 2 + a$

$b = -\frac{\beta-\sigma}{\sigma(1-\beta)}$ $\quad z(0) = 1 - \frac{\delta+n+\pi-\theta}{\epsilon}\left(\frac{\vartheta_1(0)}{\vartheta_2(0)}\right)^{-\frac{1-\beta}{\beta}}$

$\epsilon = \beta A \left(\frac{(1-\beta)AN_0}{\delta}\right)^{\frac{1-\beta}{\beta}} > 0$

Determination of initial shadow prices

The transversality conditions of the OCP impose a.o the followings constraints:

$$\frac{K_0}{{}_2F_1(0)}\left(\frac{\vartheta_1(0)}{\vartheta_2(0)}\right)^{\frac{1}{\beta}}=-\frac{\sigma\beta N_0^{\frac{\sigma+\lambda-1}{\sigma}}\vartheta_2(0)^{-\frac{1}{\sigma}}\left(\frac{\delta+n+\pi-\theta}{\epsilon}\right)^{\frac{\sigma-\beta}{\sigma(1-\beta)}}}{(\delta+n+\pi-\theta)(\beta-\sigma)-\beta(\rho+\pi-n(\sigma+\lambda-1)-\pi\sigma)},$$

$$\frac{{}_2F_1(0)}{{}_2\widetilde{F}_1(0)}=\frac{(1-\beta)\epsilon\sigma}{-((\delta-\theta)(1-\sigma)+\lambda n-\rho)\beta}\frac{K_0}{h_0}\left(\frac{\vartheta_1(0)}{\vartheta_2(0)}\right)^{\frac{1}{\beta}},$$

The effect of an initial population size fall on long-term human capital level

- The long-term growth rates do not depend on the initial population size.
- In the normal case ($\sigma > \beta$), a lower initial population size implies bigger long-run detrended levels of per capita income, per capita broad output, and average human capital.

- Previous slides outline the different mechanisms at work in one-sector (neoclassical mechanisms) and two-sector models (cross-sector allocation mechanisms and quality adjustment) endogenous growth models subject to initial epidemic shocks.

- Studies in economic history have for a long time identified other types of mechanisms which not only shaped the events following some of the major epidemics in human history, but that also may have led to **structural change**. Also contributions from UGT (Lagerloef, 2003, Boucekkine et al., 2002, 2003, 2007).

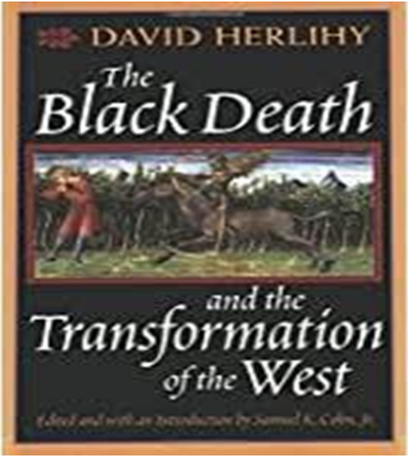
- A more recent literature has put forward retarded effects of epidemics. We single out here the so-called fetal origin hypothesis, see for example Almond and Mazumder (2005).

- Last but not least, the huge AIDS-induced literature, 1990s-2010s, has stressed the **behavioral implications of enduring epidemics**: Ben Porath effects, health capital, fertility effects...etc (Chakraborty and Das, 2005, Young, 2005).

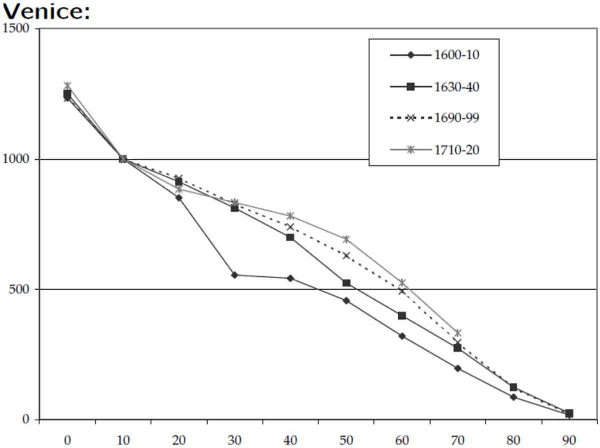
The fetal origin hypothesis: the case of the Spanish flu

- In contrast to typical influenza strains, the 1918 virus disproportionately affected young adults: approximately one-third of pregnant women contracted the debilitating virus (between October 1918 and January 1919).
- Approximately two-thirds of those in utero during the height of the Pandemic would have been born in the first six months of 1919.
- Using Decennial Census data for 1960–1980, Almond (2005) found that cohorts in utero during the height of the Pandemic displayed reduced educational attainment, increased rates of disability, lower income, and lower socioeconomic status.
- Using SIPP, Almond and Mazumder (2005) found that cohorts in utero during the Pandemic exhibit impaired health outcomes relative to cohorts born a few months earlier or later.
- That these patterns are manifest 65–80 years after the Pandemic suggests that changes to fetal health can have life-long effects.

