Economics with a Biological Foundation

Aldo Rustichini

Economics, Minnesota

Winter School 2022 at the Delhi School of Economics,
Lecture 1

General Considerations

1. Economics as a science had some important developments in the last twenty years thanks to the introduction of new methods from biology
2. Economics is now at a crossroads, and we need to evaluate how to proceed further
3. This understanding is essential because choices which are fundamental for the future of societies depend on this vision

Three new Fundamental Directions

1. **Neuroeconomics**
2. **Genetics and economics**
3. **Personality Theory**

Neuroeconomics

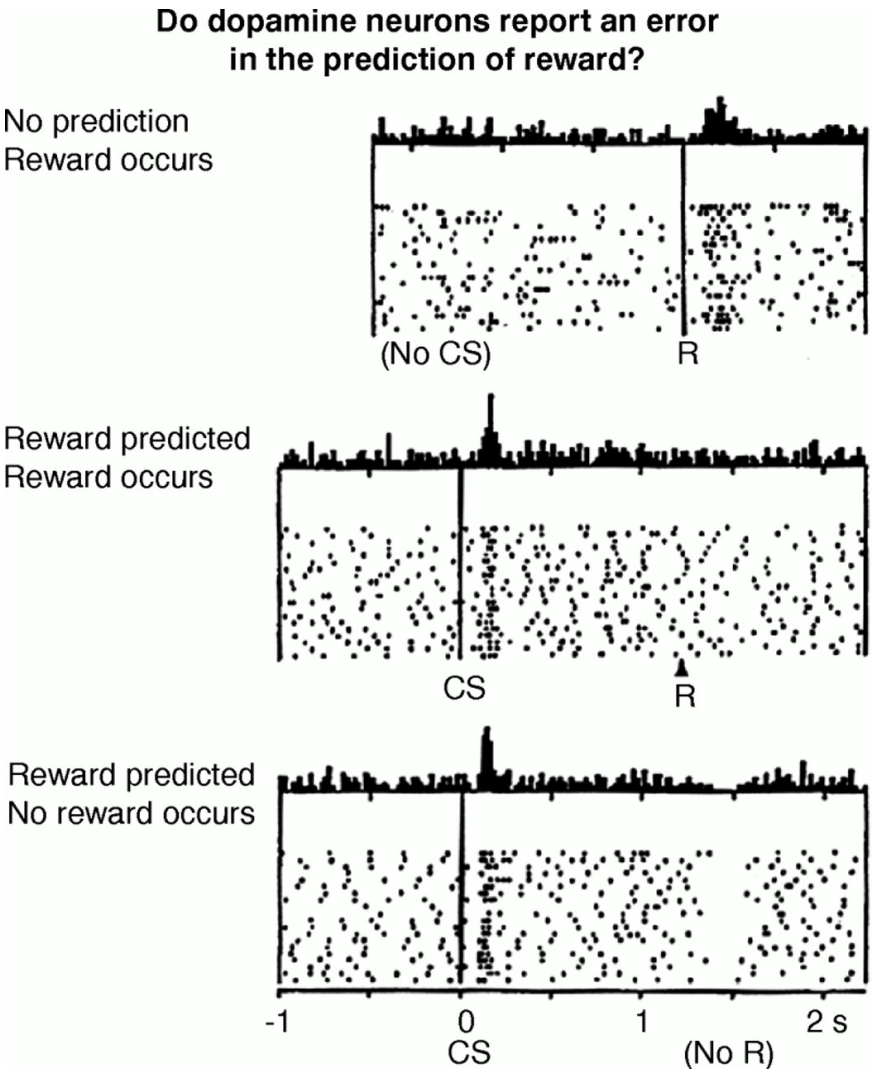
1. Neuroeconomics is the discipline that studies the neural basis of economic and strategic behaviour
2. An important part of method used is the experimental study of human choices (or animal choices) pursued by combining the observation of behavior with that of associated neural processes (*fMRI*, recording from single neurons, *EEG*, *MEG*)
3. Equally important is the study of other biological components underlying the behavior, for example the hormonal one.

What we understood: some examples

1. The neural basis of learning the value function (third lecture)
   - Formal model: Q-Learning
   - Neural correspondents of the components of the model
2. Neural basis of choice between options
   - comparison models based on diffusion processes (*DDM*)
   - richer models based on a network of groups of neurons that independently evaluate the various options
3. Adaptation of the evaluation to the environment. (third lecture)
   - Accurate understanding of the quantitative impact and time duration of these effects.
   - Comparison with anomalies of visual perception
4. Neural basis of important emotions
   - Regret, Envy
   - Empathy

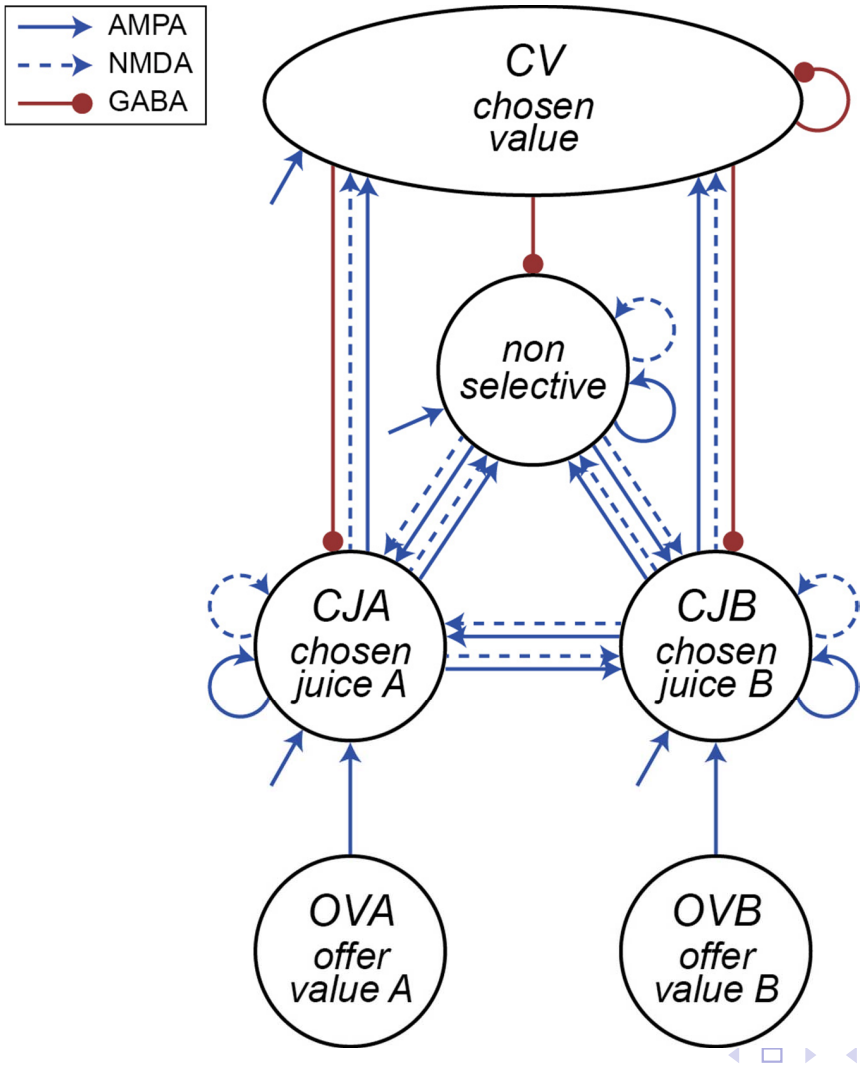
What we understood: Value function learning

