Tapping into Talent: Coupling Education and Innovation Policies for Economic Growth

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Motivation

- Benchmark endogenous growth models predict a strong response of productivity growth to R&D subsidies
- Goolsbee (1998), Romer (2000): R&D subsidies just increase scientists' wages, as supply of researchers is inelastic
- **This paper:** the mechanics of R&D policy, and how it interacts with education policy which generates the human capital in the economy

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$$\text{growth rate} \approx F(\text{"subsidy rate"} \mid \text{4 new ingredients})$$

Research Question

What does it take to turn taxpayers' money into innovation and economic growth?

How We Address This Question

- New empirical facts using Danish data including:
  - Individual income, education, IQ, parental information
  - Patent Data
  - Innovation policy
- Build a model of endogenous growth that incorporates:
  1. Talent heterogeneity
  2. Occupational choice with heterogeneous preferences
  3. Time to learn within research teams
  4. Financial frictions for students wanting education
- Calibrate model to the data and perform counterfactual policy analysis
- Key Finding: R&D subsidies can be complemented with education policy. Education policy is more effective in very unequal societies.

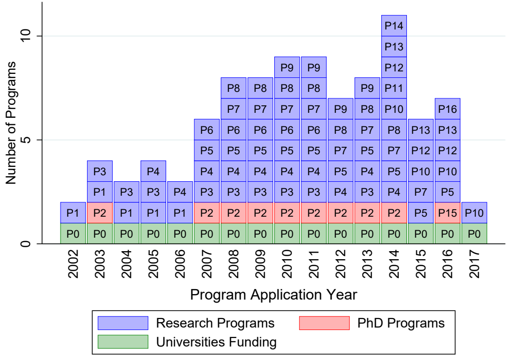
Data

Micro Data from Danmarks Statistik and Treasury Department (DST) with:

- Detailed information on innovation policy
- Individual level income, IQ and education data
- Linked parental information
- Matched employer-employee data
- Patent data from European Patent Office (EPO)

InnovationDanmark database

- "InnovationDanmark" is a wide innovation program operated by the government
- The database, starting in 2002, contains data from more than 20 national and international research and innovation instruments



▸ Program Descriptions

Outline

1. **Facts**

2. Model

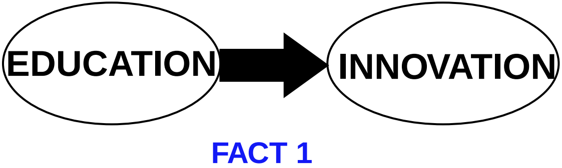
3. Empirical Analysis

4. Quantitative Analysis

Empirical Facts

Empirical Facts

Fact 1: **PhDs are more likely to become inventors.**



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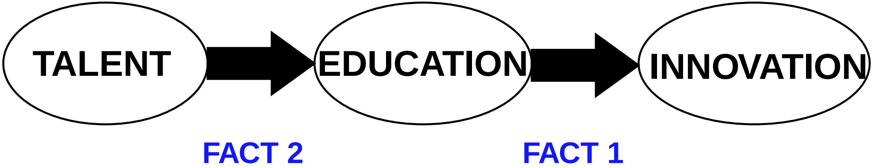
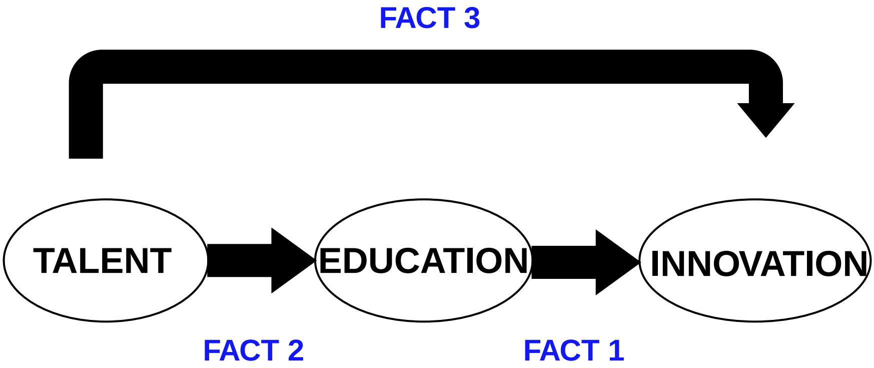
Fact 2: **Individuals with higher IQ more likely to obtain a PhD.**



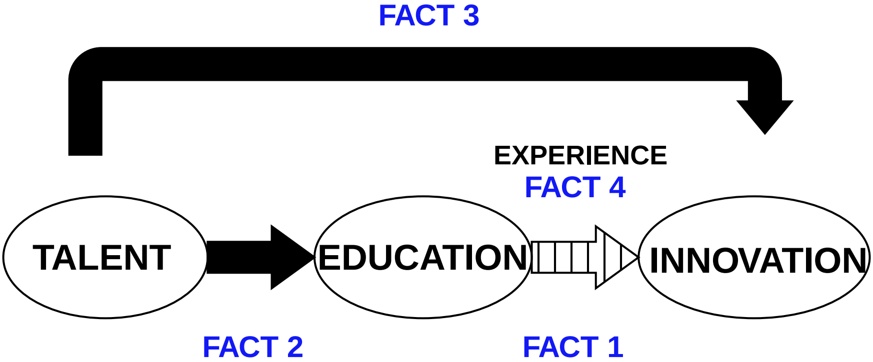
Empirical Facts

Fact 3: Individuals with higher IQ produce more innovations on average, even conditional on their education.



Empirical Facts

Fact 4: **Probability of innovation over an PhD's lifecycle has an inverted-U shape.**



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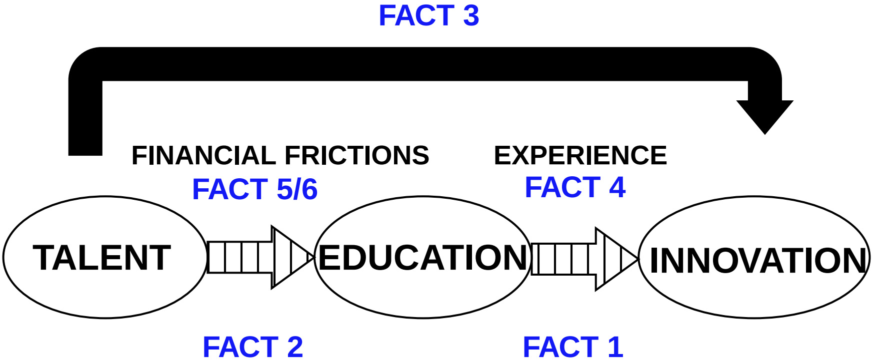