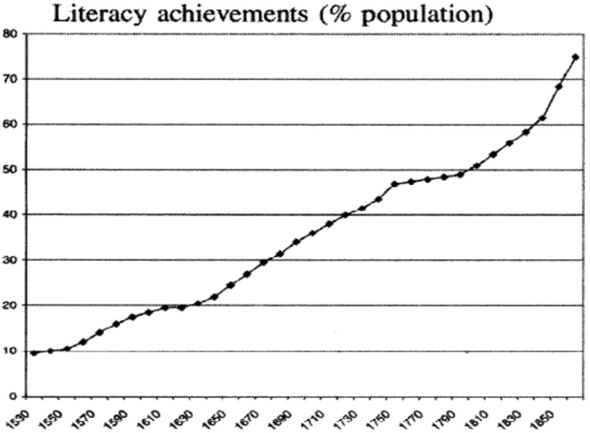
A quite substantial and brilliant economic history literature



UGT-epidemics: immunization and Ben Porath effect, Boucekkine et al. (2002, 2003)



UGT-epidemics: density vs Ben Porath effects in England, Boucekkine et al. (2007)



UGT-epidemics: Nippe Lagerlof, 2003

INTERNATIONAL ECONOMIC REVIEW
Vol. 44, No. 2, May 2003

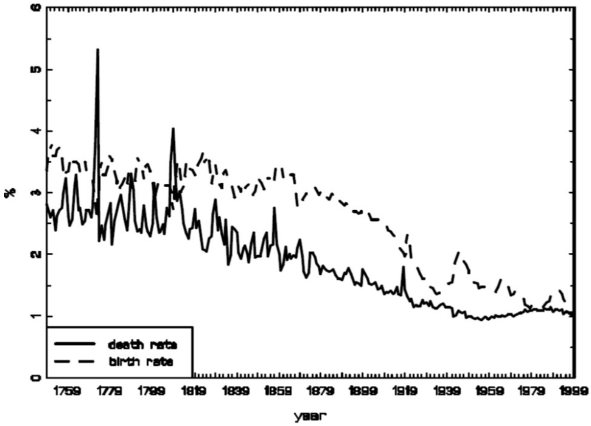
FROM MALTHUS TO MODERN GROWTH: CAN EPIDEMICS EXPLAIN THE THREE REGIMES?*

BY NILS-PETTER LAGERLÖF[1]

Concordia University and CIREQ, Canada

We model demographic and economic long-run development in a setting where mortality is endogenous and subject to epidemic shocks. The model replicates the full transition from Malthusian stagnation to modern growth. Consistent with the historical facts, the economy also passes an intermediate post-Malthusian phase where growth rates of both population and per capita income increase si-

Lagerlof's case: Sweden, 1749-1999



de la Croix & Sommacal, 2009: medecine effectiveness

Mathematical Population Studies
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713644738

A Theory of Medical Effectiveness, Differential Mortality, Income Inequality and Growth for Pre-Industrial England

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URL: http://dx.doi.org/10.1080/08898480802619538

Emergence of a new economic epidemiology in the 1990s

- Emergence of new economic epidemiology stream essentially due to the upsurge of the AIDS/HIV pandemic: enduring, massive (cumulated) death toll, and global!
- Huge literature on the macroeconomic cost of AIDS: emergence of macroeconomic-health models, with explicit modelling of the economic effects of mortality and mortality, including health expenditures and their impact on savings and growth. Applied growth, seminal Solow-like frame: Cuddington and Hancock (1994), revisited by Boucekkine et al. (2016). Development of OLG frames to cope with the age profile of mortality/morbidity (e.g Corrigan et al., 2005).
- Emerging literature on the socioeconomic impact of pandemics: in particular distributional aspects, poverty and inequalities (e.g Chakraborty, 2004, or Chakraborty and Das, 2005).
- Impact on economic behavior: schooling, investment, fertility or risk taking. Controversy on the epidemic impact on fertility, (Kalemli-Ozcan, 2002, Young, 2005, Boucekkine et al., 2009)

Alwyn Young's *gift of the dying* paper

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OF ECONOMICS

Vol. CXX May 2005 Issue 2

THE GIFT OF THE DYING: THE TRAGEDY OF AIDS AND THE WELFARE OF FUTURE AFRICAN GENERATIONS*

ALWYN YOUNG

This paper simulates the impact of the AIDS epidemic on future living standards in South Africa. I emphasize two competing effects. On the one hand, the epidemic is likely to have a detrimental impact on the human capital accumulation of orphaned children. On the other hand, widespread community infec-