Schultz, Dayan, Montague, 1997

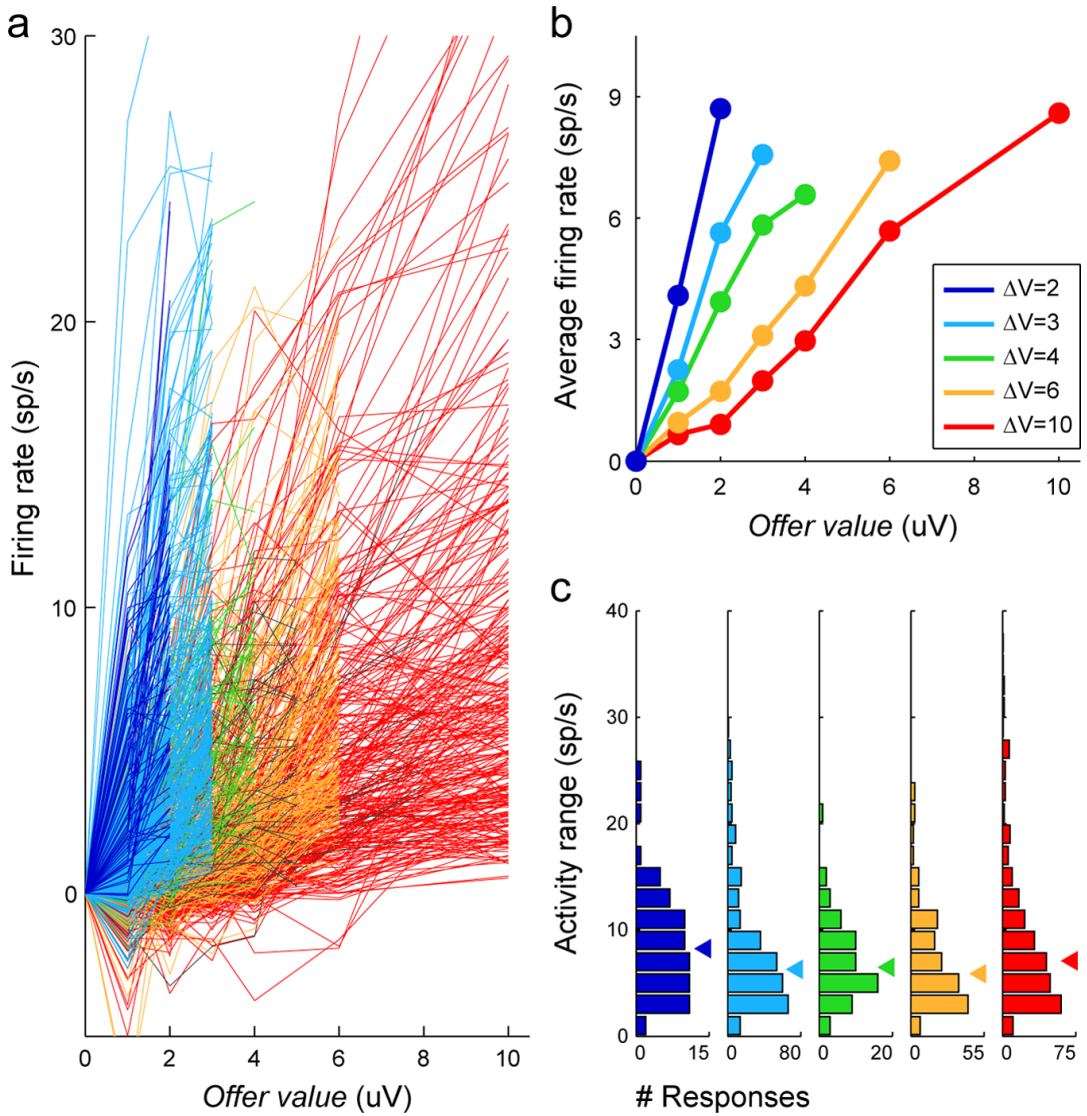


What we understood: Neural basis of choice between option

Wong & Wang 2006, Rustichini & Padoa-Schioppa 2015, Rustichini et al., 2018

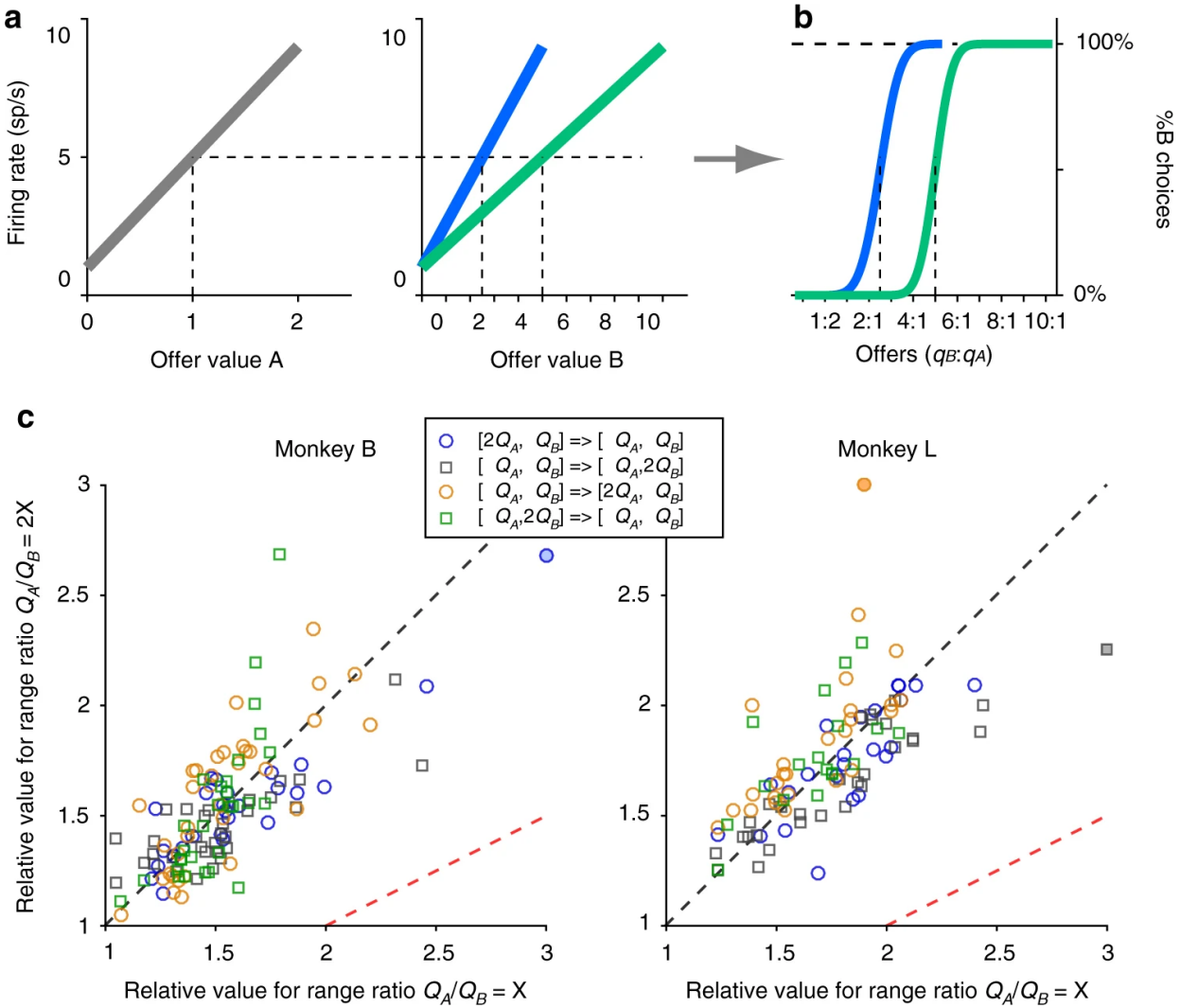


Adaptive Coding (Padoa-Schioppa, 2009)



