Haste Makes Waste? Quantity-Based Subsidies under Heterogeneous Innovations

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Motivation: Patent Surge in China

- No. of China's invention patent applications incr. from about 10,000 in 1990 (1.08% of world total) to 1.5 million in 2020 (45.69%)

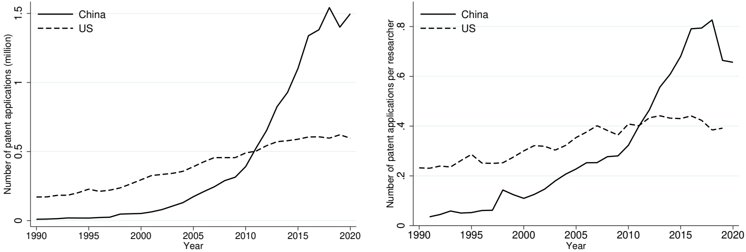


Figure: Total Patent Applications (Left) and Patents per Researcher (Right), in China and the US

Grant A-G Rate Researchers

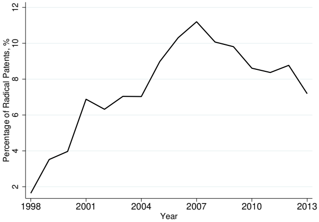
Institution Backgrd: Quantity-based Targets & Subsidies

- Outlines of Medium and Long-term National Plan for Science and Technology Development (2006-2020):
  - By 2020, the total no. of granted invention patents by Chinese nationals ranks top 5 in the world.
- Quantity targets set by the central and selected local gov't

Policy Year	Target Period	Quantity Target
Central Gov't		
2010	2011-20	Patents to reach 2 mil. & rank Top 2 in the world in 2015 Patents per 1 mil. pop. to increase by 100% (300%) by 2015 (2020)
Beijing		
2010	2011-15	Patent applications (grants) per 10,000 pop. to reach 20 (8) by 2015
2015	2016-20	Patents per 10,000 pop. to reach 80 by 2020
Guangdong		
2007	2007-20	Patent applications per 1 mil. pop. to to increase $\geq 15\%$ annually
Heilongjiang		
2011	2011-20	Patents per 10,000 pop. to surpass 2.1 by 2015
Guizhou		
2017	2016-20	Patents per 10,000 pop. to reach 2.5 by 2020

Motivation: Decline in Patent Quality

- Quantity-based subsidies might worsen the quantity-quality trade-off for innovating firms.
- Firm-level data: ASIE + Patent (eventually granted)
- Radical Patent: cited by US patents & gap btw app. years ≤ 5.



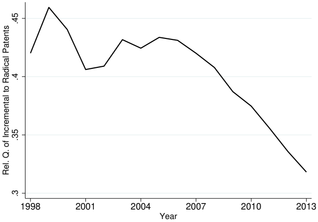


Figure: Radical Patent Share (Left) and Relative Quality of Incremental Patents (Right)

Data source | Variables | Other Q. def. | Dom. vs. Forg. | Ent. vs. Incm.

Research Questions

- How much of the patent quantity surge and quality plunge are induced by quantity-based subsidy programs?
- What is the aggregate impact of quantity-based subsidy programs on growth and welfare?
- What is a "good" innovation-promoting policy?

What We Do

- We empirically document $\uparrow$ in patent quantity and $\downarrow$ in quality.
- Develop a Schumpeterian growth model featuring firms' endogenous choices between radical and incremental innovations.
  - Incremental innovations have a smaller and diminishing impact on productivity and are less skill-intensive evidence
- Theoretically show and quantitatively evaluate the
  - $(+)$ *quantity* effect: faster creative destruction;
  - (–) *quality* effects: quality-composition and quality-crowding;

  of quantity-based innov. subsidies.
- Propose and evaluate an alternative, quality-biased, innovation policy: subsidizing human capital accumulation.

What We Find

- Introduction of quantity-based subsidies accounts for
  - 29% of the patent surge;
  - 56% of the decline in radical patent share;
  - 75% of decline in the relative quality of incremental patents;

  between the pre- and post-2008 periods.
- The (–) quality effects, especially *quality-crowding*, are dominant.
  - In net, subsidies reduce TFP gr. rate by 0.19 p.p. & welfare by 3.31%.
- An education subsidy, together with a skilled labor subsidy, effectively recovers the planner's allocation.

Related Literature

- Schumpeterian model with heterogeneous firms
  - Klette and Kortum (2004), Akcigit and Kerr (2018), and Acemoglu et al. (2020).
- China's R&D policies
  - Hu and Jefferson (2009), Li (2012), Ang et al. (2014), Fang et al. (2017), Chen et al. (2019),
  - Chen et al. (2021), Konig et al. (2022), Wei et al. (2023).
- The role of human capital in innovation and economic growth
  - Nelson and Phelps (1966), Vandenbussche et al. (2006), Akcigit et al. (2020).