Model outline (Boucekkine et al., 2009)

- 3 periods, one good overlapping generations model:
  - 1st period, probability q_t to survive to the young adult age
  - 2nd period, probability p_{t+1} to live as a senior adult, young adult consumes c_{t+1}, has n_{t+1} children, works a proportion l_{t+1} of his unit time
  - annuity market: return rate to savings is $\frac{R_{t+2}}{p_{t+1}}$
- We have the following utility function...

$$U_t = \frac{c_{t+1}^{1-\sigma_c}}{1-\sigma_c} + \frac{(q_{t+1} n_{t+1})^{1-\sigma_n}}{1-\sigma_n} + \frac{(1-\theta q_{t+1} n_{t+1} - l_{t+1})^{1-\sigma_l}}{1-\sigma_l} + p_{t+1} \frac{c_{t+2}^{1-\sigma_c}}{1-\sigma_c}$$

- ...under the intertemporal budget constraint:

$$c_{t+1} + \frac{p_{t+1}}{R_{t+2}} c_{t+2} = w_{t+1} \, l_{t+1} \qquad (1)$$

Adult mortality shock

- **Proposition**: *Under given prices w_{t+1} and R_{t+2}, a decrease in the survival probability p_{t+1} always raises fertility n_{t+1} and reduces labor supply l_{t+1} and savings s_{t+1}, for any σ_c positive.*
- Pure positive income effect, since p_{t+1} does not appear in the f.o.c. but only in the intertemporal budget constraint:

$$c_{t+1} + \frac{p_{t+1}}{R_{t+2}} \, c_{t+2} = w_{t+1} \, l_{t+1}$$

- The result is due to the presence of annuity markets (Chakraborty, 2004), but holds when removing this feature

Child mortality shock

- **Proposition**: *Under given prices w_{t+1} and R_{t+2}, a decrease in the survival probability q_{t+1} raises total fertility, but leaves net fertility, labor supply and savings unchanged for any σ_c positive.*
- a decrease in q_{t+1} is exactly compensated by a proportional rise in n_{t+1}, in order to keep constant the target number of surviving children $q_{t+1}n_{t+1}$:

$$(q_{t+1}n_{t+1})^{-\sigma_n} = \theta \left[1 - \theta\, q_{t+1}n_{t+1} - \Omega_{t+2}^{-\frac{1}{\sigma_c}}\ w_{t+1}^{\frac{1}{\sigma_c}-1}\ (q_{t+1}n_{t+1})^{\frac{\sigma_n}{\sigma_c}}\right]^{-\sigma_l}$$

- our modeling choices exclude any "hoarding effect" (Kalemli-Ozcan, 2002): Doepke (2005) however shows that this kind of precautionary demand for children disappears as soon as you allow for sequential fertility decisions

Exogenous price shocks

- **Proposition**: *For any σ_c positive and* **not equal to** 1, *an increase in the wage w_{t+1} raises labor supply l_{t+1} and reduces fertility n_{t+1}, if and only if $\sigma_c < 1$. A rise in the interest rate R_{t+2} has the same properties.*

- Optimal fertility response:

$$n_{t+1}^{-\sigma_n} = \theta q_{t+1}^{\sigma_n} \left[1 - \theta q_{t+1} n_{t+1} - q_{t+1}^{\frac{\sigma_n}{\sigma_c}} \Omega_{t+2}^{-\frac{1}{\sigma_c}} w_{t+1}^{\frac{1}{\sigma_c} - 1} n_{t+1}^{\frac{\sigma_n}{\sigma_c}} \right]^{-\sigma_l}$$

- Optimal labor response:

$$\frac{1}{\Omega_{t+2}} w_{t+1}^{1-\sigma_c} l_{t+1}^{-\sigma_c} = \theta \left[1 - \theta \Omega_{t+2}^{\frac{1}{\sigma_n}} w_{t+1}^{\frac{\sigma_c - 1}{\sigma_n}} l_{t+1}^{\frac{\sigma_c}{\sigma_n}} - l_{t+1} \right]^{-\sigma_l}$$