What we understood: Adaptation of value encoding

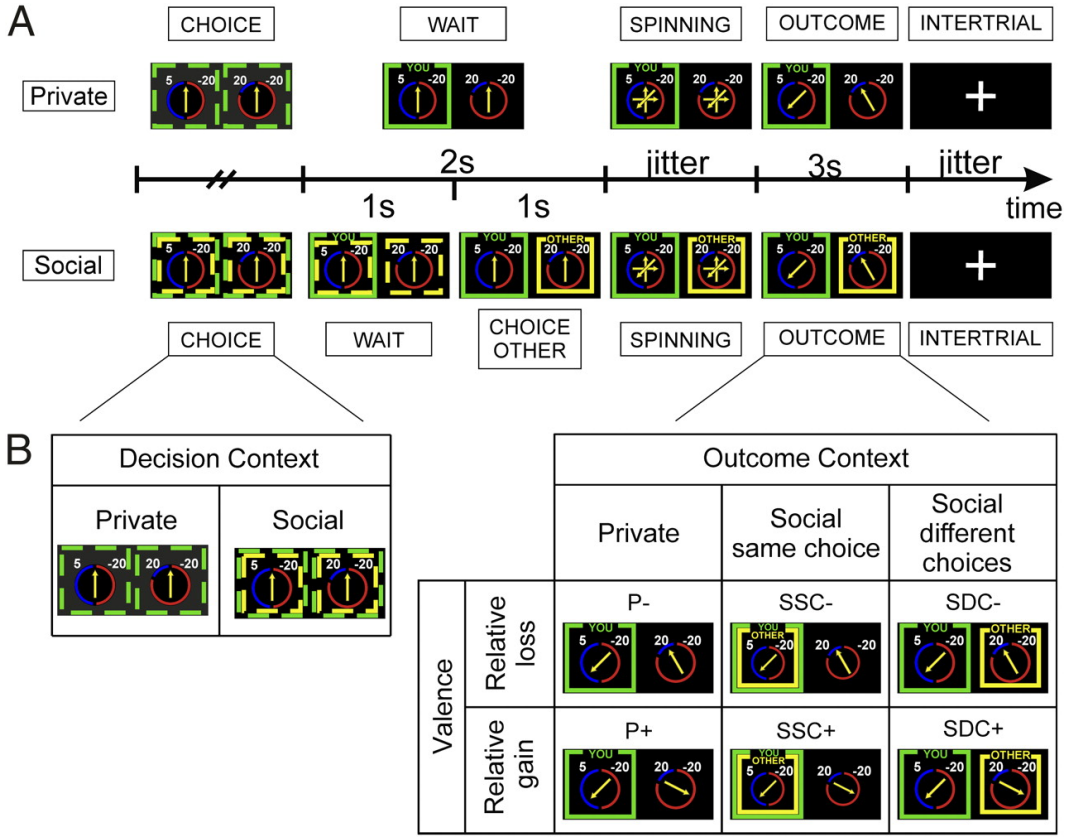
Rustichini,Conen, Cai, Padoa-SCioppa, Nature Communications,2017



What we understood: Regret and Envy

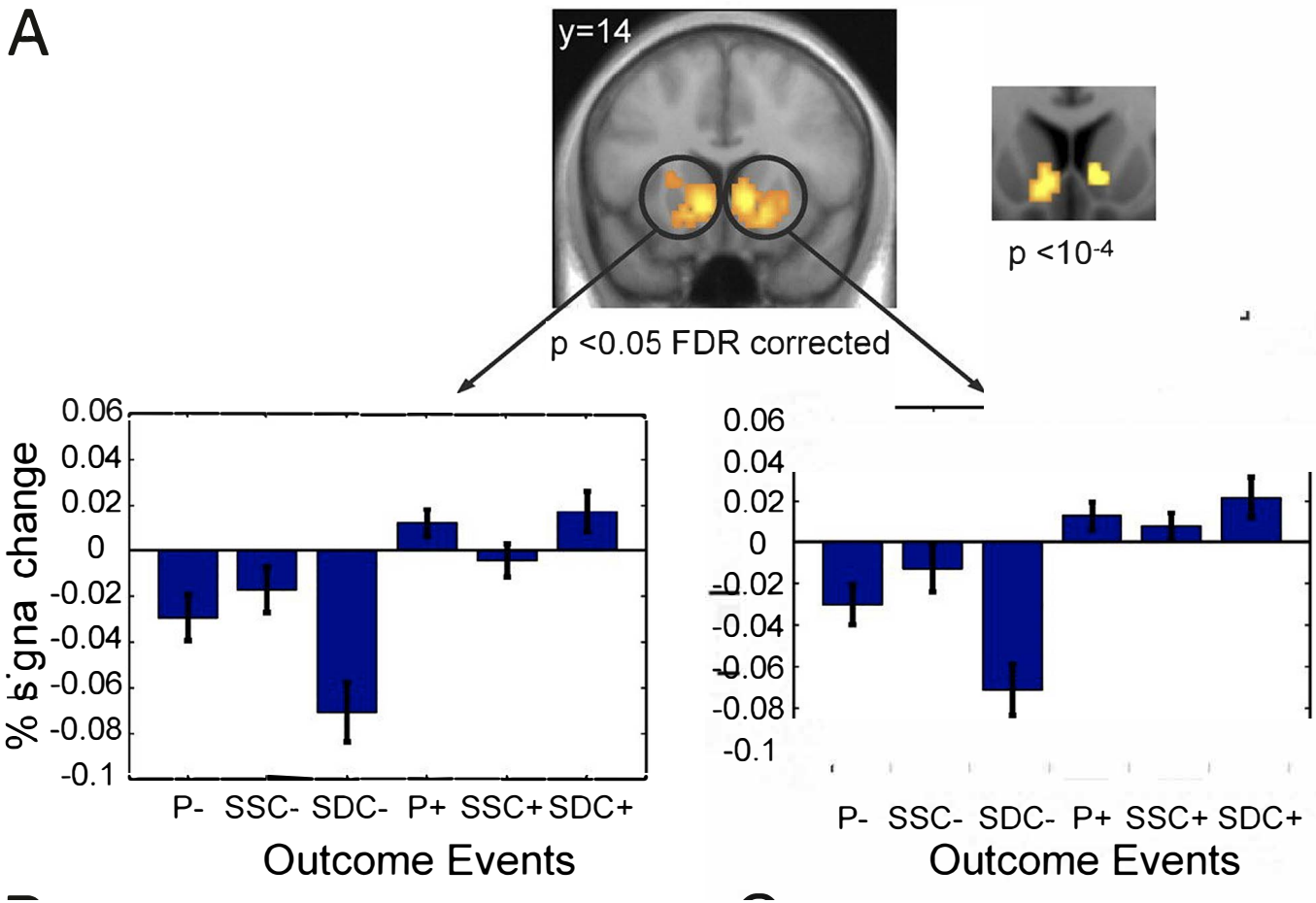
Bault, N., Joffily, M., Rustichini, A., Coricelli, G. (2011). Proceedings of the national Academy of sciences

Regret is counterfactual learning, envy is the social correspondent of regret.