Key Features of the Model

- Building on Akcigit and Kerr (2018)
  - random realization btw. radical vs. incremental innovations, with the effect of the latter gradually diminishing
- Endogenize firms' innovation choices which triggers a quantity-quality trade-off
- Quantity-based subsidy: subsidies that target the number of innovations
- R&D inputs structure: radical innovations are more skill-intensive
- Endogenize human capital accumulation

Household and Final Good

- A representative household with utility

$$U = \int_0^\infty \exp(-\rho t) \, \frac{C(t)^{1-\nu} - 1}{1-\nu} \, dt, \tag{1}$$

- A final good produced competitively by aggr. interm. varieties

$$Y(t) = \frac{1}{1-\epsilon} N(t)^\epsilon \int_0^1 q_\omega(t)^\epsilon y_\omega(t)^{1-\epsilon} d\omega, \tag{2}$$

where $y_\omega(t)$ is the quantity, and $q_\omega(t)$ the quality, of good ω

- A simple demand function

$$p_\omega(t) = q_\omega(t)^\epsilon y_\omega(t)^{-\epsilon} \tag{3}$$

Intermediate Production

- Production of intermediate goods uses unskilled labor and technology

$$y_\omega(t) = \bar{q}(t)\ell_\omega(t), \tag{4}$$

where $\bar{q}(t) \equiv \int_0^1 q_\omega(t)d\omega$ is the average quality/productivity.

- Each moment, the leading firm in product line ω solves 2-Stage price-bidding

$$\max_{y_\omega} \quad q_\omega^\epsilon y_\omega^{1-\epsilon} - \frac{w^\ell}{\bar{q}} y_\omega. \tag{5}$$

- The firm will charge a constant markup $1/(1-\epsilon)$, and the profit flow from owning product line ω is

$$\pi_\omega = \epsilon \left[(1-\epsilon)\frac{\bar{q}}{w^\ell}\right]^{\frac{1-\epsilon}{\epsilon}} q_\omega \equiv \pi q_\omega. \tag{6}$$

R&D Heterogeneity

- Undirected[1] and Heterogenous innov: radical vs. incremental
- For each product line, a radical innovation starts a new innov. cycle
- Innovations improve quality by

$$q_\omega(t_+) = \begin{cases} q_\omega(t) + \lambda \bar{q}(t) & \text{for radical innov.} \\ q_\omega(t) + \eta \alpha^{\tau_\omega - 1} \bar{q}(t) & \text{for incremental innov..} \end{cases}$$

  where τ_ω is the no. of incre. innov. from the most recent radical one
- Assume $\lambda > \eta$
- $\alpha \in (0, 1)$ governs the speed of quality-decay for incre. innov.

[1] Data on external vs internal patents: Data

R&D Heterogeneity: Input Structure

- Each firm is endowed 1 unit of research time
- The Poisson arrival rate of radical innovation is

$$X_d = z_d \underbrace{n^{1-\phi}}_{\text{firm size}} \Bigg(\overbrace{e}^{\text{research time}} \underbrace{h^{\gamma_d}}_{\text{skilled labor}} \underbrace{\overset{\text{unskilled labor}}{\ell^{1-\gamma_d}}} \Bigg)^{\phi}. \qquad (7)$$

Divide by n gives $x_d \equiv X_d/n = z_d[e(h/n)^{\gamma_d}(\ell/n)^{1-\gamma_d}]^{\phi}$

- The Poisson arrival rate of incremental innovation is

$$X_m = z_m\ n^{1-\phi}\Big((1-e)h^{\gamma_m}\ell^{1-\gamma_m}\Big)^{\phi}. \qquad (8)$$

- Assume $\gamma_m < \gamma_d$

Quantity-Based Subsidies

- Map innovations to patents.
  - x_d (x_m) : the number of newly created radical (incremental) patents
  - Firm size n corresponds to the stock of active patents.
- We model quantity-based subsidies to innovating firms as $n \times b_n \bar{q}$, that is, subsidies rewarding the number of active patents a firm holds, disregarding the underlying quality.
- An equivalent (but more cumbersome) way is to use $nx \times b_x \bar{q}$, that is, subsidies rewarding the number of newly created patents.