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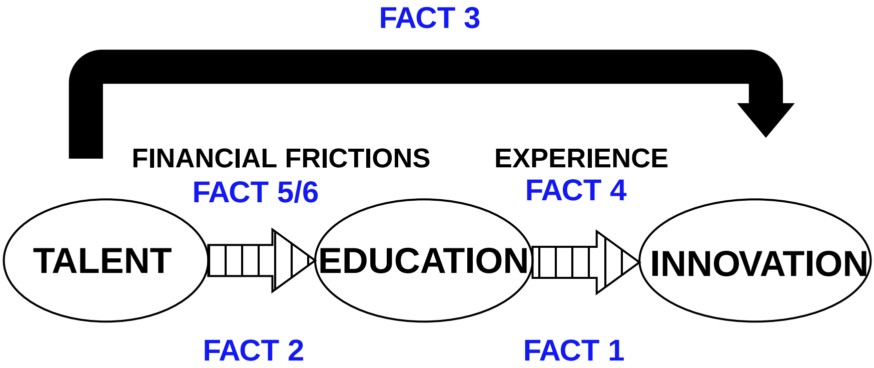

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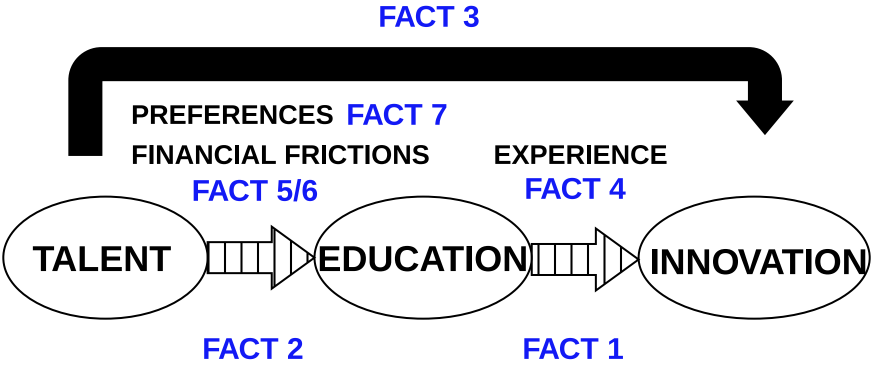
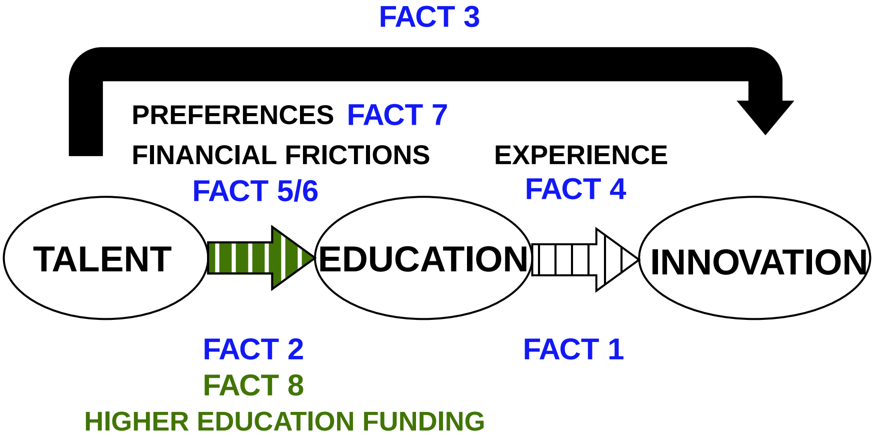


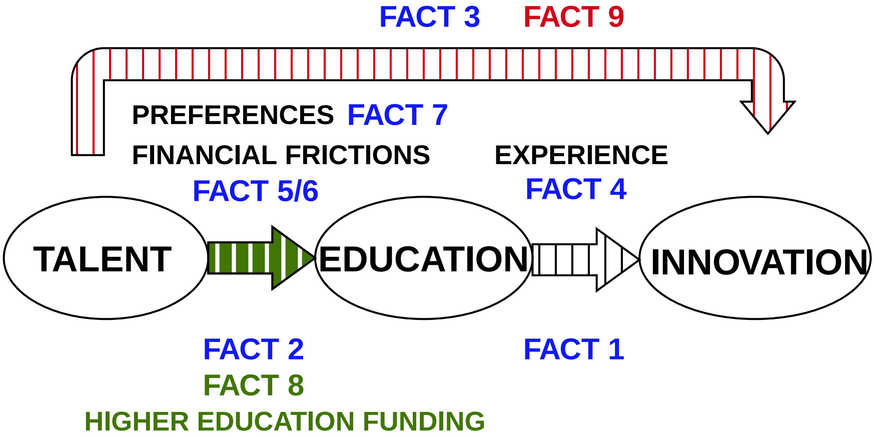
Empirical Facts

Fact 8: **Education funding increases the supply of researchers.**

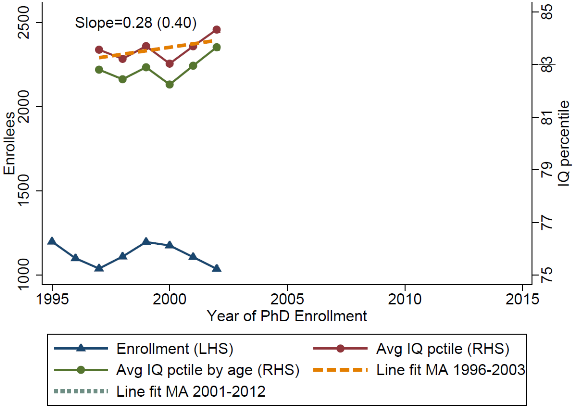


Empirical Facts

Fact 9: **As the number of PhD enrollees increases, average IQ of enrollees falls.**



Fact 9: Tradeoff Size vs. Quality of Researchers



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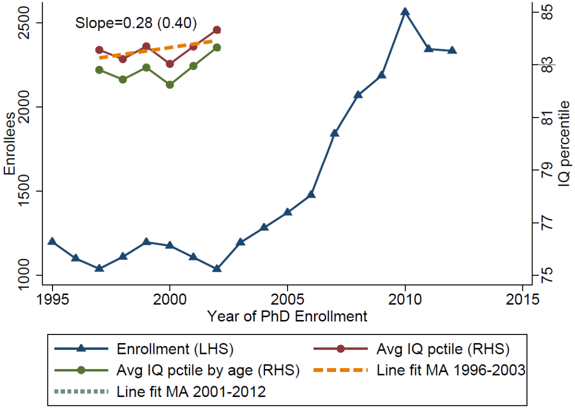

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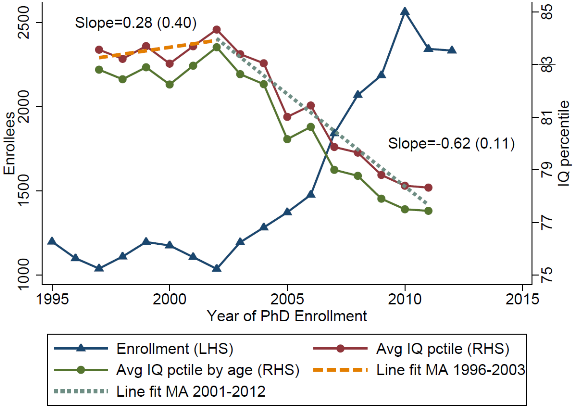

Outline

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2. **Model**
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Model Outline

The model features

- A research sector and a final goods production sector
- Individual talent creates ideas, and is heterogeneous
- A team structure in the research sector where team members “learn”
- Costly education with financial frictions
- Heterogeneous preference for research.

