Women Inventors and Economic Growth

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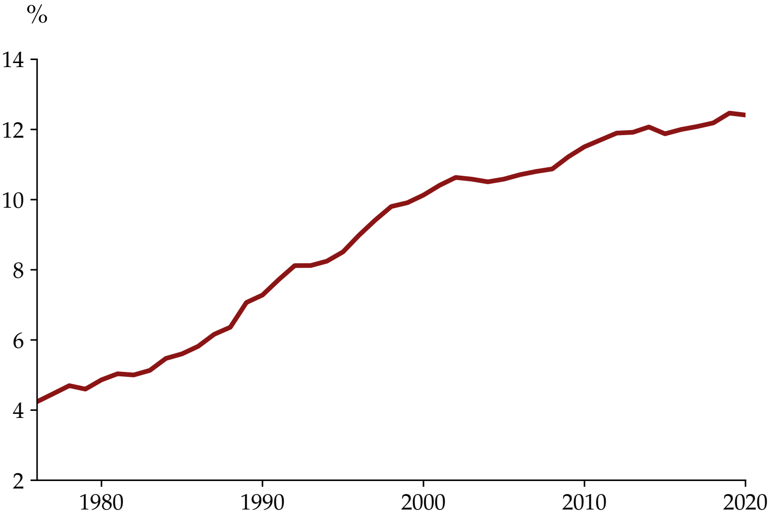
Female share of U.S. inventors



Why inventors?

Nonrival ideas imply increasing returns to scale:

$$y_t \propto R_t^{\gamma} \qquad y_t = \text{income/person},\ R_t = \text{inventors}$$

What happens if we double the number of inventors?

$$\frac{y_{t+\Delta}}{y_t} \approx 2^{\gamma} \quad \underset{\text{if } \gamma = 1/3}{\Longrightarrow} \quad 26\% \uparrow \text{in } y_t$$

Misallocation can have dynamic implications:

- Standing on the shoulders of giants or ideas getting harder to find?
- Role models today influencing the quantity of researchers tomorrow?

Allocation of talent

If no gender differences in *innate* inventive potential:

- Women under-representation reveals large talent misallocation

Three key questions:

- Sources of barriers to female innovation?
- Macroeconomic consequences?
- Optimal policy?

Related literature

Macroeconomic consequences of talent misallocation:

- Hsieh, Hurst, Jones and Klenow (2019), Hsieh and Moretti (2019), Bryan and Morten (2019), Lagakos and Waugh (2013), Buera, Kaboski and Shin (2011), Morazzoni and Sy (2022), Chiplunkar and Goldberg (2021) and Bento (2021)

Misallocation of *inventive* talent:

- Celik (2022), Akcigit, Pearce and Prato (2020), Einiö, Feng and Jaravel (2022), Arkolakis, Lee and Peters (2020), Prato (2021), Manera (2022) and Babalievsky (2022)

Gendered barriers to innovation:

- Bell, Chetty, Jaravel, Petkova and Van Reenen (2018), Carrell, Page and West (2010), Hunt, Garant, Herman and Munroe (2013), Ross, Glennon, Murciano-Goroff, Berkes, Weinberg and Lane (2022), Jensen, Kovács and Sorenson (2018), Kim and Moser (2021), Hannon (2021) and Pairolero, Toole, DeGrazia, Teodorescu and Pappas (2022)

Contributions

1. Focus on large and salient source of talent misallocation
   - Women represent perhaps largest source of underutilized inventive talent
   - Ample scope to expand aggregate research effort
2. Relative importance of misallocation sources
   - Unified framework with "apples to apples" comparisons
   - Help identify policy and research priorities
3. Macroeconomic counterfactuals with general equilibrium forces
   - Price adjustments and transition dynamics
   - Winners and losers? Does it matter for welfare?