Equilibrium

- High- and Low- type firms Value Function
- Entry Entry and Exit Entrants' Value Function
- Human capital accumulation Education and Skill Supply
- We focus on equilibrium featuring a balanced growth path, where the average productivity of the economy, $\bar{q}(t)$, grows at a constant rate g.
  Aggregation under Stationarity Market Clearing

Equilibrium: the Quantity-Quality Trade-off

- The ratio between radical and incremental innovation intensities satisfies

$$\frac{x_d}{x_m} \propto \underbrace{\frac{A(1+\lambda)+B}{A(1+\bar{\eta})+B}}_{\text{innovation return}} \times \underbrace{\left(\frac{w^h}{w^\ell}\right)^{-(\gamma_d-\gamma_m)}}_{\text{input structure}}.$$

- Subsidies may alter firm choices through B, the indirect return of innovation, which is identical for both kinds of innovations.
- Equilibrium impact through the skill premium

Equilibrium: Growth Decomposition

- Aggregate innovation intensity (total patents)

$$\delta = \delta_d + \delta_m$$

$\delta_d(\delta_m)$ aggregate intensity of radical (incre.) innov. [sum of x]

- The aggregate growth rate is

$$g = \delta_d \lambda + \delta_m \bar{\eta} \quad = \delta[\frac{\delta_d}{\delta}\lambda + (1 - \frac{\delta_d}{\delta})\bar{\eta}]$$

$\bar{\eta}$ denotes the expected step-size of incremental innovations.

- The aggregate welfare is

$$U = \frac{1}{1-\nu}\left[\frac{{C_0}^{1-\nu}}{\rho - (1-\nu)g} - \frac{1}{\rho}\right].$$

Growth Decomposition

- The growth rate differential can be decomposed into

$$\Delta g = \underbrace{\Delta\delta \times \left[\frac{\delta_d}{\delta}\lambda + \left(1 - \frac{\delta_d}{\delta}\right)\bar{\eta}\right]}_{\text{(i) quantity-creative destruction}} + \underbrace{\delta \times \left[\Delta\frac{\delta_d}{\delta} \times (\lambda - \bar{\eta})\right]}_{\text{(ii) quality-composition}} + \underbrace{\delta \times \left[\left(1 - \frac{\delta_d}{\delta}\right) \times \Delta\bar{\eta}\right]}_{\text{(iii) quality-crowding}}.$$

- The last "quality-crowding" channel exists because $\bar{\eta}$ is endogenously decreasing in δ_m/δ.

Calibration I

Table: Externally Calibrated Parameters

Para	Value	Meaning	Source
Aggregate Economy			
ρ	0.02	time discount rate	literature
ν	3	intertemporal elasticity of substitution	literature
ϵ	0.22	E.o.S. in final good production	profitability
L	1	total population	normalization
d	0.03	death rate of the population	years of working
R&D Sector			
ϕ	0.49	innovation elasticity w.r.t. R&D	Patent-RDexp elast.
η	$\alpha\lambda$	initial step-size of incremental inno.	assumption

Calibration II

Table: Internally Calibrated Parameters Identification

Para	Value	Meaning	Target	Data(%)	Model(%)
R&D Sector					
$z_{\mathrm{H}d}$	1.029	H-type's radical productivity	share of radical innov.	8.01	8.01
$z_{\mathrm{H}m}$	1.038	H-type's incremental productivity	H-type's R&D intensity	17.78	17.49
$z_{\mathrm{L}m}$	1.016	H-type's incremental productivity	L-type's R&D intensity	15.02	15.02
γ_d	0.796	skill intensity in radical innov.	H-type's skill intensity	34.12	34.08
γ_m	0.453	skill intensity in incremental innov.	L-type's skill intensity	25.42	25.41
b_n	0.029	quantity-based subsidy	subsidy-to-R&D ratio	20.42	20.44
Other Sectors					
λ	0.158	step-size of radical innovations	TFP growth rate	1.97	1.97
α	0.862	quality decay	average citation ratio	33.28	33.27
ξ	0.035	education productivity	wage premium	243	243
x_{E}	0.068	entry rate	entrants' patent share	21.00	20.98
χ	0.138	cost of becoming H-type	fraction of H-type firms	26.98	26.99

Model Fit

- The size of subsidy, b_n, sums up to about 3% of the value-added and 15% of the profit.
- Our estimate of α is lower than what is reported in Akcigit and Kerr (2018) about US patents, implying a faster quality decay among incremental patents in China.
- The magnitude of quantity-quality trade-off generated by the model is empirically supported by a DID analysis of the Innocom program.

detail more model fit

Effects of Quantity-Based Subsidies I

- In the data, compared to the pre-2008 trend, we estimate detail
  - a relative $\uparrow$ of 34.57% in patent quantity;
  - a relative $\downarrow$ of 40.89% in the share of radical patents;
  - a relative $\downarrow$ of 20.27% in the avg citation ratio btw. incre. and radical patents.
- Patent quantity & quality in baseline (B.M.) and a counterfactual economy (C.F.) without innov. subsidies

Variable	**Meaning**	**B.M.**	**C.F.**	$\Delta_{\textbf{Model}}$	$\Delta_{\textbf{Data}}$	$\frac{\Delta_{\textbf{Model}}}{\Delta_{\textbf{Data}}}$
δ	creative destruction	25.53%	23.18%	10.14%	34.57%	29.33%
δ_d/δ	radical share	8.01%	10.39%	-22.91%	-40.89%	56.03%
$\bar{\eta}/\lambda$	step-size ratio	33.27%	39.27%	-15.28%	-20.27%	75.38%