General equilibrium framework

- We now move to a general equilibrium framework, and place ourselves in the case $\sigma_c < 1$
- Production function:

$$Y_t = K_t^{\alpha} \ (l_t \ L_t)^{1-\alpha} \tag{2}$$

- Full capital depreciation in one period:

$$K_{t+1} = L_t \ s_t \tag{3}$$

- Evolution of active population:

$$L_{t+1} = q_t \ n_t \ L_t \tag{4}$$

Infant mortality in general equilibrium

- **Proposition**: *In general equilibrium, an increase in child mortality via a decrease in q_{t+1} has no impact on equilibrium prices, w_{t+1} and R_{t+2}. Therefore, a rise in child mortality in general equilibrium does unambiguously raise total fertility.*
- This property directly stems from the absence of effect of infant mortality on net fertility:

$$w_{t+1} = (1-\alpha)\left(\frac{s_t}{(q_t\ n_t)\ l_{t+1}}\right)^{\alpha}, \quad R_{t+2} = \alpha\left(\frac{s_{t+1}}{(q_{t+1}\ n_{t+1})\ l_{t+2}}\right)^{\alpha-1}$$

Adult mortality in general equilibrium

- **Proposition**: *In general equilibrium, an increase in adult mortality via a decrease in p_{t+1} causes wages w_{t+1} to unambiguously go up. Therefore, when $\sigma_c < 1$, a rise in adult mortality has an ambiguous effect on fertility in general equilibrium.*
- Indeed: $w_{t+1} = (1-\alpha)\left(\frac{s_t}{q_t \; n_t \; l_{t+1}}\right)^{\alpha}$
- Hence, a rise in child mortality unambiguously lead to a rise in total fertility, while the effect of adult mortality is ambiguous because of the "second-round" effect through prices (wage)

Model outline (Chakraborty and Das, 2005)

- 2 periods, one good overlapping generations model. The probability of surviving from youth to old-age is endogenous and depends upon an agent's health capital, h_t. Inviduals only differ in initial wealth: distribution $G_t(W)$. But fertility is exogenous: individuals give birth to a single offspring, before they realize their mortality shock. **Altruism**: intended (or unintended) bequests, b_{t+1}.
- We have the following utility function for an individual born at t.

$$U_t = u(c_t) + \phi(h_t)\left(u(c_{t+1}) + \theta v(b_{t+1})\right)$$

- ...under the per-period budget constraints (for surviving individuals):

$$c_t = \bar{w} + W_t - s_t - h_t \quad , \quad c_{t+1} = \bar{w} + Rs_t - b_{t+1} \qquad (5)$$

Some specifications and properties

- Isoelastic functions: $u(x), v(x) = \frac{x^\sigma}{1-\sigma}$, $\sigma < 1$. Optimality conditions lead to optimal investment, h as a function of wealth, W: $h = \eta(W)$.
- Let ϵ_ϕ be the health capital elasticity of survival, then ioptimal ntended and unintended bequests amount to (with $\beta = \theta^{1/\sigma}$):

$$b_{t+1} = \frac{\beta}{1+\beta}\frac{1-\sigma}{\epsilon_\phi}R\eta(W) \equiv \Psi_1(W),$$

$$s_t = \frac{1-\sigma}{\epsilon_\phi}\eta(W) - \frac{\bar{w}}{R} \equiv \Psi_2(W).$$

- Wealth dynamics, $W^i_{t+1} = \Psi(W^i_t)$, are Markovian with

$$W^i_{t+1} = \Psi_1(W^i_t),$$

with prob. $\phi\left(\eta(W^i_t)\right)$, and $W^i_{t+1} = \Psi_2(W^i_t)$ otherwise.

Optimal health investment

Proposition 1 *Optimal health investment, $h = \eta(W)$, implicitly defined by equation (14), satisfies the following properties:*

(i) $\eta(0) > 0$ *as long as* $\bar{w} > 0$,

(ii) $\partial\eta(W)/\partial W \geq 0$ *with* $\lim_{W\to\infty} \partial\eta(W)/\partial W = 0$, *and*

(iii) $\partial^2\eta(W)/\partial W^2 < 0$ *for* $\sigma < \varepsilon_{\phi(\eta(W))}$, $\partial^2\eta(W)/\partial W^2 > 0$ *for* $\sigma > \varepsilon_{\phi(\eta(W))}$, *while* $\lim_{W\to\infty} \partial^2\eta(W)/\partial W^2 = 0$.

- Till the Covid outbreak-related literature, the economic epidemiology literature on epidemics has been quite baroque, it started with an extreme disaster approach (inspired by Hirshleifer) and has been almost "confused" with the economic analysis (short and long-term) of mortality shocks.
- The distance to epidemiological modelling has been huge, at least in development studies. Chakraborty et al. (2010) is an exception: it's to our knowledge the first paper introducing some kind of (intra-period) infection dynamics in such studies.
- The introduction of standard math epidemiology modelling in economics traces back to work by health economists by the end of the 90s (e.g. Goeffard and Philipson, 1996). The first proper epi-econ piece of work can be attributed to Gersovitz and Hammer (2004).
- The first epi-econ model with factor accumulation came almost one decade later. We study this in the second lecture.