Outline

1. Theory
2. Evidence
3. Counterfactuals

Theory

- Semi-endogenous growth with expanding varieties
- Two occupations
  1. Inventors
  2. Workers
- Heterogeneity: talent, gender and cohort
- Order of exposition:
  1. Economic environment
  2. Equilibrium allocation with distortions

Population and preferences

Overlapping generations in "perpetual youth":

$$\dot{N}_t = nN_t \quad \text{where} \quad n = b - d > 0$$

- Cohort κ enters *employed* population N_t at rate b and retires at rate d
- Labor force composed of as many women and men

Lifetime utility of person from cohort κ:

$$U_i = \int_{\kappa}^{\infty} e^{-(\rho+d)(t-\kappa)} \ln(c_{it}) \mathrm{d}t - \beta s_i^{1+\nu}$$

Technology

Final sector produces final good with intermediate input varieties:

$$Y_t = \left(\int_0^{A_t} y_{jt}^{\frac{\sigma-1}{\sigma}} \mathrm{d}j \right)^{\frac{\sigma}{\sigma-1}}$$

Intermediate firms produce a variety with physical capital and production labor:

$$y_{jt} = k_{jt}^{\alpha} \ell_{jt}^{1-\alpha}$$

Research sector combines "ideas" with research labor to invent new varieties:

$$\dot{A}_t = A_t^{\phi} R_t$$

Occupations, role models and talent

There are two occupations:

- Inventors
- Workers

Must receive *exposure* to innovation e_i through role models to choose to invent:

$$e_i \sim \text{Bernoulli}(I_{g\kappa}^{\epsilon_g} \times I_{\neg g\kappa}^{\epsilon_{\neg g}})$$

Each person born with a draw of *innate* inventive talent z_i:

$$F(z) = 1 - z^{-\theta}$$

Exposure and talent are uncorrelated: Bell et al. (2018)

Human capital and labor supply

Human capital accumulated through schooling:

$$h_i = s_i^{\eta}$$

Inelastic labor supply in each occupation:

- Worker: supply h_i units of production labor
- Inventor: supply $z_i \times h_i$ units of research labor

Resource constraints

Resource constraint for research labor:

$$R_t = \int_0^{N_t} \mathbb{1}_{\{i \in R\}} z_i h_i \mathrm{d}i$$

Resource constraint for production labor:

$$L_t = \int_0^{N_t} \mathbb{1}_{\{i \in L\}} h_i \mathrm{d}i \quad \text{where} \quad L_t \equiv \int_0^{A_t} \ell_{jt} \mathrm{d}j$$

Resource constraint for final good:

$$\dot{K}_t = Y_t - \delta K_t - C_t$$

Economic environment

$\dot{N}_t = nN_t$	Population
$U_i = \int_\kappa^\infty e^{-(\rho+d)(t-\kappa)} \ln(c_{it}) \mathrm{d}t - \beta s_i^{1+\nu}$	Lifetime utility
$Y_t = \left(\int_0^{A_t} y_{jt}^{\frac{\sigma-1}{\sigma}} \mathrm{d}j\right)^{\frac{\sigma}{\sigma-1}}$	Final good
$y_{jt} = k_{jt}^\alpha \ell_{jt}^{1-\alpha}$	Variety production
$\dot{A}_t = A_t^\phi R_t$	Variety creation
$e_i \sim \text{Bernoulli}(I_{g\kappa}^{\epsilon_g} \times I_{\neg g\kappa}^{\epsilon_{\neg g}})$	Exposure to innovation
$z_i \sim \text{Pareto}(\theta)$	Inventive talent
$h_i = s_i^\eta$	Human capital
$R_t = \int_0^{N_t} \mathbb{1}_{\{i \in R\}} z_i h_i \mathrm{d}i$	Research labor resources
$L_t = \int_0^{N_t} \mathbb{1}_{\{i \in L\}} h_i \mathrm{d}i$	Production labor resources
$\dot{K}_t = Y_t - \delta K_t - C_t$	Final good resources

Production and research problems

Perfect competition in the final sector:

$$\max_{y_{jt}} \{P_t Y_t - \int_0^{A_t} p_{jt} y_{jt} \mathrm{d}i\}$$

Free entry and monopolistic competition in the intermediate sector:

$$\max_{p_{jt}, k_{jt}, \ell_{jt}} \{p_{jt} y_{jt} - (r_t + \delta) k_{jt} - w_t^L \ell_{jt}\}$$

Monopolistic competition in the research sector:

$$\max_{q_t, R_t} \{q_t A_t^{\phi} R_t - w_t^R R_t\}$$

Gendered distortions/frictions

Labor market distortion: $(1 - \tau_{gt}^{L}) \times$ earnings

- Workplace gender discrimination or unequal access to patenting/financial resources

Human capital distortion: $(1 + \tau_{g\kappa}^{H}) \times$ schooling disutility

- Discrimination in development of skills or adverse learning environment in STEM