Research Teams

- Mass 1 of individuals with heterogeneous talent $z \sim F(z)$ and death rate δ

$$1 = \underbrace{L}_{\text{production workers}} + \underbrace{\tilde{n}}_{\text{researchers}}$$

- Individuals can work as production workers or researchers
  - In order to become a researcher, an individual must get a PhD

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- Researchers work in teams composed of :
  - Team members: PhDs earning the skilled wage $w_s(t)$
  - Team leaders: team members stochastically become leaders with Poisson arrival rate $\lambda \rightarrow$ time to learn

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  - Team leaders: team members stochastically become leaders with Poisson arrival rate λ $\rightarrow$ time to learn
- A team leader with talent z hires n team members and lab equipment a to produce with probability ϕ an idea of quality

$$q = z^{\eta_1} n^{\eta_2} a^{\eta_3}$$

where η_1 is the team leader's span of control as in Lucas (1978) and $\eta_1 + \eta_2 + \eta_3 = 1$
$\rightarrow$ Individuals with higher talent produce more innovation

Education

- Universities open $\tilde{n}$ PhD slots for individuals
- In order to obtain a PhD, an individual must pay an education cost $\kappa(t)$
- The cost must be paid upfront, so individuals rely on parental income

  $\rightarrow$ Individuals with higher father's income are more likely to obtain a PhD.
- Parental resources distributed as a Pareto:

$$Pr(y_j(t) > y) = \left(\frac{y_{min}}{y}\right)^{\tilde{\theta}}$$

- Assume everyone can go to school if resources are equally distributed:

$$y_{min} = \frac{\tilde{\theta} - 1}{\tilde{\theta}} \kappa(t)$$

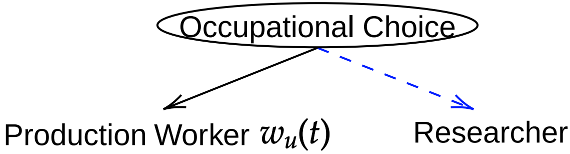
Financial Frictions

- A fraction μ of the population has perfectly assortative matching between IQ and parental resources, i.e. $y_j = z_j$
- For the remaining $1 - \mu$ parental resources independent of IQ

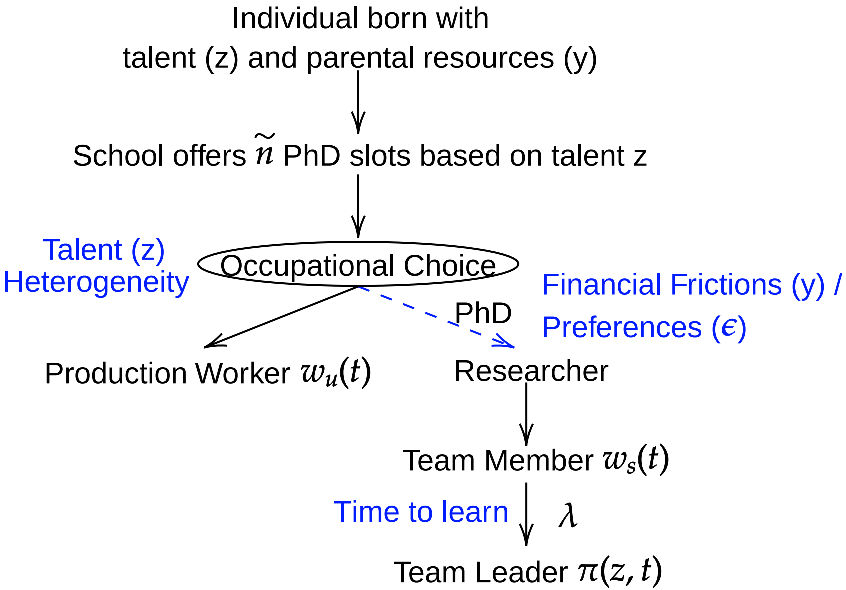
  $\rightarrow$ Individual's IQ is correlated with father's income, but not perfectly.
- Thus the probability that an individual with random parental resources can afford education is:

$$Pr(y_j(t) > \kappa(t)) = \left(\frac{\tilde{\theta} - 1}{\tilde{\theta}}\right)^{\tilde{\theta}}$$

Occupational Sorting - Models in the Literature



Occupational Sorting - Our Framework



School's Problem

- With $\tilde{n}$ slots open:

$$\tilde{n} = \underbrace{\Pr(z \geq \bar{z})}_{high\ talent} \times \underbrace{\Pr(z \text{ chooses research})}_{preference\ for\ research} \times \underbrace{\tilde{\mu}}_{financially\ unconstrained}$$

- Where $\tilde{\mu} = \mu + (1-\mu)\left(\frac{\theta-1}{\theta}\right)^{\theta}$ is the probability an individual above the cutoff can afford education
- Given the individual's decision problem, $\tilde{n}$ will determine a $\bar{z}$ talent cutoff above which talent the school accepts

Occupational Choice: Production Worker or Researcher?

- An individual born at time b with discount rate ρ, *distaste* for research $\tilde{\epsilon} \sim U(0, Ez)$, would optimally choose to get a PhD if

$$V^{PhD}(z) - \ln(\tilde{\epsilon}) > V^{worker}$$

$$\int_b^\infty e^{-(\delta+\rho)(t-b)} \left[e^{-\lambda(t-b)} \ln(w_s(t)) + (1 - e^{-\lambda(t-b)}) \ln(\pi(z,t)) \right] dt - \ln(\tilde{\epsilon}) > \int_b^\infty e^{-(\delta+\rho)(t-b)} \ln(w_u(t)) dt$$

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- integrating with the school's problem yields the cutoff $\bar{z}$

$$\bar{z} = \left[\frac{\tilde{\mu}}{\tilde{n}E} \left(\frac{w_{s,0}}{w_{u,0}} \right)^{\frac{\delta+\rho}{\lambda}} \frac{\pi_0}{w_{u,0}} \right]^{\frac{1}{\theta}} \tag{1}$$

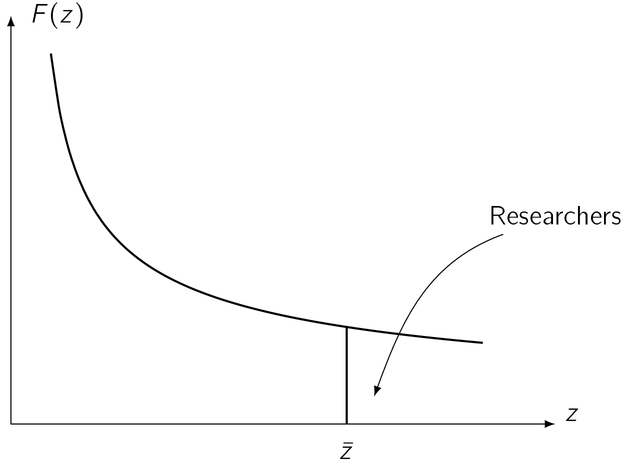
- where $w_{s,0}, w_{u,0}, \pi_0$ are compensations of all occupations