Effects of Quantity-Based Subsidies II

- The introduction of b_n causes a 0.19 percentage points drop in the TFP growth rate, and a welfare loss of 3.31%.
- Decompose the effects of subsidies on growth into three channels

Δ_{Growth}	(i) quantity	(ii) quality-composition	(iii) quality-crowding
-0.0019	0.0017	-0.0007	-0.0026
	-89.47%	36.84%	136.84%

- Negative quality effects, especially the quality-crowding effect, dominate. Robustness

Quality-Biased Policy I: Planner's Allocation

- Quantity-based subsidies hurt growth and welfare due to a micro-level quantity-quality tradeoff. Is there a better and implementable policy?
- We first evaluate the "room for improvement" by looking at a constrained planner's allocation.
  - allow the planner to decide the skill supply, but let individual firms produce and price as in the market economy.
  - The optimal skill supply is 14.36% of pop., more than tripled compared to the eqm. level of 4.04%.
  - The aggr. gr. rate $\uparrow$ from 1.97% to 5.51%, and welfare $\uparrow$ by 16.85%.

Quality-Biased Policy II: HC Subsidies

- To implement the planner's allocation, we propose a quality-biased policy: subsidizing human capital accumulation.
  - Edu. subsidy, b_e, and skilled labor wage subsidy, b_h.
  - HC subsidy incr. both innov. quantity and quality
  - Policymakers can implement any desired skill allocation with a proper comb. of b_e and b_h. Prop. 3

- Subsidy comparison

Variable	Meaning	B.M.	$\mathbf{b_n}$+5%	$\mathbf{b_e}$+5%	$\mathbf{b_h}$+5%
$R(x)/Vadd$	avg R&D intensity	15.84%	16.02%	15.73%	15.75%
δ_d/δ	radical share	8.01%	7.91%	8.63%	8.51%
w^h/w^ℓ	skill premium	2.43	2.44	2.38	2.39
g	TFP growth rate	1.97%	1.96%	2.07%	2.05%
U	social welfare	100%	99.80%	101.14%	100.93%

Extension: Decreasing Return to Scale

- Innovation costs scale up linearly with firm size in baseline.
- Extend to introduce decreasing return to scale in innovation
  - $z_d(n) = z_d n^{-\psi_d}$, $z_m(n) = z_m n^{-\psi_m}$.
  - Calibrate and find a rather mild D.R.S.: $\psi_d = 0.061$ and $\psi_m = 0.055$
- Impact of subsidies on innov. quantity, quality, and growth

Variable	Meaning	Model	C.F.	Δ_{Model}	Δ_{Data}	$\frac{\Delta_{\text{Model}}}{\Delta_{\text{Data}}}$
δ	creative destruction	25.43%	23.16%	9.80%	34.57%	28.35%
δ_d/δ	radical share	7.37%	9.52%	-22.58%	-40.89%	55.22%
$\bar{\eta}/\lambda$	step-size ratio	31.45%	37.20%	-15.46%	-20.27%	76.27%

Δ_{Growth}	(i) quantity	(ii) quality-composition	(iii) quality-crowding
-0.0018	0.0015	-0.0006	-0.0024
	-83.33%	33.33%	133.33%

Conclusion

- Motivated by the Chinese patent quantity surge and quality decline since the middle 2000s, we construct a Schumpeterian growth model featuring heterogeneous innov.
- decompose the impact into (+) quantity and (-) quality channels and show that quantity-based subsidies reduce welfare by 3.31%, as the (-) quality-crowding channel dominates.
- propose quality-biased skill subsidies which effectively recover the planner's allocation.
  - short vs long run;
  - attract talents trained overseas
- the model misses the following kind of learning by doing: experience accu. in doing incre. innov. promotes ability in doing radical ones

Motivation: Researchers per Million Inhabitant back

Table: Researchers per Million Inhabitants, 2013

	China	US	Europe	Japan	France	Germany
(1)	1071.1	3984.4	2941.9	5194.8	4124.6	4355.4
(2)	0.2%	1.5%	1.8%	1.2%	1.7%	2.7%

Note: Row (1) shows full-time equivalent researchers per million Inhabitants in 2013, and row (2) the share of Ph.D. degree holders in labor force. Data source: USESCO.ORG.