Exposure to innovation: $e_i \sim \text{Bernoulli}\big(\underbrace{(1 - \tau_{g\kappa}^{E})}_{\text{Distortion}} \times \underbrace{I_{g\kappa}^{\epsilon_g} I_{\neg g\kappa}^{\epsilon_{\neg g}}}_{\text{Friction}}\big)$

- Distortion from gender norms and stereotypes
- "Technological" externality from role models

Individual's problem

Choose occupation $\in \{R, L\}$ as well as consumption and schooling:

$$U_i = \max_{c_{it}, s_i} \int_{\kappa}^{\infty} e^{-(\rho+d)(t-\kappa)} \ln(c_{it}) \mathrm{d}t - (1 + \mathbb{1}_{\{i \in R\}} \tau_{g\kappa}^{H}) \beta s_i^{1+\nu}$$

Subject to flow budget constraint with initial condition $a_{i\kappa} = 0$:

$$\dot{a}_{it} = \begin{cases} r_t a_{it} + (1 - \tau_{gt}^{L}) w_t^R z_i h_i - c_{it} & \text{if } i \in R \\ r_t a_{it} + w_t^L h_i - c_{it} & \text{if } i \in L \end{cases}$$

Assumptions:

1. Perfect foresight conditional on distortions prevailing forever
2. No inheritances and consume remaining wealth in retirement
3. Distortions normalized to zero for workers and τ^L are budget-neutral for inventors

Consumption and schooling choices

Standard consumption-saving problem:

$$\frac{\dot{c}_{it}}{c_{it}} = r_t - \rho - d \quad \text{and} \quad c_{it} = \begin{cases} (\rho + d)[a_{it} + (1 - \tau^L_{gt})\omega^R_t z_i h_i] & \text{if } i \in R \\ (\rho + d)(a_{it} + \omega^L_t h_i) & \text{if } i \in L \end{cases}$$

Standard consumption-leisure problem:

$$s_i = \left[\frac{\eta}{\beta(1+\nu)(\rho+d)(1 + \mathbb{1}_{\{i \in R\}} \tau^H_{g\kappa})} \right]^{\frac{1}{1+\nu}}$$

τ^L reduces consumption and τ^H discourages human capital accumulation!

Lifetime utility by occupation

Optimal consumption and schooling choices imply:

$$U_i = \begin{cases} \ln\left[\frac{1-\tau^L_{g\kappa}}{(1+\tau^H_{g\kappa})^{\frac{\eta}{1+\nu}}} \times \omega^R_\kappa \times z_i\right] + \text{const.} & \text{if } i \text{ chooses } R \\ \ln(\omega^L_\kappa) + \text{const.} & \text{if } i \text{ chooses } L \end{cases}$$

Occupation choice

Choose to invent if utility maximizing and received exposure to innovation:

$$U_i^R > U_i^L \quad \text{and} \quad e_i = 1$$

Choose to invent if talent exceeds selection threshold:

$$\underline{z}_{g\kappa} \equiv \underbrace{\frac{(1+\tau_{g\kappa}^H)^{\frac{\eta}{1+\nu}}}{1-\tau_{g\kappa}^L}}_{\text{Distortions}} \times \underbrace{\frac{\omega_\kappa^L}{\omega_\kappa^R}}_{\text{PDV wages}}$$

- Larger distortions "raise the bar" differentially by gender
- Wage streams affect career choices regardless of gender
- Occupation choice made once and irreversible thereafter

Extensive margin (quantity)

Fraction from gender g and cohort κ who go on to invent:

$$P(z_i \geq \underline{z}_{g\kappa} \cap e_i = 1) = \underbrace{\frac{(1-\tau^E_{g\kappa})(1-\tau^L_{g\kappa})^{\theta}}{(1+\tau^H_{g\kappa})^{\frac{\theta\eta}{1+\nu}}}}_{\text{Distortions}} \times \underbrace{I^{\epsilon_g}_{g\kappa} I^{\epsilon_{\neg g}}_{\neg g\kappa}}_{\text{Role models}} \times \underbrace{\left(\frac{\omega^R_\kappa}{\omega^L_\kappa}\right)^{\theta}}_{\text{PDV wages}}$$

- Distortions shrink the pool of potential inventors
- Second term captures externality from *relevant* role models
- PDV wages reflect GE trade-offs between production and research