Individuals w/ higher talent+preference for team leadership want PhD

Parental income not a factor in whether an individual *wants* to obtain a PhD

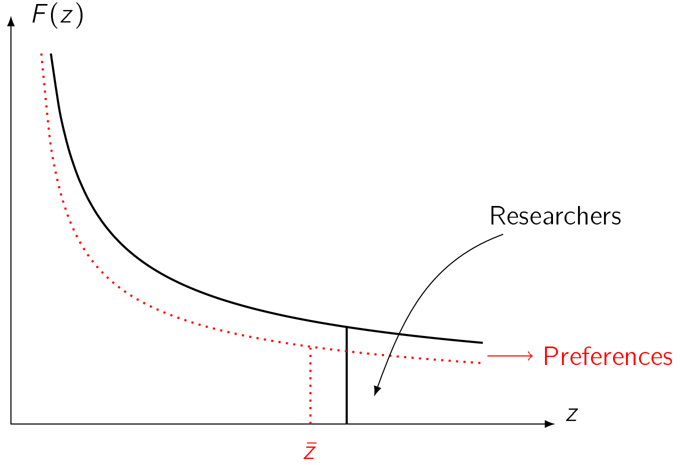
Occupational Choice: Production Worker or Researcher?

- Allocation of talent in absence of frictions



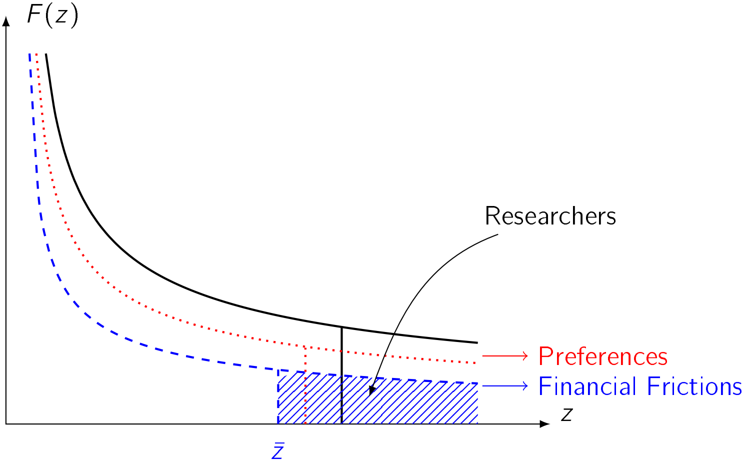
Occupational Choice: Production Worker or Researcher?

- Due to taste shock, some talented individuals do not want to become researchers



Occupational Choice: Production Worker or Researcher?

- Due to financial frictions, some talented individuals cannot afford to become researchers



Growth Rate of the Economy

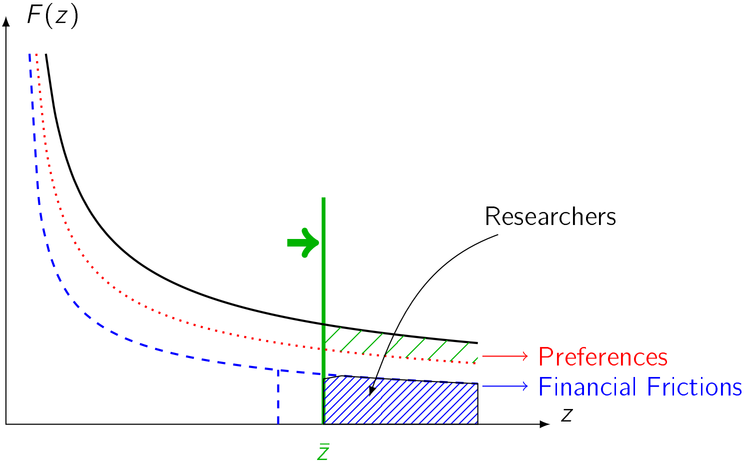
- Productivity growth in the economy is $\frac{\dot{\bar{A}}(t)}{\bar{A}(t)} = \int_j q_j dj$
- The fraction of individuals that go into research is $\tilde{n}$
- In addition, exogenous arrival rate ξ of idea proportional to IQ for everyone
- The growth rate is

$$g = \underbrace{\tilde{n}}_{\text{amt. of researchers}} \times \underbrace{\phi \frac{\lambda}{\lambda+\delta} \int_{z^*}^{\infty} \Pr(z \to PhD) q(z) f(z) dz}_{\text{idea arrival} \times \text{team leaders} \times \text{quality of ideas}} + \underbrace{\xi \int_1^{\infty} z\, dz}_{\text{exogenous arrival}}$$

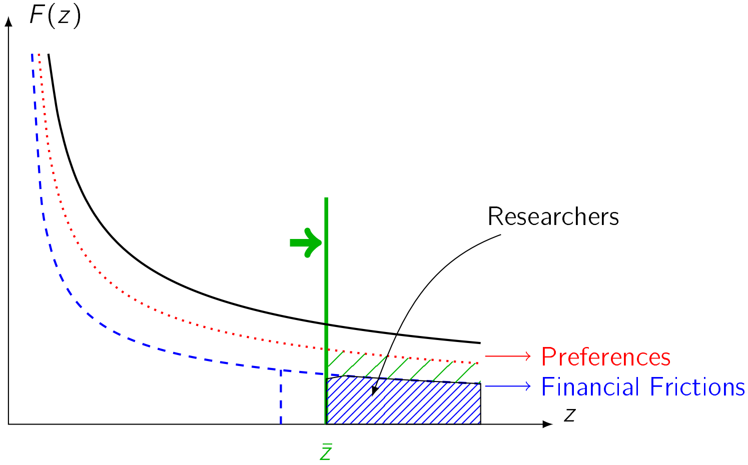
$$g = \phi \frac{\lambda}{\lambda+\delta} \tilde{n} \left[\frac{\delta}{\lambda} \frac{\theta-1}{\theta} \right]^{\frac{\eta_2}{\eta_1+\eta_2}} \left(\eta_3 \phi \frac{\pi}{r} \right)^{\frac{\eta_3}{\eta_1+\eta_2}} \frac{\theta}{\theta-1} \bar{z}^{\frac{\eta_1}{\eta_1+\eta_2}} + \xi \frac{\theta}{\theta-1}$$