What we understood: Regret and Envy

P: private, **SSC:** social same choice, **SDC:** social different choice,



What we understood: Summary

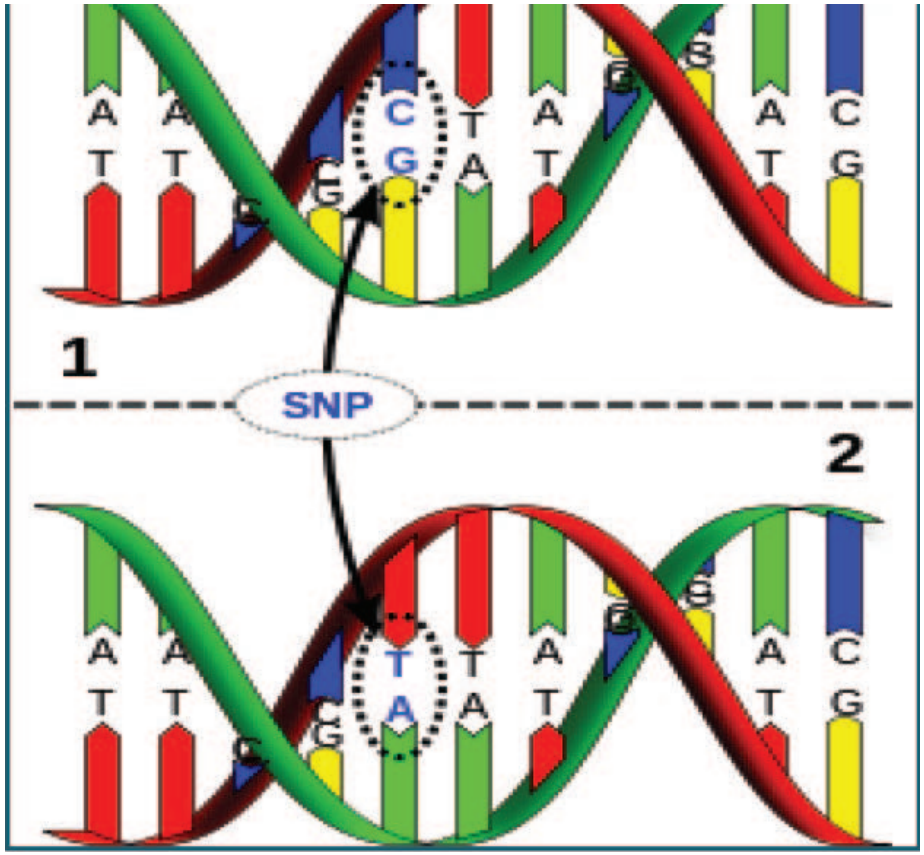
1. Replacement of the as if models with mechanistic models of choice
2. Replacement of the optimality of choice with the optimality of the process producing choice

Genoeconomics

1. Genoeconomics is the discipline that studies the genetic basis of economic and strategic behavior
2. The analysis was conducted until a few years ago (2000) with indirect methods (for example studies on identical and non-identical twins, adoption studies)
3. The discipline changed radically after the completion of the Human Genome Project (HGP, 2000)

SNP's

W. Sukhumsirichart, "Polymorphisms."



Genotype for each subject

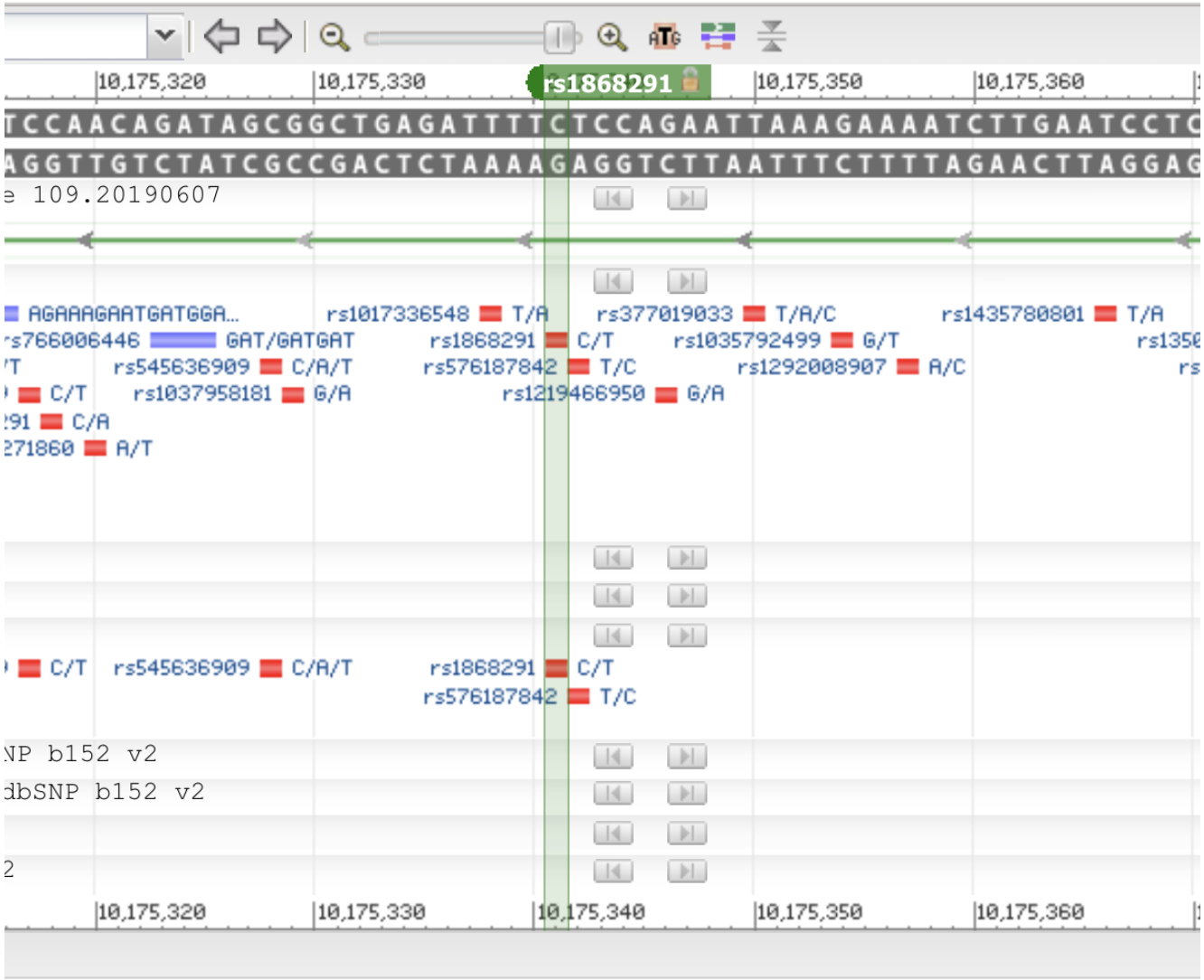
	chr	rs	allele_1	allele_2	gene	subject_1	subject_2	subject_3	subject_4
1	16	rs1868291	T	C	GRIN2A	0	0	0	0
2	16	rs727605	C	T	GRIN2A	0.5	0	0	0.5
3	16	rs1014531	G	A	GRIN2A	0	0	0.5	0.5
4	12	rs1421109	G	T	GRIN2B	0	0	0	0.5
5	12	rs2192977	T	A	GRIN2B	0.5	0	0	0
6	12	rs220599	G	A	GRIN2B	0	0	0.5	0.5
7	17	rs690578	G	A	GRIN2C	0	1	0	0
8	19	rs892200	C	T	GRIN2D	0	0.5	0	0
9	9	rs1337682	T	C	GRIN3A	0	0	0	0.5
10	9	rs942139	G	A	GRIN3A	0	0.5	0	0.5
11	9	rs2485534	T	A	GRIN3A	0	0	0	0
12	19	rs2285907	G	C	GRIN3B	0	0.5	0	0.5
13	8	rs9100	G	T	GRINA	0	0	0.5	0.5
14	6	rs2073287	T	C	GRM1	1	0.5	1	1
15	6	rs2300620	T	G	GRM1	0	0	0	0.5
16	7	rs17126	G	A	GRM3	0.5	1	0.5	0
17	7	rs2189814	T	C	GRM3	0.5	0.5	0.5	0.5
18	6	rs2499724	C	A	GRM4	0.5	1	0.5	0
19	11	rs1499037	T	C	GRM5	1	0	0	0.5
20	11	rs160520	G	A	GRM5	1	0	0	0.5
21	11	rs566277	C	G	GRM5	0	0	0	0
22	11	rs524874	G	A	GRM5	0	1	0.5	0.5