Intensive margin (quality)

Average supply of research labor from gender g and cohort κ:

$$\mathbb{E}[z_i \times h_i | z_i \geq \underline{z}_{g\kappa} \cap e_i = 1] \propto \frac{\omega_\kappa^L}{(1-\tau_{g\kappa}^L)\omega_\kappa^R}$$

- Labor market distortion: $\tau^L > 0$
  - *Selection* effect: drive out marginally talented individuals
- Human capital distortion: $\tau^H > 0$
  - *Selection* effect: drive out marginally talented individuals
  - *Direct* effect: discourage human capital accumulation
- Exposure to innovation is uncorrelated with talent: $e_i \perp z_i$

Equilibrium

Time path for allocations and prices such that:

- Individuals choose consumption, schooling and occupation optimally
- Final sector chooses variety quantities optimally
- Intermediate firms choose variety price and production factors optimally
- Research sector chooses patent price and research labor optimally
- Resource constraints are satisfied and markets clear
- Distortions are budget-neutral

Assumptions and moments to infer distortions?

Identifying assumptions:

- No gender differences in intrinsic inventive potential
- Exposure is uncorrelated with talent: Bell et al. (2018)
- τ^L is budget-neutral and only women face τ^H and τ^E

Model's *cohort*-level implications:

- Average schooling $\propto 1/(1+\tau^H_{g\kappa})^{\frac{1}{1+\nu}}$
- Average research productivity (IM) $\propto 1/(1-\tau^L_{g\kappa})$
- Fraction of inventors (EM) $\propto (1-\tau^E_{g\kappa})(1-\tau^L_{g\kappa})^{\theta} I^{\epsilon_g}_{g\kappa} I^{\epsilon_{\neg g}}_{\neg g\kappa} / (1+\tau^H_{g\kappa})^{\frac{\theta\eta}{1+\nu}}$

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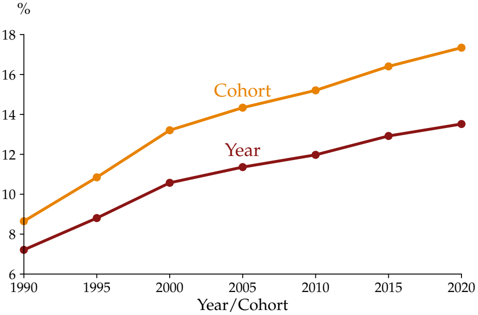
Patent data

USPTO data from PatentsView since 1976:

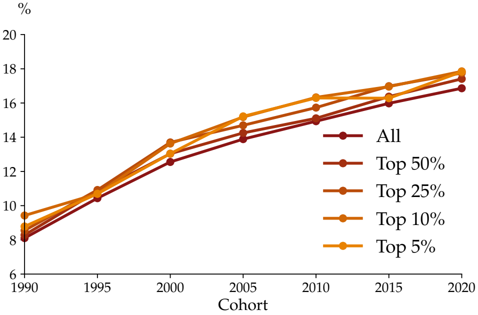
- 3.7M patents granted to 1.7M *disambiguated* inventors residing in the U.S.
- Infer gender from first name
- Infer cohort from first appearance (starting in 1986)
- *Value*-weighted patents as inventive output (Kogan et al., 2017):
    - Stock market response to patent grant news
    - Gender composition almost identical to full sample
    - Robust to gender biases (Jensen et al., 2018)
    - Adjust for co-inventors, technology classes and experience