Equilibrium Equations

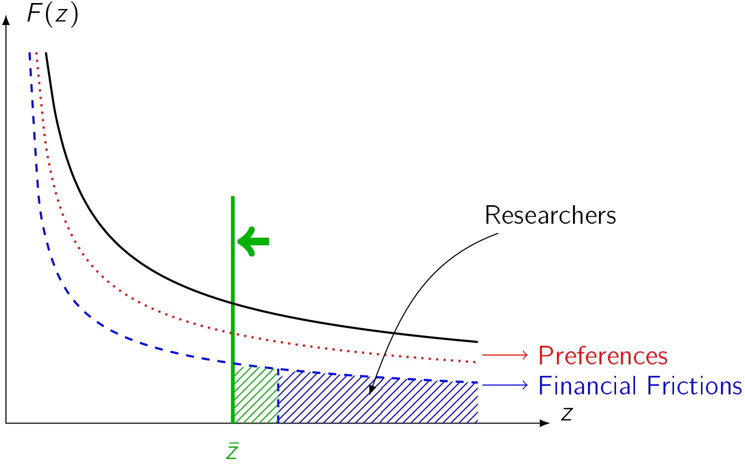
Policy Exercise 1: R&D subsidy



Policy Exercise 2: Subsidy to Cost of Education



Policy Exercise 3: Increase PhD Slots



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Talent Heterogeneity

Talent Heterogeneity Matters

Fact 1: PhDs are more likely to become inventors.

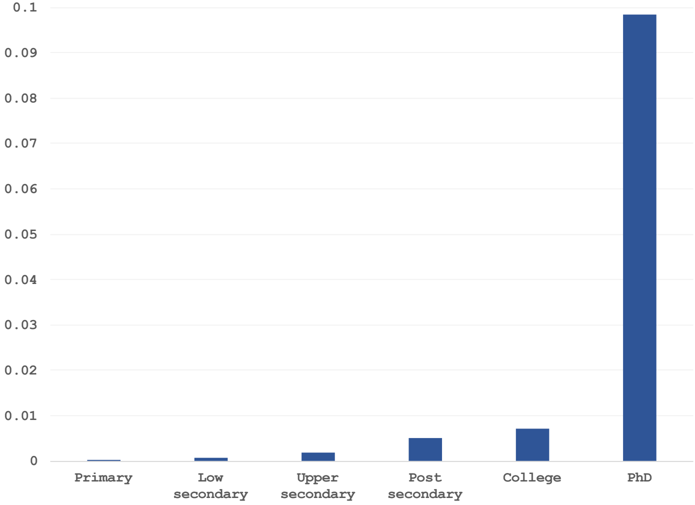


Figure: Fraction of individuals with at least one patent by education group.

Talent Heterogeneity Matters

Fact 2: Individuals with higher IQ more likely to obtain a PhD.

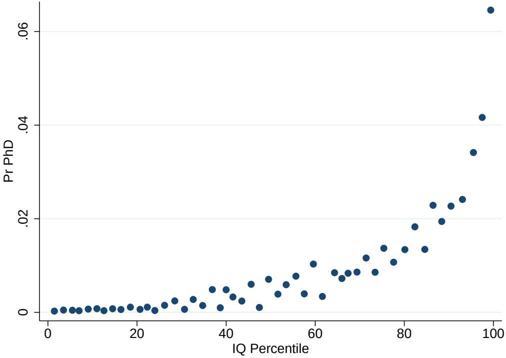


Figure: Fraction of individuals with a PhD by IQ percentile.

Talent Heterogeneity Matters

Fact 3: **Higher IQ people are more likely to become inventors, even conditional on their education.**

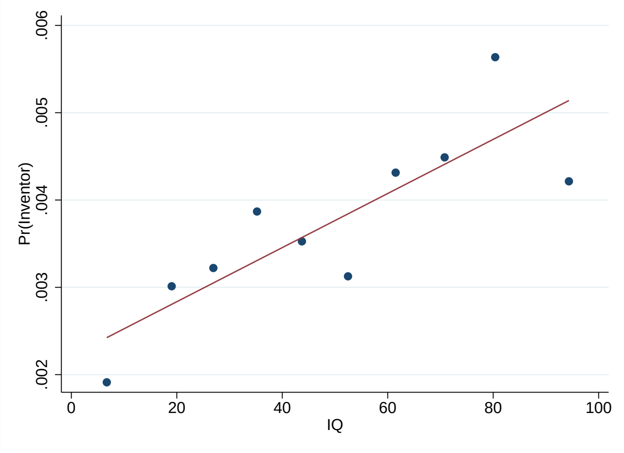


Figure: Pr(Inventor|Education level) and IQ

Time to Build Human Capital

Time to Learn/Build

Fact 4: The probability of innovation over an inventor's lifecycle has an inverted U shape.

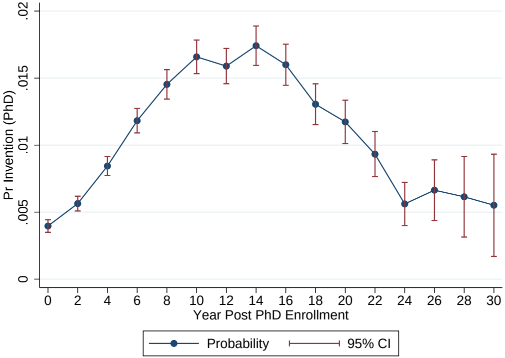


Figure: Fraction of PhDs applying with ≥ 1 patent, year post PhD enrollment.

Financial Frictions

Financial Frictions I

Fact 5: Individuals with higher father's income are more likely to get a PhD.

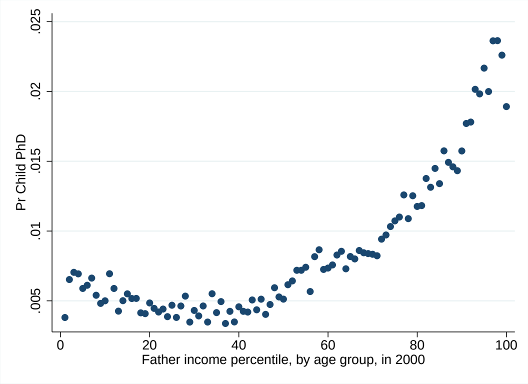


Figure: Proportion of individuals with a PhD by father's income percentile.

Look into pr innovation on Y-axis, father's age on X and Y-axis

Financial Frictions II

Fact 6: Individuals' IQ is correlated with father's income, but not perfectly.

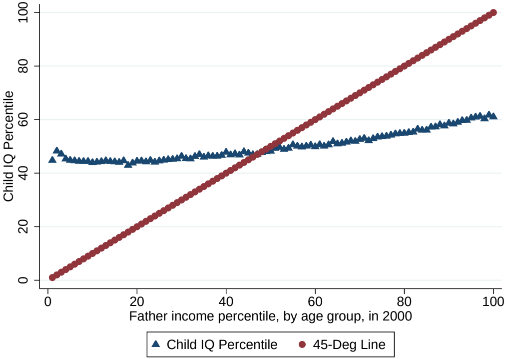


Figure: Average individual IQ percentile by father's income percentile.