GWA Studies

1. *HGP* allows the study of the individual variants of the nucleotide sequence of each individual, in particular of the most common variants
2. *Association* of a phenotype (i.e. an individual characteristic of interest to economists, for example intelligence) with the profile of *SNP*'s
3. *GWAS* = Genome Wide Association Study, study of *association on the entire genome*
4. *On the whole genome* rather than on special variants taken as candidates on the basis of some hypothesis (wide-ranging analysis)
5. Based on the coefficients estimated on a large sample (up to 3 million) and on the individual genome, an individual index can be calculated for each individual a single numerical score of "propensity" for that phenotype (*polygenic index*).

Single Nucleotide Polymorphisms (*SNP*'s)

A look at *dbSNP*



SNP and estimated coefficients for a phenotype

chr[1] 1

	chr	snp	a1_gwas	eaf	beta	a2	aa	whg_gwas	ehg_gwas	ys_gwas	an_gwas
1	1	rs3094315	G	.1514	-.00034	A	.	.187841	.067062	.275074	.142544
2	1	rs12124819	A	.7534	.00224	A	.	.805265	.708259	.855907	.806391
3	1	rs28765502	C	.2721	.00062	T	.	.293799	.180174	.336063	.379175
4	1	rs7419119	G	.1956	-.00159	T	T	.187864	.1071	.301381	.223163
5	1	rs950122	G	.8265	.00209	G	G	.888598	.933675	.811673	.717794
6	1	rs13302957	A	.94558	.01256	A	G	.895127	.971375	.89232	.926375
7	1	rs6696609	C	.7381	-.00465	C	C	.748911	.840348	.634459	.679222
8	1	rs13303368	C	.6259	.00155	C	C	.637048	.635491	.380561	.625773
9	1	rs8997	G	.95238	-.00413	G	A	.99999	.899998	.99999	.831192
10	1	rs4075116	T	.7517	.00466	T	C	.716461	.711068	.633235	.874404
11	1	rs3934834	T	.1463	.00122	C	C	.223088	.179764	.17603	.318136
12	1	rs9442372	G	.5884	.00277	G	G	.493709	.520314	.46175	.520937
13	1	rs3737728	A	.2415	-.004	G	G	.31922	.383238	.333307	.215834
14	1	rs9442398	A	.2432	-.00392	G	G	.302574	.430809	.256696	.19246
15	1	rs6687776	T	.1395	-.00499	C	C	.226012	.307714	.100211	.188605
16	1	rs9651273	G	.7415	-.00061	G	A	.631894	.903016	.674052	.675154
17	1	rs147606383	A	.03231	-.00012	G	G	1.000e-05	1.000e-05	.024756	.042848
18	1	rs4970405	G	.09694	-.00625	A	A	.080652	.083992	.096237	.158729
19	1	rs12726255	G	.1224	-.00561	A	G	.052937	.112964	.130353	.219438
20	1	rs7540009	G	.97619	.00409	G	G	.871357	.986093	.977251	.949558
21	1	rs11807848	T	.6395	.00307	T	C	.447148	.588475	.666348	.48269
22	1	rs9442373	A	.6173	.00163	C	C	.332149	.659979	.515359	.481359
23	1	rs2298217	T	.119	-.00484	C	C	.12068	.182247	.155835	.172931
24	1	rs12145826	A	.08844	.00464	G	G	.042145	.001726	.079172	.281438
25	1	rs4970357	C	.06973	.00276	A	A	.22221	.029936	.112252	.062593
26	1	rs11260603	C	.2279	-.00411	T	C	.246208	.414433	.270543	.056472
27	1	rs9442380	T	.05102	.00158	C	C	.147668	.010416	.100676	.106154
28	1	rs7553429	C	.02211	-.00066	A	C	1.000e-05	.035401	.055514	.01107
29	1	rs4970362	G	.6718	.00106	G	A	.474806	.560819	.655434	.788869
30	1	rs9660710	C	.95918	-.00246	C	C	.79878	.967629	.922096	.965697
31	1	rs6670693	G	.005102	.00737	A	A	1.000e-05	1.000e-05	1.000e-05	1.000e-05

Polygenic Score (PGS)

1. A Genome-wide association study (*GWAS*) produces estimated beta coefficients of the univariate regression of a phenotype on Single Nucleotide Polymorphisms (*SNP*'s) values.
2. Foe exampleÃ§

$$\text{phenotype} = \text{educational attainment (EA)}$$

3. A Polygenic score (*PGS*)is a numerical value, computed for each individual, summarizing the probability ("risk") of a phenotype on the basis of the individual's genotype and the *GWAS*-estimated betas.