Female share of inventors by cohort and productivity

(a) Year vs. Cohort

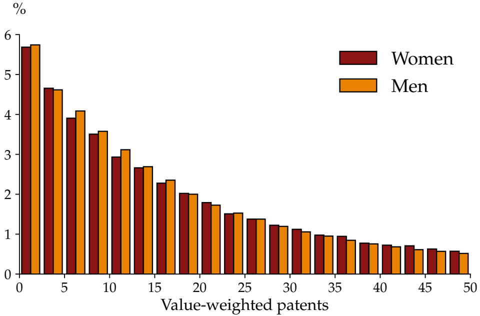


(b) Productivity Quantiles

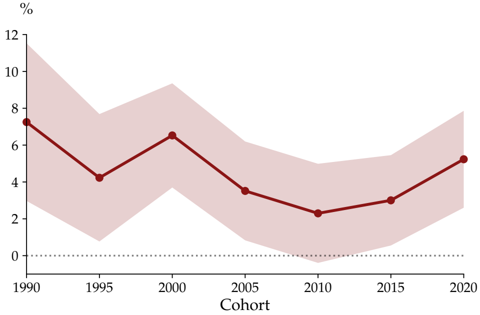


Distribution of inventive productivity by gender

(a) Productivity Distribution



(b) Productivity Gender Gap



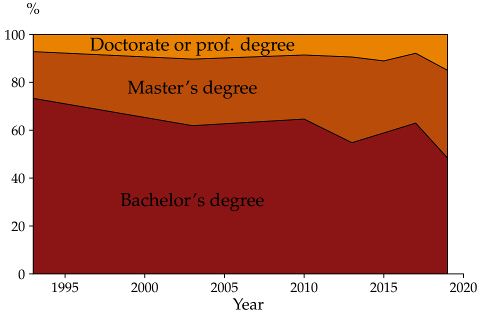
Educational attainment data

National Survey of College Graduates between 1993 and 2019:

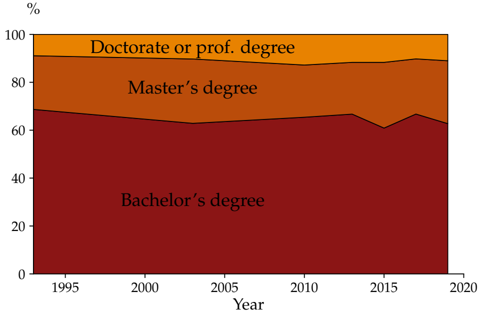
- Restrict on employed R&D workers between 30-34 years old
- Delivers sample of about 2500 individuals per wave
- 1995 and 2003 waves asked whether respondents were granted patents
  - 71% and 47% of patentees reported R&D as main activity
  - R&D workers were 4.6x and 5.3x more likely to patent

Educational attainment of R&D workers by gender

(a) Women



(b) Men



Note: Both in 1995 and 2003, the educational attainment advantage of women was slightly more pronounced among patentees than R&D workers.

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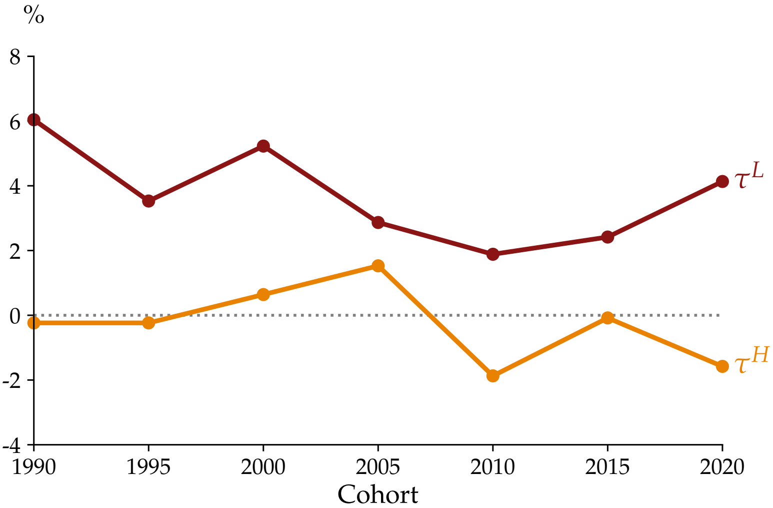
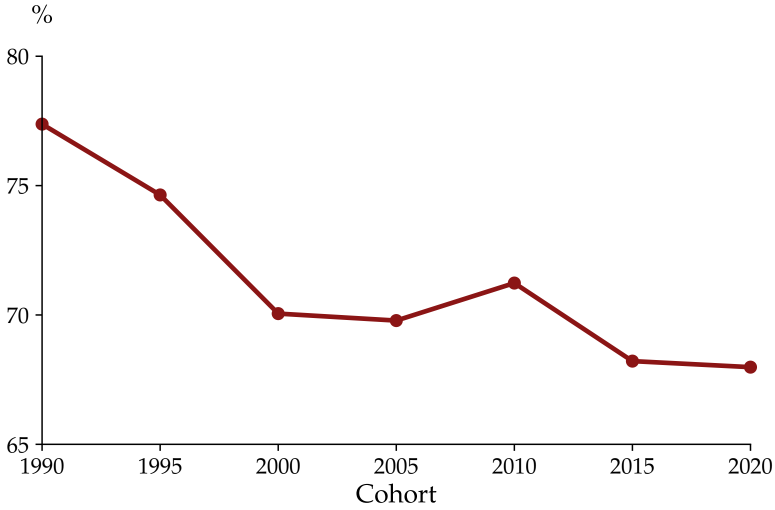
Calibration