Heterogeneous Preferences

Heterogeneous Preferences

Fact 7: Many unconstrained individuals with high IQ do not get a PhD.

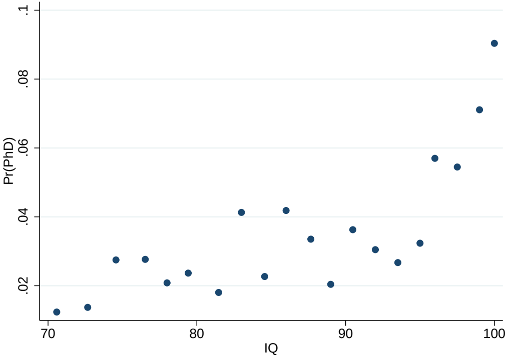


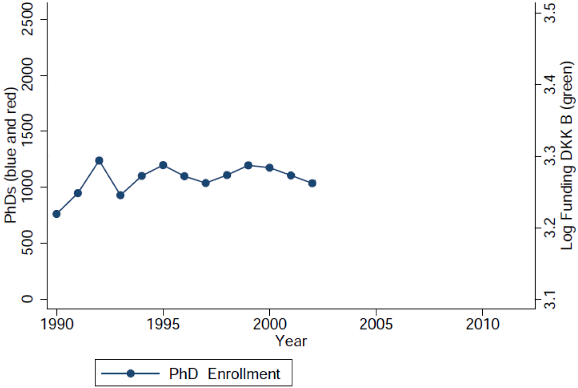
Figure: Pr(PhD) on IQ, parents in top 5% income distribution

90% of top IQs still do not take a PhD

Policy Intervention

Increasing the Supply of Inventors

Until 2002, PhD enrollment is flat.



Note: PhDs funded data is not present pre 2000 or so

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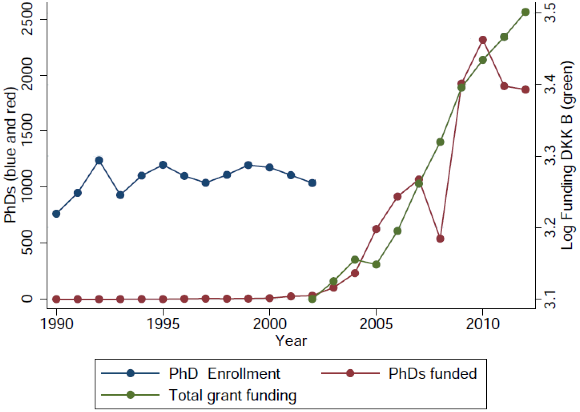

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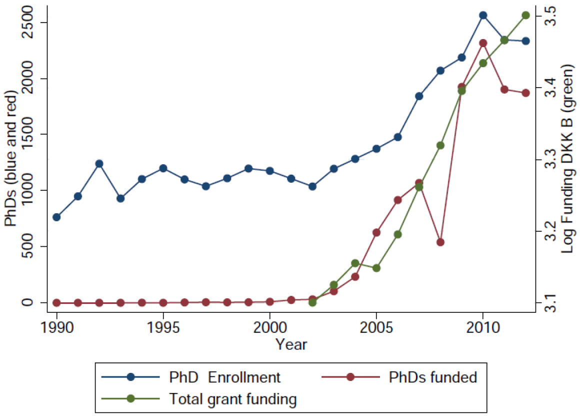

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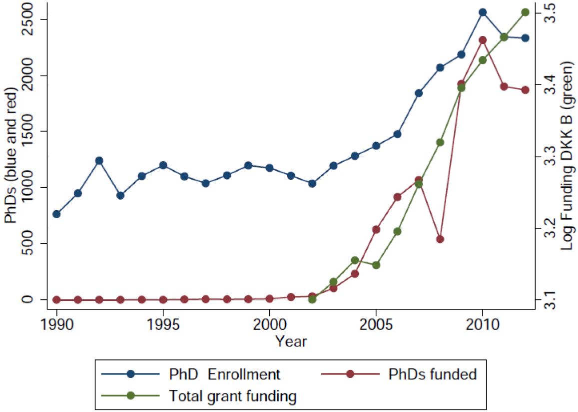

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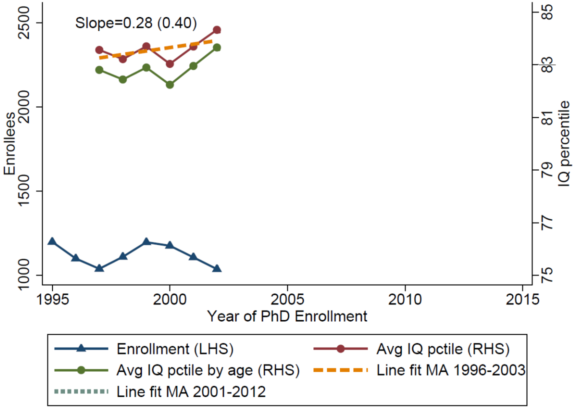
Tradeoff Size vs. Average Quality of Researchers Pool



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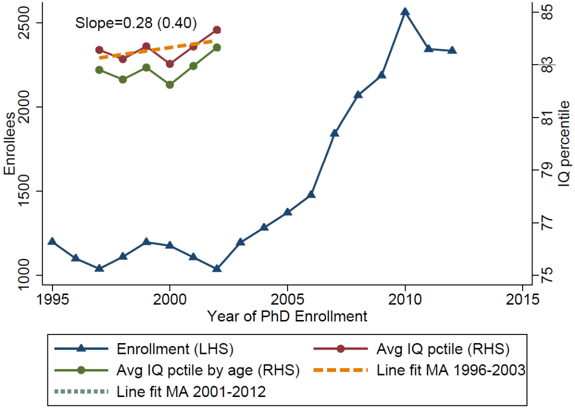

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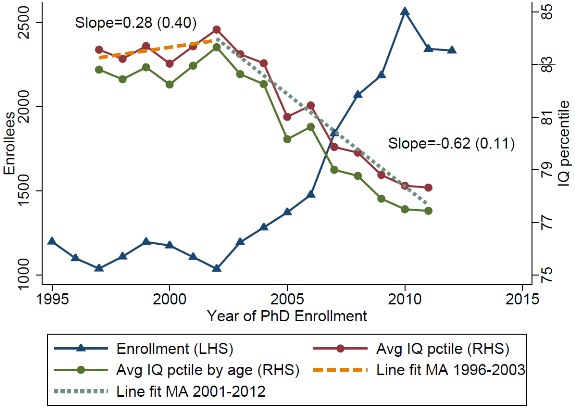