Genotype for each subject

	chr	rs	allele_1	allele_2	gene	subject_1	subject_2	subject_3	subject_4
1	16	rs1868291	T	C	GRIN2A	0	0	0	0
2	16	rs727605	C	T	GRIN2A	0.5	0	0	0.5
3	16	rs1014531	G	A	GRIN2A	0	0	0.5	0.5
4	12	rs1421109	G	T	GRIN2B	0	0	0	0.5
5	12	rs2192977	T	A	GRIN2B	0.5	0	0	0
6	12	rs220599	G	A	GRIN2B	0	0	0.5	0.5
7	17	rs690578	G	A	GRIN2C	0	1	0	0
8	19	rs892200	C	T	GRIN2D	0	0.5	0	0
9	9	rs1337682	T	C	GRIN3A	0	0	0	0.5
10	9	rs942139	G	A	GRIN3A	0	0.5	0	0.5
11	9	rs2485534	T	A	GRIN3A	0	0	0	0
12	19	rs2285907	G	C	GRIN3B	0	0.5	0	0.5
13	8	rs9100	G	T	GRINA	0	0	0.5	0.5
14	6	rs2073287	T	C	GRM1	1	0.5	1	1
15	6	rs2300620	T	G	GRM1	0	0	0	0.5
16	7	rs17126	G	A	GRM3	0.5	1	0.5	0
17	7	rs2189814	T	C	GRM3	0.5	0.5	0.5	0.5
18	6	rs2499724	C	A	GRM4	0.5	1	0.5	0
19	11	rs1499037	T	C	GRM5	1	0	0	0.5
20	11	rs160520	G	A	GRM5	1	0	0	0.5
21	11	rs566277	C	G	GRM5	0	0	0	0
22	11	rs524874	G	A	GRM5	0	1	0.5	0.5

GWAS-betas from the training sample

	rs	beta
1	rs1000000	.0037899
2	rs10000003	.0027337
3	rs10000005	-.0020734
4	rs10000010	-.001455
5	rs10000011	.013238
6	rs10000013	-.0035131
7	rs10000015	.0001121
8	rs10000017	.0006121
9	rs10000018	-.0016085
10	rs1000002	-.0004003
11	rs10000021	-.0027193
12	rs10000023	-.0008973
13	rs1000003	.002029
14	rs10000030	-.0033601
15	rs10000033	.0053658
16	rs10000036	-.0028181
17	rs10000037	-.0044699
18	rs10000038	-.0015369
19	rs10000039	-.0061476
20	rs10000041	-.0084939

4.5 millions later ...

	rs	beta
4479377	rs9999949	.0063186
4479378	rs999995	-.0027654
4479379	rs9999952	-.0024505
4479380	rs9999953	.0097556
4479381	rs9999955	-.00307
4479382	rs9999956	.0115451
4479383	rs9999959	-.0072458
4479384	rs9999960	-.0009108
4479385	rs9999962	-.0008974
4479386	rs9999966	.0019648
4479387	rs9999974	-.0014927
4479388	rs9999976	-.0028747
4479389	rs9999979	-.0008776
4479390	rs9999981	-.0003413
4479391	rs9999982	-.0050843
4479392	rs9999983	-.0047322
4479393	rs9999992	.0010196
4479394	rs9999995	.0031268
4479395	rs9999997	.0077593
4479396	rs9999998	.0005755

How a Polygenic Score (PGS) is computed

1. The *PGS* is computed as a weighted sum of the values of the individual's variants, using as weights the *GWAS*-estimated coefficients from a training sample, including variants that do not achieve significance at conventional threshold, appropriately corrected for Linkage Disequilibrium (*LDPred*).
2. For a given genotype g, the *PGS* is:

$$PGS(g) = \sum_{k=1}^{K} \beta(k) g(k)$$

PGS and Social Mobility

Rustichini et al, Journal of Political Economy, 2023

1. **Formulate predictions of a model** integrating a genetic law of motion of skill
2. in a unique set of data with complete genetic information on parents and children, in addition to information on education, personality traits, intelligence, family environment and income
3. Estimate **effect size for gene** $\times$ **environment correlation** and of the degree of assortative matching.
4. **Explore pathways** from genotypes to educational and economic success, and how they are mediated by Intelligence and non-cognitive skills.

Standard parental investment, with twins

The i^{th} household solves:

$$\max_{(E^i, I_1^i, I_2^i)} \mathbf{E}_{(\theta_1^i, \theta_2^i)} \left((1-\delta) \ln E^i + \delta \sum_{j=1,2} y_j^i \right), \tag{1}$$

subject to:

$$E^i + \sum_{j=1,2} I_j^i = Y^i \tag{2}$$

$$h_j^i = \alpha_I \ln I_j^i + \alpha_\theta \theta_j^i + \epsilon_j^{h,i}, j = 1, 2 \tag{3}$$

$$y_j^i = \alpha_h h_j^i + \epsilon_j^{y,i}, j = 1, 2 \tag{4}$$

Optimal Investment:

$$\hat{I}^i = \frac{\delta \alpha_{Ih}}{1 - \delta + 2\delta \alpha_{Ih}} \exp(y^i) \equiv \psi \exp(y^i).$$

Skill Transmission

How does θ_{t+1} depend on θ_t?

We replace the standard AR(1) Model

$$\theta_{t+1} = \eta\theta_t + \epsilon^{\theta}_{t+1}$$

with a genetic model.

Skill Transmission

1. Genotype: K bi-allelic loci, $\{A, a\}$ say;
2. We shorten $aa = 1, aA = 0.5, AA = 0$
3. Genotype set: $G^K \equiv \{0, 0.5, 1\}^K$; K is *large* (order: tens of thousand)
4. The genetic component of skill transmission from parents to children follows:

$$H : (g_m, g_f) \mapsto H(g_m, g_f) \in \Delta(G^K). \tag{5}$$

5. H follows well known rules of Mendelian inheritance; for instance if $K = 1$ so $G^K = \{0, 0.5, 1\}$, then $H(0.5, 0.5)$ is $(0.25, 0.5, 0.25)$, and $H(0, 1)$ is $(0, 1, 0)$.