Parameter	Symbol	Value	Source
Discount rate	ρ	0.02	Standard calibration
Cobb-Douglas	α	1/3	Standard calibration
Depreciation rate	δ	0.05	Standard calibration
Retirement rate	d	1/30	Average work-life of 30 years
Entry rate	b	$d + 0.05$	0.5% U.S. population growth
Schooling disutility	β	36.8	15.9 expected years of schooling
Schooling disutility	ν	1	Frisch elasticity of LS $= 1$
Return to schooling	η	1.59	10% Mincerian return
Pareto shape	θ	2	Assumption
Knowledge spillover	ϕ	-2.1	Bloom et al. (2020)
Variety substitution	σ	2.45	Degree of IRS $= 1/3$
Own gender role models	ϵ_g	0.24	Bell et al. (2018)
Other gender role models	$\epsilon_{\neg g}$	0	Bell et al. (2018)

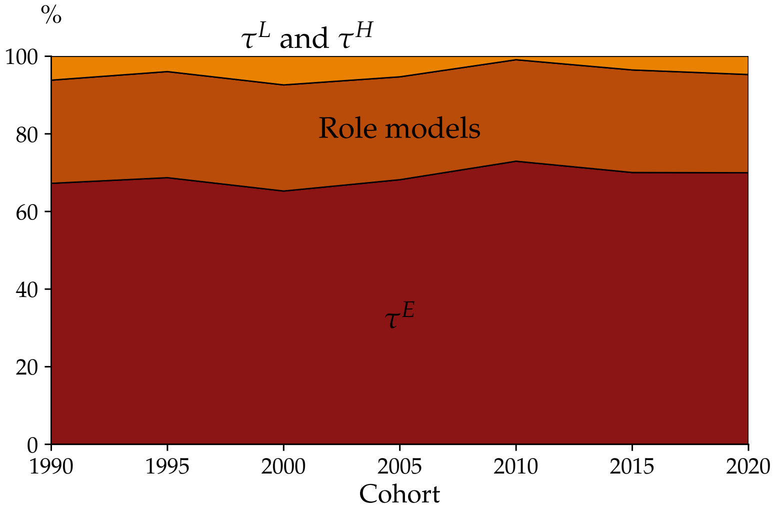
Labor market and human capital distortions



Exposure distortion

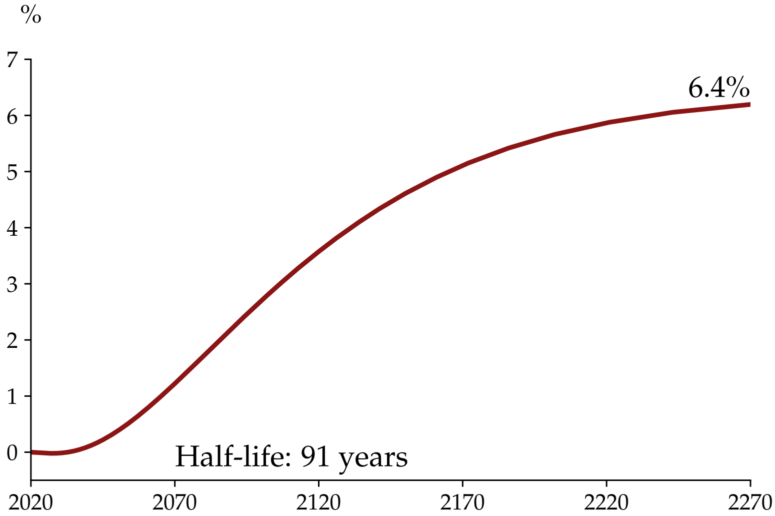


Decomposition of underrepresentation



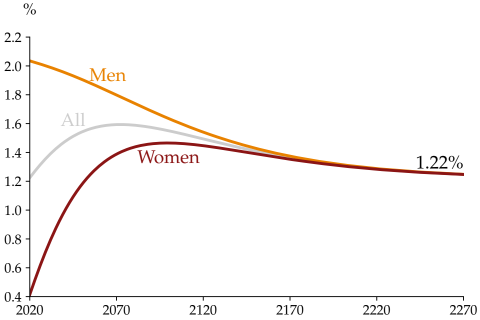
What if we got rid of all distortions in 2020?