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Moments from the Data

Moment	Data	Model
— Panel A. For Direct Matching —		
Corr(Parent Income, Child IQ) (μ, Fact 6)	0.175	0.175
PhD share of the labor force ($\tilde{n}$)	0.01	0.01
— Panel B. For Joint Calibration —		
Peak Year Innovation Post PhD (Fact 4)	14	13
Pr Innovation at Peak (Fact 4)	0.018	0.018
Mean team size	2.50	2.50
Variance of team size	3.62	3.62
Skill premium of PhDs	0.74	0.74
PhD post-student/student income	1.66	1.66
Median percentile IQ of PhDs (Fact 2, Fact 7)	0.83	0.83
PhD Patent Share	0.23	0.23
Growth rate	0.02	0.02

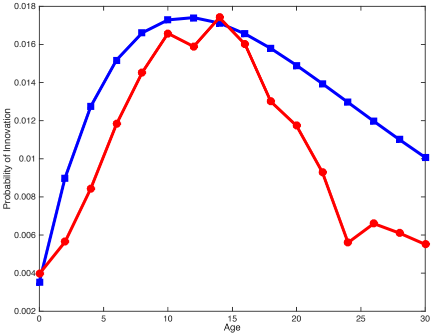
Parameter Values

Parameter	Description	Value	Main Identification
	— Panel A. External Match —		
ρ	discount rate	0.03	
r	interest rate	0.03	risk neutrality and ρ
β	Labor share output	0.106	Akcigit and Kerr 2016
	— Panel B. Direct Data Match —		
μ	Corr(Parental Income, Child IQ)	0.175	Corr(Parental Income, Child IQ)
$\tilde{n}$	PhD share of the labor force	0.01	Pr(PhD)
κ	Cost of Education	0.04	College room & board cost
	— Panel C. Internal Calibration —		
λ	rate at which skilled $\rightarrow$ leader	0.040	mean time size
δ	death rate	0.060	Pr(innovation, peak)
η_1	skilled labor share idea production	0.477	PhD graduate/ PhD student income
η_3	lab equipment share idea production	0.090	growth rate
η_2	worker share idea production	0.433	1-η_1-η_3
θ	Pareto Shape	2.558	variance of team size
ϕ	innovation rate	0.095	Pr(innovation, peak)
ψ	cost of raising capital	0.069	Skill premium
E	preference shock parameter	3.414	Mean Percentile IQ PhDs
ξ	exogenous idea arrival	0.009	PhD Patent Share

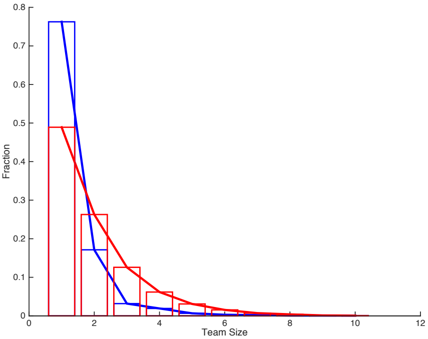
Notes: All parameters are estimated jointly.

Goodness of Fit for Targeted Moments

Figure: Comparing data (red) and model simulated (blue) moments



(a) Lifecycle of innovation probability



(b) Team Size Distribution

Financial Frictions and Economic Growth

- In order to understand our economy, we think about the *level* of growth with financial frictions and without:

Table: Steady State Growth at Different Levels of Financial Frictions

1-Level of frictions (μ)	**Growth rate (%), no subsidies**
0	1.93
0.175	2.00
0.50	2.08
1	2.17

- Note the large effect of changing financial frictions on economic growth

Results

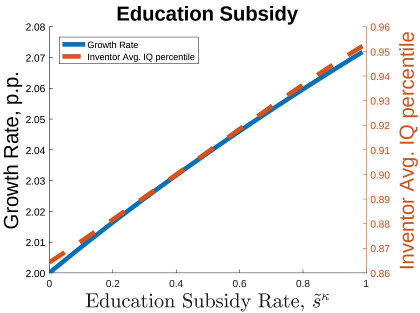
1. Policy Counterfactuals in Steady State
2. Policy Complementarity
3. Interplay between Inequality and Effectiveness of Policy
4. Policy Effectiveness at different Policy Horizons: Transitional Dynamics

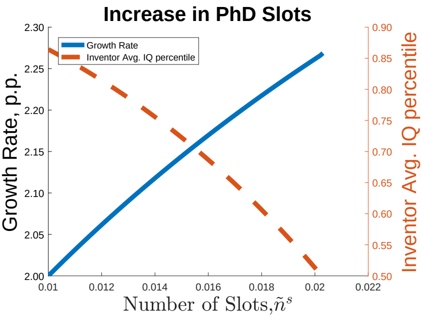
Result 1: Policy Effectiveness vs. Standard Models

Table: "Missing Growth" Accounting

	20% R&D subs.	
	Growth rate p.p	Δ Growth rate p.p.
No subsidy	2.00	
On Impact (1 year)	2.01	0.01
Without time to learn	2.08	0.08
Without talent heterogeneity	2.09	0.09
Without financial frictions	2.23	0.23
Standard models	2.40	0.40

Result 1: Education Policy, Steady State

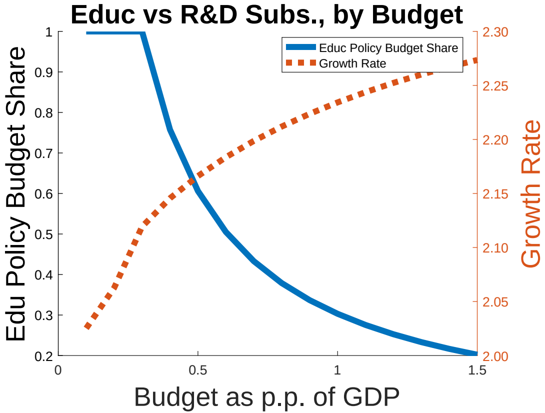




Policy Complementarities

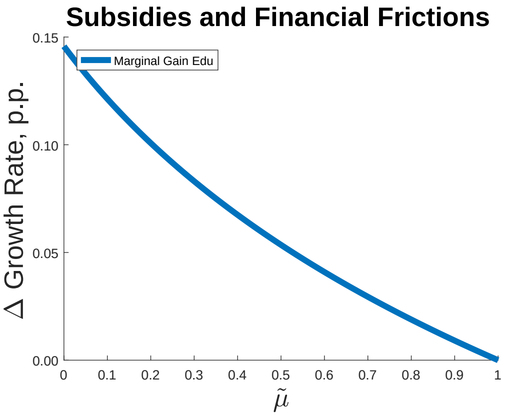
Result 2: Optimal Subsidy Allocation in Steady State

- Allocation of budget across subsidy for different budget levels
- Keeping slots at baseline level 0.01
- For small budgets, allocation entirely to education: building pool of talent is more effective than R&D subsidy