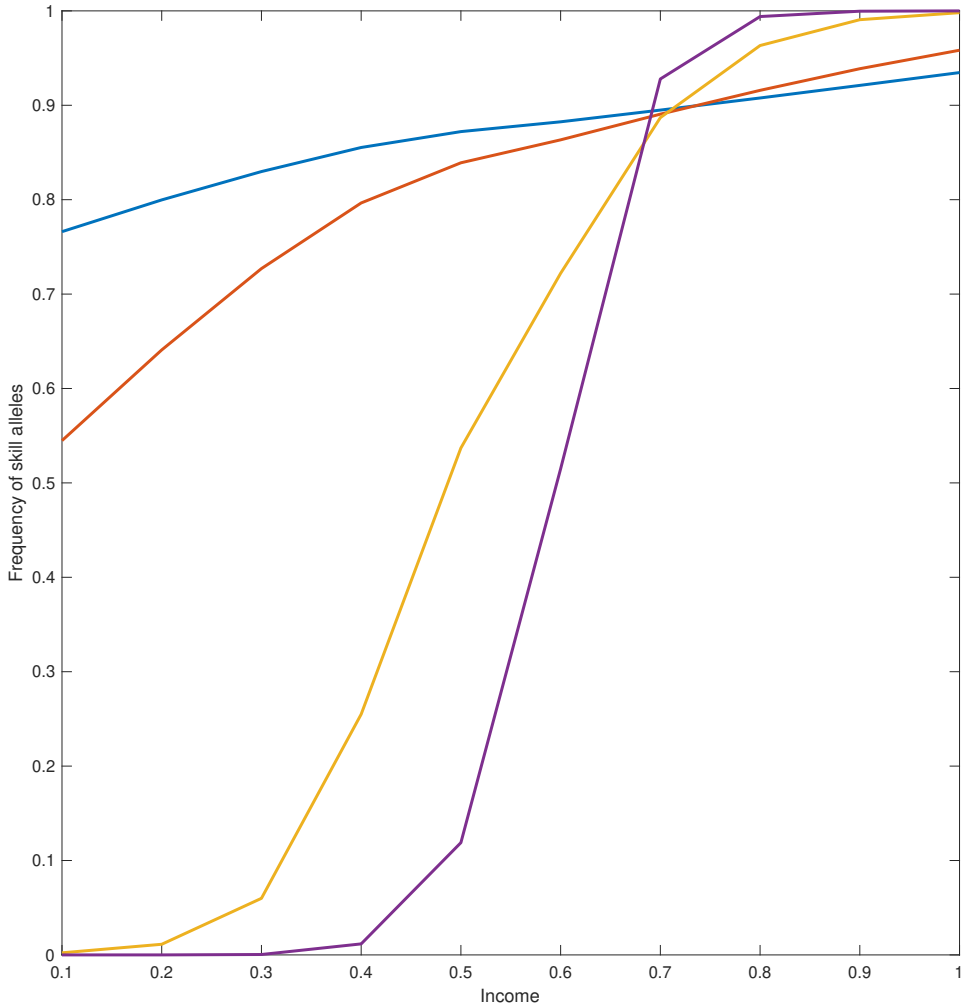
Matching Process

1. Parents are matched on ordered characteristics (skill, income) and idiosyncratic characteristics (physical appearance)
2. The utility from the matching with a partner of a skill and income type determines the value of the matching
3. Stable matching as equilibrium concept

Stochastic Process on $\Delta(G \times Y)$

1. The process of matching of parents, generation of children, parental investment and accumulation of human capital determines a stochastic process on the product of genotypes, income, characteristics;
2. The process is non-linear, so proving existence of the invariant measure is harder
3. The convergence to the invariant measure can be studied, and simulated;
4. The convergence is fast.

Allele with strong affect on educational attainment has steeper frequency gradient with respect to income



Income at the age 29, on family income, *PGS* , and Personality.

	(1) b/se	(2) b/se	(3) b/se
Family Income	0.134***	0.128***	0.078**
	(0.027)	(0.027)	(0.032)
Male	0.277***	0.276***	0.313***
	(0.025)	(0.025)	(0.029)
Male × Family Income	–0.060**	–0.060**	–0.050*
	(0.025)	(0.025)	(0.030)
PGS		0.078***	0.021
		(0.025)	(0.028)
Education Years			0.256***
			(0.035)
IQ			0.008
			(0.029)
MPQ PA			0.061**
			(0.026)
MPQ NA			–0.024
			(0.027)
MPQ CN			0.034
			(0.032)
Externalizing			–0.072*
			(0.037)
Academic effort			0.057
			(0.038)
Academic problems			–0.017
			(0.034)

SEM of Pathways from *PGS* to Education Years.

PGS of children

Equation	Variable	b	z	p value	CI
Ed Yrs	C	0.285	4.87	<0.001	[0.171, 0.401]
		(0.058)			
	NC	0.856	3.11	0.002	[0.315 , 1.4397]
		(0.276)			
	PGS	0.014	0.35	0.725	[-0.066 , 0.94]
		(0.041)			
	PGS mother	0.033	0.71	0.282	[-0.027 , 0.093]
		(0.030)			
	PGS father	0.019	0.66	0.512	[-0.039 , 0.078]
		(0.030)			
	Educ Parents	0.136	4.58	<0.001	[0.078 , 0.194]
		(0.29)			
	Family Income	0.075	2.38	0.017	[0.013 , 0.137]
		(0.031)			
	Male	-0.151	-2.77	0.007	[-0.260 , -0.041]
		(0.055)			
	Constant	0.376	9.85	<0.001	[0.301 , 0.450]
		(0.027)			
C	PGS	0.287	9.21	<0.001	[0.226,0.349]
		(0.031)			
NC	PGS	0.040	1.95	0.051	[-0.0002, 0.081]
		(0.025)			

SEM of Pathways from *PGS* to Education Years.

PGS of children and parents

Equation	Variable	b/se	z	p value	CI
Educ Parents	PGS mother	0.182	5.62	<0.001	[0.118 0.245]
		(0.032)			
	PGS father	0.301	8.96	<0.001	[0.235, 0.367]
		(0.033)			
	Constant	0.066	2.00	0.045	[0.001, 0.132]
		(0.033)			
Family Income	PGS mother	0.091	3.12	<0.001	[0.034, 0.149]
		(0.029)			
	PGS father	0.154	5.05	<0.001	[0.094, 0.213]
		(0.030)			
	Constant	0.131	4.28	<0.001	[0.070, 0.198]
		(0.030)			
Ed Years	Educ Parents	0.183	8.76	<0.001	[0.142, 0.224]
		(0.021)			
	Family Income	0.112	4.84	<0.001	[0.066, 0.157]
		(0.023)			
	PGS	0.103	4.84	0.002	[0.038, 0.167]
		(0.032)			
	PGS mother	0.052	2.26	0.094	[-0.006, 0.084]
		(0.023)			
	PGS father	-0.003	-0.13	0.899	[-0.051, 0.044]
		(0.024)			
	Male	-0.139	-2.85	0.004	[-0.235, -0.043]
		(0.048)			
	Constant	0.345	13.43	<0.001	[0.284, 0.395]
		(0.025)			

Personality Theory

1. Individual economic and political behavior is dictated by broader characteristics than those traditionally examined by economics
   - Economics: attitude to risk, subjective discount factor
   - Intelligence
   - Conscientiousness
2. Understanding of the hereditary and environmental components of these characteristics
   - Understanding of reasons for the existence of inequality and social mobility
   - Possible endogenous nature of institutions (the distribution of the genotype in a society influences the possible institutions)
3. Preliminary elements for understanding biological causal pathways