Income per person

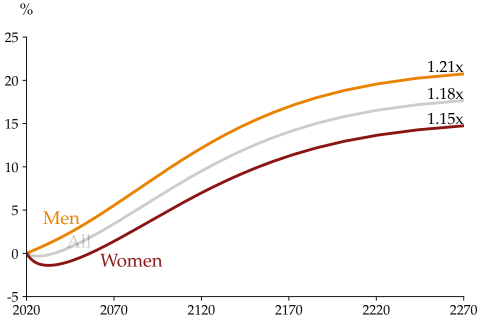


Extensive and intensive margins

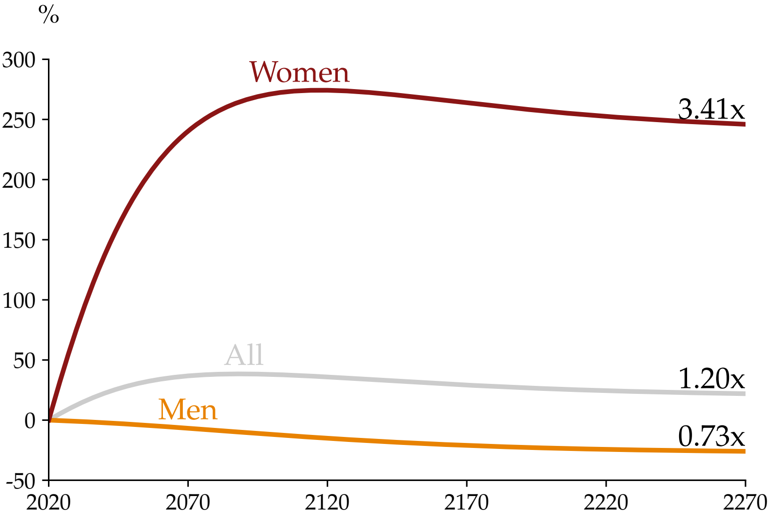
(a) Extensive



(b) Intensive



Research labor supply by gender



Welfare

Utilitarian social welfare function:

$$W_t(\lambda) = \underbrace{\int_{-\infty}^{t} be^{-b(t-\kappa)}\mathbb{E}[U_{it}(\lambda)]\mathrm{d}\kappa}_{\text{Surviving cohorts}} + \underbrace{\int_{t}^{\infty} be^{-(\rho-n)(\kappa-t)}\mathbb{E}[U_{i\kappa}(\lambda)]\mathrm{d}\kappa}_{\text{Future cohorts}}$$

By how much should we permanently raise consumption to be indifferent?

$$W_t^{2020}(\lambda) = W_t^*(1) \quad \Longrightarrow \quad \lambda = 1.021$$

2.1% permanent increase in consumption:

- 85% from higher *average* consumption
- 15% from lower consumption *inequality*

Distributional implications

How are the gains shared in the economy?

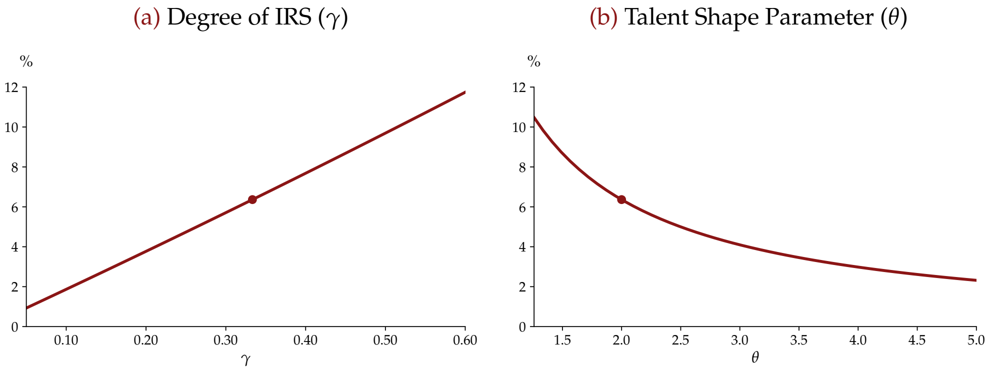
- 2.8% $\uparrow$ in consumption for future cohorts
- 0.3% $\uparrow$ in consumption for surviving cohorts

Among surviving cohorts, who are the winners and losers?