Number of Granted Patents back

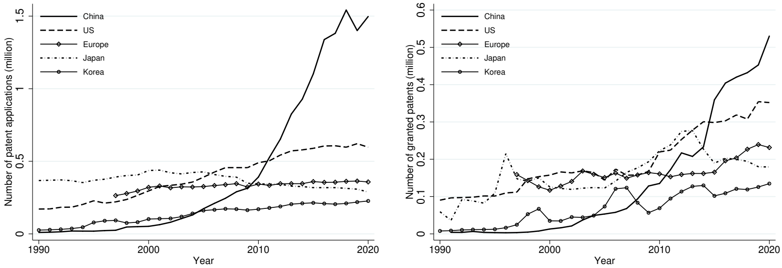


Figure: Number of Applied (Left) and Granted (Right) Patents in China and Advanced Economies

Number of Granted Patents back

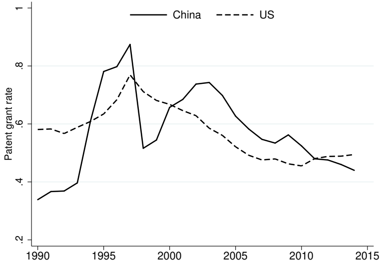


Figure: Patent Grant Rate (Left) and Number of Patents-Eventually-Granted Per Researcher (Right)

Data Source back

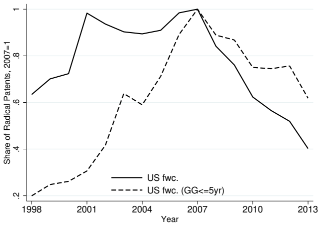
- Annual Survey of Industrial Enterprises (ASIE): covers all Chinese industrial firms with sales above 5 million RMB for the periods 1998-2013.
- Innography Patent Database: provides information on patent ID, patent class, forward and backward citations, legal status and etc, from 1985 onwards.
- Firm Innovation Activity Database: contains industrial firms' R&D investments and skill composition of R&D personnel for the periods 2008-2014.
- Construct an ASIE sample from 1998-2013, restricting to manufacturing firms, then merge patent data to the sample.
- For calibration of the model, further merge the Firm Innovation Activity Database to the ASIE sample.

Variable Construction back

- Radical patent: if it has ever been cited by any U.S. patents within a 5-year gap between the application dates.
- High-type firm: if it creates at least one radical patent over the sample period.
- Skilled labor: those with a medium or senior professional title (*zhonggaoji zhicheng*).
- Skill intensity: the ratio between skilled labor and total R&D personnel (*keji huodong renyuan*).

Share of Radical Patents under Alternative Definitions

back



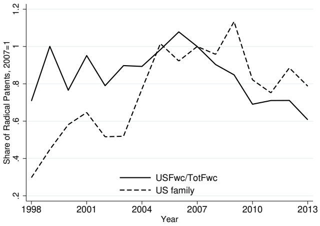


Figure: Share of Radical Patents under Alternative Definitions

Quality Decline: Domestic vs. Foreign Firms back

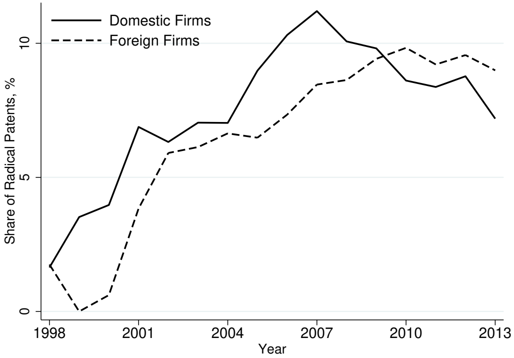


Figure: Quality Decline: Domestic vs. Foreign Firms

Quality Decline: Entrants vs. Incumbent Firms back

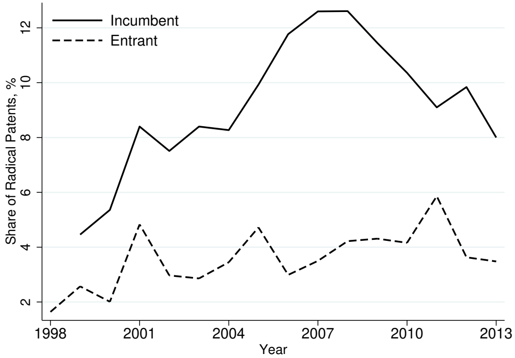


Figure: Quality Decline: Entrants vs. Incumbent Firms

Two-Stage Bidding Game back

- In stage 1, firms decide whether to pay an arbitrarily small but positive market-entry cost.
- In stage 2, all firms that have paid the cost in stage 1 compete in Bertrand competition. As the firm who owns the leading technology and produces the highest quality of the good, would announce a limit price which makes all others earn a non-positive profit in stage 2, they optimally decide not to enter and compete in stage 1.
- Therefore in equilibrium, the firm owning the leading technology will be able to charge a monopolistic price, until being replaced in the future by a successful innovator.

Internal vs. External Patents back

Table: No. and Share of External Patents for Domestic Industrial Firms

Period	No. of external patents	No. of patents	Share of external patents
1998-2013	279,800	296,254	94.45%
2011-2013	159,490	167,823	95.03%

Note: External patents are defined as those with a self-citation rate no more than 50%.