Result 3: Education Policy and Inequality

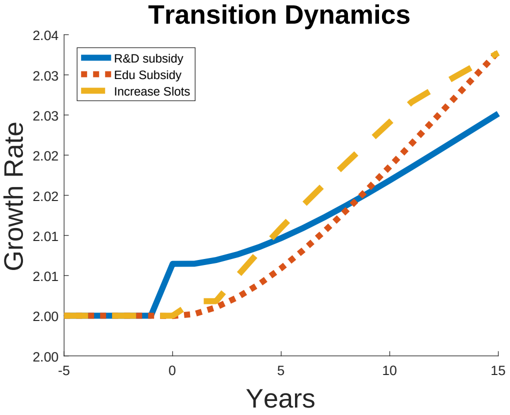
- Compute growth response to 0.3 p.p. GDP subsidy to cost of education at different level of financial frictions
- Plot growth with subsidy minus baseline growth
- Education Policy is more effective in more unequal societies



Transitional Dynamics

Result 4: Transitional Dynamics, General Equilibrium

- Subsidy of 0.3% GDP



Revenue Equivalence

Conclusions

- In this project we open the black box of R&D subsidies and document the necessary steps to transform a subsidy into productivity growth
- We document microeconomic aspects of innovation that standard endogenous growth model are missing:
    1. Talent heterogeneity
    2. Preferences for Research/Private Sector
    3. Time to build Human Capital
    4. Financial Frictions
- Taking these margins into account, through the lens of a quantitative model we show that productivity growth response to R&D subsidies is:
    - Small relative to educational subsidies (financial constraints high)
    - In more equal societies (those can easily afford education), education policy is more effective in drawing in researchers
    - To increase the quantity of researchers, PhD slots need to expand
    - Delayed over time

Appendix

Market for Ideas

- The value of operating a product line is linear:

$$rV(A_j) = \frac{\pi}{r} + \frac{x(1-s)vq}{r}\overline{A}$$

- The surplus change from buying an idea of quality q is :

$$\Delta V_i(t) = \frac{\pi}{r} q\overline{A}(t)$$

- The surplus is shared between team leader and final good producer
- W.l.o.g. we assume that team leaders have full bargaining power
- Then the price of a unit quality idea is :

$$p(t) = \frac{\pi}{r}\overline{A}(t)$$

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Equilibrium Conditions

Equilibrium is defined by 7 equations in seven unknowns:

$$w_u(t) = \frac{\beta}{1-\beta}\overline{A}(t) \tag{2}$$

$$p(t) = \frac{\tilde{\beta}(1-\tilde{n})}{r}\overline{A}(t) \tag{3}$$

$$M = \frac{\delta R}{\lambda + \delta} \tag{4}$$

$$U = 1 - R \tag{5}$$

$$\frac{w_s(t)}{p(t)} = \left[\frac{\lambda \bar{z}}{\delta}\frac{\theta}{\theta-1}\right]^{\frac{\eta_1}{\eta_1+\eta_2}} \eta_2 \phi \left(\eta_3 \phi \frac{\pi}{r}\right)^{\frac{\eta_3}{\eta_1+\eta_2}} \tag{6}$$

$$\bar{z} = \left[\frac{\tilde{\mu}}{\tilde{n}E}\left(\frac{\phi\gamma\pi}{r}\right)^{\frac{(1+(\delta+\rho)/\lambda)}{\eta_1+\eta_2}} \left(\frac{1-\beta}{\beta}\left(\frac{\psi}{1-\beta}\right)^{\frac{1}{\beta}}\right)^{1+(\delta+\rho)/\lambda} \left[\frac{\lambda}{\delta}\frac{\theta}{\theta-1}\right]^{\frac{\eta_1\frac{\delta+\rho}{\lambda}-\eta_2}{\eta_1+\eta_2}} \eta_3^{\frac{\eta_3(1+(\delta+\rho)/\lambda)}{\eta_1+\eta_2}} \eta_2^{\frac{\delta+\rho}{\lambda}} \eta_1\right]^{\overline{\eta_1(\theta-(\delta+}} \tag{7}$$

$$g = \phi\frac{\lambda}{\lambda+\delta}\tilde{n}\left[\frac{\delta}{\lambda}\frac{\theta-1}{\theta}\right]^{\frac{\eta_2}{\eta_1+\eta_2}} \left(\eta_3\phi\frac{\pi}{r}\right)^{\frac{\eta_3}{\eta_1+\eta_2}} \frac{\theta}{\theta-1}\bar{z}^{\frac{\eta_1}{\eta_1+\eta_2}} + \xi\frac{\theta}{\theta-1} \tag{8}$$

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Program Descriptions

Research Subsidies		
P1 P7	FP6 / FP7	VI & VII European Community Framework Program for Research, Technological Development and Demonstration.
P3	Innovation Consortia	Joint project between firms and knowledge institutions to develop and mature research-based knowledge.
P4 P8	Innovation Pilot / Innovation Coupon	Promote cooperation between SME's and institutions to increase SMEs' innovation capacity.
P5	Innovation Agents	Innovation Agents offer knowledge and guidance to SMEs for technological innovation and business development.
P6	Open Funds	Public-Private cooperation for other projects.
P9	SPIR	Strategic Platform for Innovation and Research
P10	Horizon 2020	Part of EU Framework Program for Research & Innovation.
P11	High Tech Fund	Supports strategic R&D initiatives in high-tech.
P12	InnoBooster	Knowledge-based innovation projects for SMEs, start-ups and companies established by researchers.
P13	Int'l Cooperation	Projects in cooperation with international partners.
P14	Community P'ship	Innovation-oriented problem-solving for manufacturing.
P16	Grand Solutions	High risk projects with high value creation.

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Program Descriptions

Education Subsidies		
P0	Universities Funding	Educational and Research grants for Universities.
P2 P15	Business PhD / Business Postdoc	Business-oriented research project conducted in collaboration between a private company and a university.

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R&D Subsidies in the Data

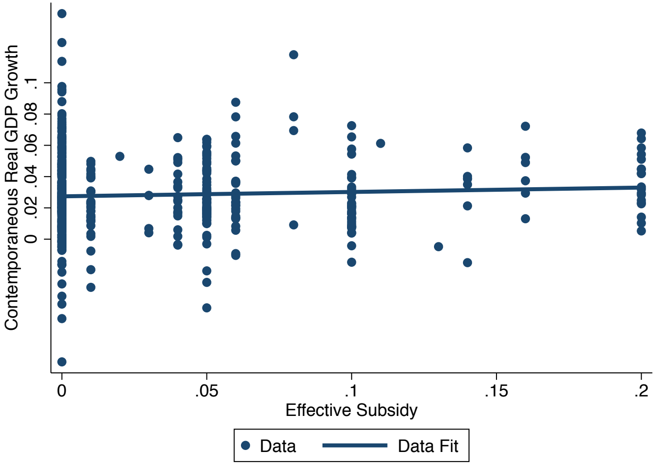

Figure: GDP Growth and R&D Subsidies 1997-2006, by U.S. State

Data Source: Wilson (2009), Bureau of Economic Analysis

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Revenue Equivalence of Policies

For cost of parents supporting children in school

- The cost of education is taken as the cost of room and board in college+PhD in Denmark (estimate coming from an international students association). This is because education is free in DK.

For the cost of adding a slot

- We use the PhD tuition fees charged to international students. This delivers the cost for the school.

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