Personality and Economic Analysis

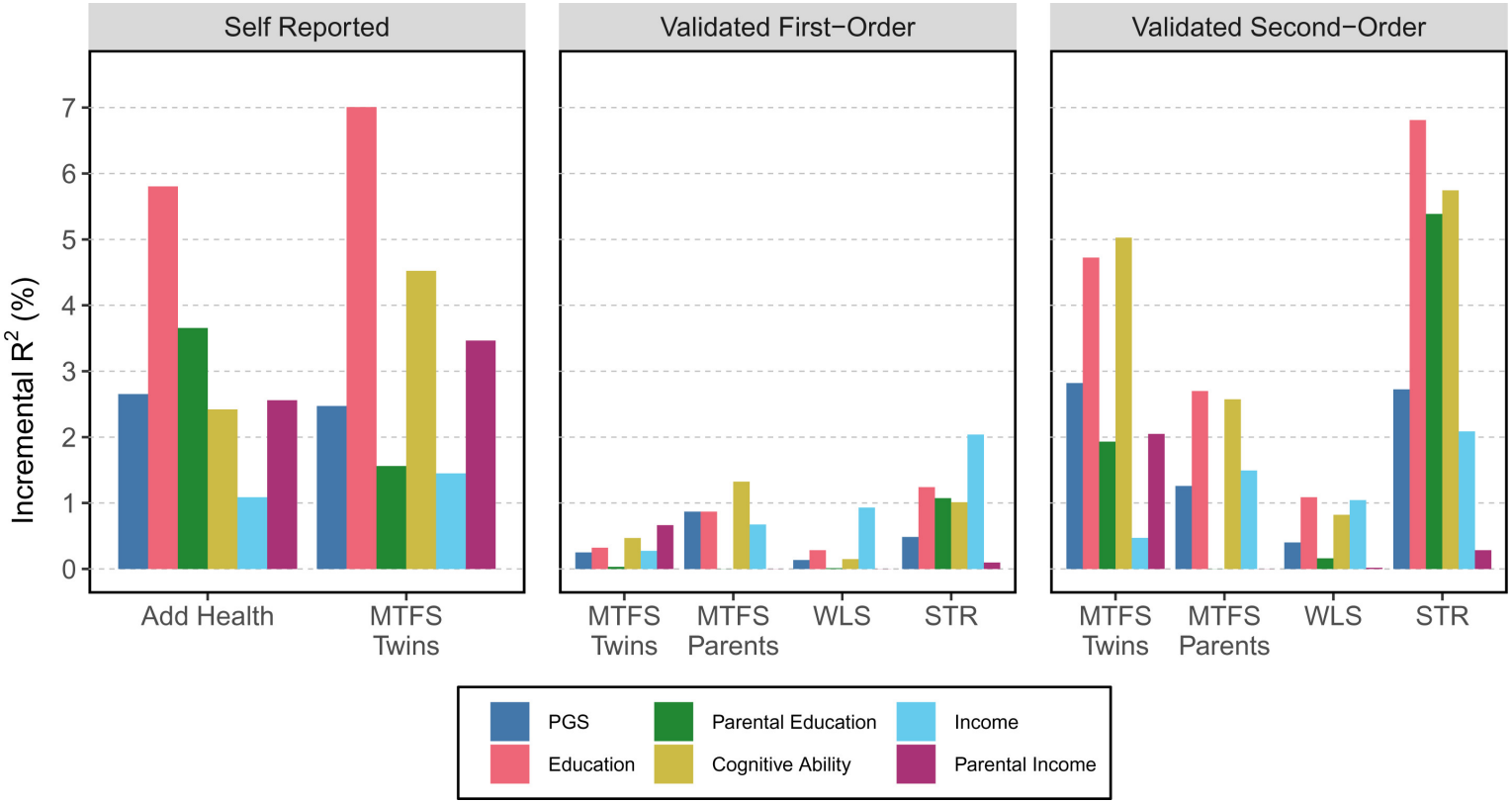
Examples of implications

1. Social mobility and inequality: not just economic preferences, not just intelligence
2. Strategic behavior:
3. Personality and Institutions: the *PGS* for *EA*

Genes and Voter participation

Dawes, Okbay, Oskarsson, Rustichini, PNAS 2021

Increase in R^2 of voter participation induced by relevant variables including *PGS* of *EA*.



Some General Implications

U

p to this point there is universal consensus. In the next part we derive some general implications of this analysis.

Warning

What follows is my opinion, perhaps a minority opinion (minority of one).

Two Views

A widespread view of this extension of economic analysis is this:

1. Neuroeconomics and Genoeconomics are the foundation of economics on different (more specifically "non-neoclassical") bases.
2. Behavioral Economics is the most coherent plan to implement this program

Two Views

My thesis:

1. Neuroeconomics, Genoeconomics and Personality Theory are part of a new foundation of economics on a biological basis
2. Classical Economics has a unique understanding of human society, which is the outcome of the modern revolution in social sciences beginning with the modern view of political philosophy (Machiavelli and then Hobbes).
3. There are two fundamental concepts have to be preserved, which are the core of the revolutionary understanding provided by economics. Not by chance, they are under relentless critique

Two fundamental concepts of economics

1: Individualism

Economic and social behavior, in all historical periods, is the result of a combination of individual behavior

1. This behavior is well explained by a personal and rational interest
2. Consequently, incentives matter
3. Ignoring this fact will not make it go away

Two fundamental ideas of economy

2: Equilibrium

The process producing social and economic behavior starting from the behavior of individuals is provided by a concept of equilibrium,

1. A specific equilibrium is valid in historically determined institutional arrangements
2. General Economic Equilibrium, Nash Equilibrium.

The third component

3: Biological Materialism

1. Individual behavior has been in past economic analysis modeled temporarily, and for lack of alternatives, with models *"as if"* ("Individuals behave *as if* they are maximizing a utility function")
2. Individual behavior has biological underpinnings that we can now begin to understand
3. The premise that it is possible to study the biological foundation of human nature is based on the assumption (which can be demonstrated, if is successful) that this foundation exists
4. Understanding the genetic basis of these
5. This view produces mechanistic models
6. It is the completion of a program that began at the dawn of our civilization (Democritus, Plato, Lucretius, Hobbes).

Socrates' Noble Lie

> *While all of you in the city are brothers, we will say in our tale, yet God in fashioning those of you who are fitted to hold rule mingled gold in their generation, for which reason they are the most precious but in the helpers silver, and iron and brass in the farmers and other craftsmen. And as you are all akin, though for the most part you will breed after your kinds.*

Plato Republic, Book III, 414 b.

The Truth of the Lie

> *Obviously, then, we must arrange marriages, sacramental so far as may be. And the most sacred marriages would be those that were most beneficial how imperative, then, is our need of the highest skill in our rulers, if the principle holds also for mankind.*

Plato Republic, Book V, 458 d.

Opposite idea: Idealistic view of society

Opposite to materialistic view¿

1. Human nature does not exist but it is exclusively the result of a historical-social process
2. Corollary 1: Men are potentially all equal, all differences among men are constructed by society
3. Corollary 2: every difference between groups is due to discrimination
4. Corollary 3: Human Nature infinitely malleable and subject to the transforming action of reason.
    - Reason has to be organized in the state
    - The state can make use of the enlightened advice of intellectuals
    - Citizens will follow the suggestions-indications-mandates of the prince-state

Variants of idealism

1. Historical materialism is a variant of the Hegelian left
2. The new man

- *He is a hunter, a fisherman, a herdsman, or a critical critic, and must remain so if he does not want to lose his means of livelihood; while in communist society, where nobody has one exclusive sphere of activity but each can become accomplished in any branch he wishes, society regulates the general production and thus makes it possible for me to do one thing today and another tomorrow, to hunt in the morning, fish in the afternoon, rear cattle in the evening, criticize after dinner, just as I have a mind, without ever becoming hunter, fisherman, herdsman or critic.*

  K. Marx–F. Engels, 1846, The German ideology

- *In a higher phase of communist society, after the enslaving subordination of the individual to the division of labor, and therewith also the antithesis between mental and physical labor, has vanished; after labor has become not only a means of life but life's prime want; after the productive forces have also increased with the all-around development of the individual, and all the springs of co-operative wealth flow more abundantly –only then can the narrow horizon of bourgeois right be crossed in its entirety and society inscribe on its banners: From each according to his ability, to each according to his needs!*

  K. Marx–F. Engels, 1875, Critique of the Gotha Program