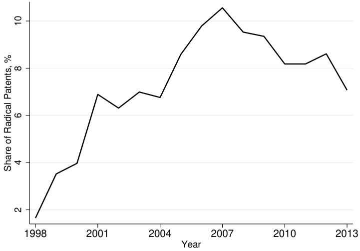


Figure: Radical Patent Share among External Patents

Skill Intensity back

Table: Skill Intensity for Firms of Different Types

	2011	2012	2013	Average
Skill intensity of high-type firms	34.91%	34.53%	33.02%	34.12%
Skill intensity of low-type firms	26.83%	25.19%	24.69%	25.42%

Note: Skill intensity is defined as the fraction of R&D personnel with a medium or senior professional title. To clear the effects of age and size, we first run a firm-level regression of skill intensity against age and log(employment) and then use the residual to obtain the numbers above.

Entry and Exit back

- A firm that loses all its product lines exits the economy.
- A total mass of 1 of potential entrants pursuing incremental innovations at rate x_{E}.
- Upon a successful innovation, the potential entrant enters the economy with one product line in its portfolio.
- Successful entrants are of the low-type by default. After paying an overhead investment $K(p)$, they receive a probability $p \in [0,1]$ turning into the high-type.

Education and Skill Supply I back

- At each point of time, a flow dL of old workers die and young workers rejoin. The young need to attain education to become skilled.
- Upon entry, each young individual randomly draws a type θ from a distribution of talent. It requires $1/\theta$ units of education service, for her to become skilled.
- Education service is produced by existing skilled workers, employed in the education sector at the competitive wage rate w^h, and with technology $s = \xi \ h^{\text{teacher}}$.

Education and Skill Supply II back

- With education subsidy b_e and skilled labor subsidy b_h, a young worker chooses to invest in education and become skilled if and only if

$$\frac{e^{-(r-g+d)}}{r-g+d}\frac{w^h}{1-b_h}-(1-b_e)\frac{1-e^{-(r-g+d)}}{r-g+d}\frac{1}{\theta\xi}\frac{w^h}{1-b_h}\geq\frac{w^\ell}{r-g+d},$$

- That is, obtaining education if and only if her type is above the threshold

$$\theta^*\equiv\max\left\{\frac{1-b_e}{\xi}\left[1-e^{-(r-g+d)}\right]\left(e^{-(r-g+d)}-(1-b_h)\frac{w^\ell}{w^h}\right)^{-1},1\right\}.$$

Incumbents' Value Function back

- The value function (for a high-type incumbent) is

$$
\begin{aligned}
& rV_{\mathsf{H}}(Q,\bar{q}) - \dot{V}_{\mathsf{H}}(Q,\bar{q}) \\
&= \max_{x_d, x_m} \sum_{q_\omega \in Q} \Big\{ \underbrace{\pi q_\omega}_{\text{profit}} + \underbrace{\delta\left[V_{\mathsf{H}}\left(Q \backslash \{q_\omega\}, \bar{q}\right) - V_{\mathsf{H}}(Q,\bar{q})\right]}_{\text{loss from creative destruction}} \Big\} \\
&+ \underbrace{n \times x_d \left[\mathbb{E}_{\omega'} V_{\mathsf{H}}\left(Q \cup \{q_{\omega'} + \lambda \bar{q}\}, \bar{q}\right) - V_{\mathsf{H}}(Q,\bar{q})\right]}_{\text{return from radical innovations}} \\
&+ \underbrace{n \times x_m \left[\mathbb{E}_{\omega'} V_{\mathsf{H}}\left(Q \cup \{q_{\omega'} + \eta \alpha^{\tau_{\omega'}-1} \bar{q}\}, \bar{q}\right) - V_{\mathsf{H}}(Q,\bar{q})\right]}_{\text{return from incremental innovations}} \\
&- \underbrace{n \times R(x_d, x_m)}_{\text{R\&D cost}} + \underbrace{n \times b_n \bar{q}}_{\text{quantity-based subsidy}} .
\end{aligned}
$$

- The value function takes the form $V(Q,\bar{q}) = \sum_i A q_i + n B \bar{q}$.

Entrants' Value Function back

- The value function for a potential entrant

$$rV_{\mathsf{E}} = x_{\mathsf{E}} \left[\max_{p} \left\{ pV_{\mathsf{H}} + (1-p)V_{\mathsf{L}} - K(p) \right\} - V_{\mathsf{E}} \right],$$

where

$$V_{\mathsf{H}} \equiv \mathbb{E}_{\omega'} V_{\mathsf{H}} \left(\{ q_{\omega'} + \eta \alpha^{\tau_{\omega'}-1} \bar{q} \}, \bar{q} \right),$$
$$V_{\mathsf{L}} \equiv \mathbb{E}_{\omega'} V_{\mathsf{L}} \left(\{ q_{\omega'} + \eta \alpha^{\tau_{\omega'}-1} \bar{q} \}, \bar{q} \right),$$

are the expected values of a successful entrant with one product line.

- Since all entrants are ex-ante identical, they choose the same overhead investment size $K(p^*)$.