- 0.3% $\uparrow$ in consumption for surviving cohorts of workers
- 2.2% $\uparrow$ in consumption for surviving cohorts of women inventors
- 1.3% $\downarrow$ in consumption for surviving cohorts of men inventors

Robustness to parameter values?

Steady state income per person: the role of γ and θ



Other important parameters

Parameter	Value	$\uparrow y$ (%)	Half-Life (years)	$\uparrow W$ (%)
Baseline		6.36	90.6	2.12
d	1/20	6.36	78.2	2.35
	1/40	6.36	101.0	1.95
ϕ	0.8	6.36	107.2	1.72
	-6.2	6.36	89.5	2.15
ϵ_g	0.33	6.01	88.6	2.05
	0.14	7.87	92.7	2.55

Optimal policy and affirmative action

Affirmative action and role model externality

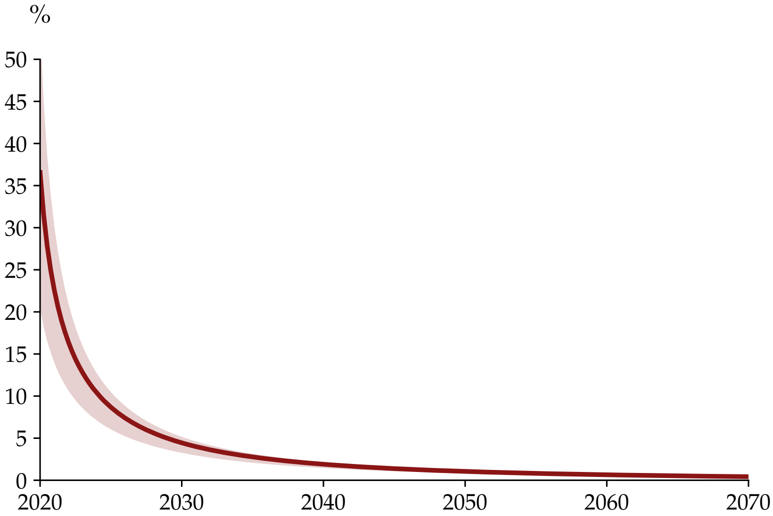
Slow transition through importance of relevant role models raises two questions:

1. Differentially subsidize women inventors to accelerate transition?
2. How costly is the role model externality?

Solve dynamic optimal allocation:

1. When planner has access to gender-*specific* vs. gender-*neutral* R&D subsidies
2. When planner faces role model externality or not

Optimal gender-specific R&D subsidies



Costs of gender-neutral R&D subsidies and role model externality

If planner only had access to gender-neutral R&D subsidies:

- Achieve 0.003% lower consumption-equivalent welfare
- 95% confidence interval of ϵ_g: [-0.001%, -0.007%]

If planner could magically get rid of role model externality:

- Achieve 3.31% higher consumption-equivalent welfare
- 95% confidence interval of ϵ_g: [1.93%, 4.67%]

Theoretical extensions

Theoretical extensions

1. Talent heterogeneity across technological fields
   - Large economic gains from labor reallocation between production/research
   - Insignificant economic gains from reallocation of inventors across fields
2. On-the-job human capital distortion
   - Operates through selection with perfect foresight
3. Inventive talent uncertainty and gendered risk aversion
   - Insignificant dampening effect from "fuzzy" selection into inventorship
   - Operates through selection
4. Gendered occupational preferences
   - Operates through selection

Conclusion

1. Why are there so few women inventors?
    - Women and men inventors are similarly productive and educated
    - Can't be explained by distortions operating through *selection* or *education* alone
    - Potentially important role for "exposure to innovation"
2. 6.4% gain in steady state income per person
    - From higher quality rather than quantity of inventors
3. 2.1% permanent increase in consumption per person
    - Mostly coming from higher average consumption
    - Mostly captured by future generations
    - Current men inventors would prefer status quo
4. Costly role model externality calls for affirmative action