Aggregation under Stationarity I

- We focus on a BGP where $\dot{\bar{q}}(t)/\bar{q}(t) = g$, while other aggregate variables grow proportionally and all relevant distributions are stationary.
- Denote $\mu_{j,n}$ the mass of j-type firms of size n under a stationary distribution, where $j =$ H,L.
- Denote δ_d and δ_m the creative destruction rates due to radical and incremental innovations.

$$\delta_d = \sum_n \mu_{\mathsf{H},n} \times n x_{\mathsf{H}d}; \quad \delta_m = \sum_j \sum_n \mu_{j,n} \times n x_{jm} + x_{\mathsf{E}},$$

  where $x_{\mathsf{H}} = x_{\mathsf{H}d} + x_{\mathsf{H}m}$ and $x_{\mathsf{L}} = x_{\mathsf{L}m}$.
- The economy-wide creative destruction rate is simply $\delta = \delta_d + \delta_m$.

Aggregation under Stationarity II back

- Under a stationary step-size distribution of incremental innovations, the expected step-size is

$$\bar{\eta} = \eta \Bigg/ \left(\alpha + \frac{1-\alpha}{\delta_d/\delta} \right). \tag{9}$$

- $\bar{\eta}$ decreases under a faster decay rate, i.e., a smaller α.
- As the fraction of incremental innovations in the economy, δ_m/δ, increases, $\bar{\eta}$ also decreases, that is, quality-crowding.

Proposition 1 back

Proposition 1: Definition of the creative destruction rate δ guarantees that

$$\sum_j \sum_n \mu_{j,n} \times n = 1.$$

Market Clearing back

- For the unskilled workers,

$$\sum_j \sum_n \mu_{j,n} \times n\hat{\ell}_j + \int_0^1 \ell_\omega d\omega = \ell^{\text{supply}}.$$

- For the skilled workers,

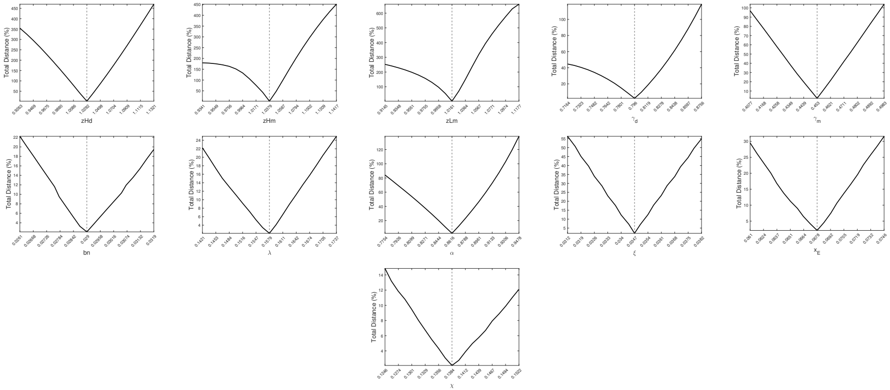
$$\sum_j \sum_n \mu_{j,n} \times n\hat{h}_j + h^{\text{teacher}} = h^{\text{supply}}.$$

- For the final good,

$$C + x_{\mathsf{E}} \times K(p^*) = Y.$$

Identification I back

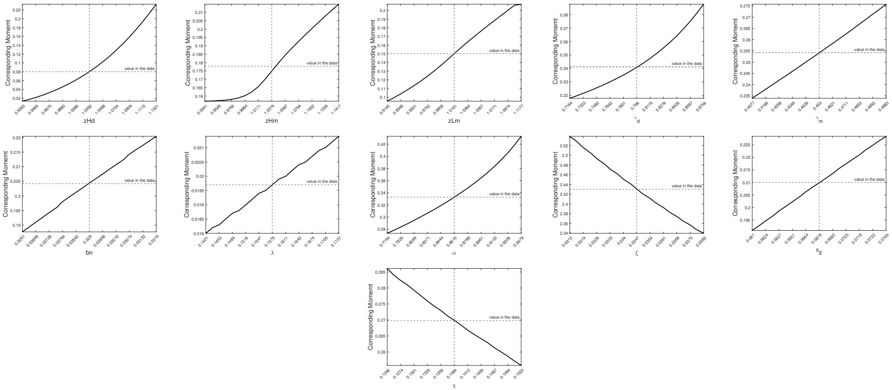
Figure: Total Distance w.r.t. Each Parameter



Note: This figure shows how the total distance changes as we move each parameter up and down by 10% from its benchmark value while keeping the others unchanged.

Identification II back

Figure: Informative Moment w.r.t. Each Parameter



Note: This figure checks the sensitivity of each of the 11 model-generated moments as a function of the corresponding parameter.

The Innocom Program back

- On top of the general quantity-based subsidies eligible for all, HTE firms are rewarded more, which potentially causes firm-level variations regarding the share of radical innovations.
- We find a 24.10% decline in its share of radical patents after a high-type firm receives HTE recognition, using a DID regression.

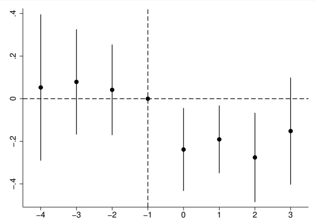


Figure: Event Study

- Our (extended) model generates a 26.55% decline in its share of radical innovations once a high-type firm receives HTE recognition.

Model Fit: Non-targeted Moments I back

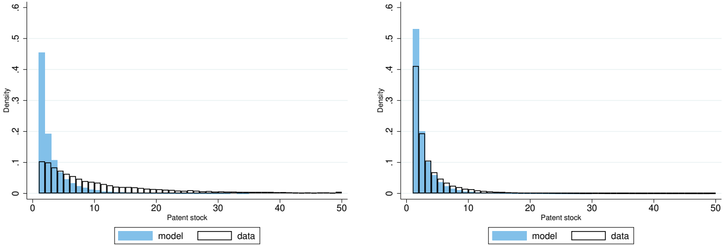
Table: Size Ratio between High- and Low-Type Firms in the Data and Model

	Employment	Revenue	Profit
Data	1.139	1.249	1.420
Model	1.332	1.332	1.332

Note: This table reports the relative ratio for variables of interest, between average high- and low-type firms in the 2011-2013 period, and we trim the bottom and the top 5 percent of the sample.

Model Fit: Non-targeted Moments II back

Figure: Distribution of Patent Number among High- and Low-Type Firms



Note: This figure shows the distribution of patent numbers among high- (panel (a)) and low-type (panel (b)) firms. Patent stock is calculated as the sum of all active patents within the 2011-2013 period, and the distribution of patent stock is then estimated for the two sub-groups.

Estimating Quantity Surge and Quality Decline back

- To estimate the magnitude of patent quantity increase above, and of radical patent share below, their natural trends in the post-2008 period, we
  - first fit the pre-2008 data with a linear trend and then use that trend to extrapolate to obtain the "natural" level for years after 2008 trend;
  - then by calculating the deviation of the actual level from 2011 to 2013 from the predicted values in relative terms, we obtain the estimation of the magnitude of patent surge above the trend, and of radical share decline below the trend.
- For the average citation ratio between incremental and radical patents, the pre-2008 linear trend turns out to be almost zero.

Key Margins for the Growth and Welfare Implications back

- Three key margins: scarce research time, quality decay, and the heterogeneity in skill intensities.
- We counterfactually shut down each of them and see effects on the model's growth and welfare implications.

Table: Pre vs. Post Changes when Corresponding Margins are Shut Down

Parameter	**Margin**	Δ_δ	$\Delta_{\delta_d/\delta}$	$\Delta_{\bar{\eta}/\lambda}$	Δ_g	$\Delta_{\textbf{welfare}}$
e	research time	6.36%	-0.24%	-0.06%	0.21 p.p.	0.29%
α	quality decay	9.34%	-41.58%	0.00%	-0.05 p.p.	-1.92%
γ_d, γ_m	skill intensity	8.77%	-12.49%	-8.36%	-0.04 p.p.	-1.79%
baseline results		10.14%	-22.91%	-15.28%	-0.19 p.p.	-3.31%

Note: Δ represents changes in the variable from the counterfactual (without b_n) to the benchmark economy (with b_n) when the corresponding margin is shut down. We present Δ_g in absolute percentage point (p.p.) changes, while the others are presented in relative percentage changes (%).

Implementing the Socially Optimal θ^*_{SP} I back

Proposition 3: For any given $\theta^*_{SP} \in [1, \theta^*_{CE})$, there exists a set $\mathcal{G}$ of different combinations of $(b_e, b_h) \in [0, 100\%]^2$ to implement the allocation in a market equilibrium. Moreover,

1. to implement the given θ^*_{SP}, policymakers face a linear trade-off between b_e and b_h;
2. when the talent threshold θ^*_{SP} is low enough, the set $\mathcal{G}$ does not contain $(0, b_h)$ or $(b_e, 0)$.

Implementing the Socially Optimal θ^*_{SP} II back

- To implement the socially optimal θ^*_{SP} in our benchmark case, policymakers can choose (b_e, b_h) located on the solid line in the following graph.

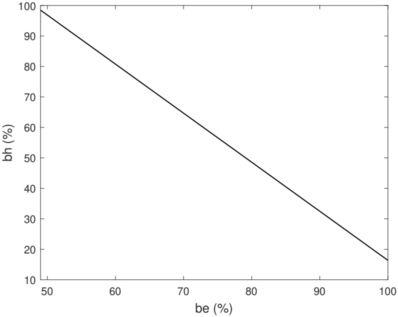


Figure: Combinations of (b_e, b_h) to Implement $\theta^*_{SP} = 2.6$.