Haste Makes Waste? Quantity-Based Subsidies under Heterogeneous Innovations

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ABFER 10th Annual Meeting
May 24th 2023
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
Institution Backgrd: Quantity-based Targets & Subsidies

  - 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

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


![Graph showing the percentage of Radical Patents and the relative quality of Incremental Patents from 1998 to 2013.]

**Figure:** Radical Patent Share (Left) and Relative Quality of Incremental Patents (Right)
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 ↑ in patent quantity and ↓ 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.
- Theoretically show and quantitatively evaluate the
  - (+) quantity effect: faster creative destruction;
  - (−) quality effects: quality-composition and quality-crowding;
- 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**

- **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**
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

\[ U = \int_{0}^{\infty} \exp(-\rho t) \frac{C(t)^{1-\nu} - 1}{1-\nu} \, dt, \quad (1) \]

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

\[ Y(t) = \frac{1}{1-\epsilon} N(t)^{\epsilon} \int_{0}^{1} q_{\omega}(t)^{\epsilon} y_{\omega}(t)^{1-\epsilon} \, d\omega, \quad (2) \]

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

▶ A simple demand function

\[ p_{\omega}(t) = q_{\omega}(t)^{\epsilon} y_{\omega}(t)^{-\epsilon} \quad (3) \]
Intermediate Production

- Production of intermediate goods uses unskilled labor and technology

\[ y_\omega(t) = \bar{q}(t) \ell_\omega(t), \]  

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 \( \omega \) solves 2-Stage price-bidding

\[ \max_{y_\omega} q_\omega^\varepsilon y_\omega^{1-\varepsilon} - \frac{w^\ell}{\bar{q}} y_\omega. \]  

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

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

\[ X_d = z_d n \left[ \frac{1}{\phi} \right] \left( e \frac{h^{\gamma_d}}{n} \frac{\ell^{1-\gamma_d}}{n} \right)^{\phi} \]  

Divide by \( n \) gives

\[ x_d \equiv X_d/n = z_d \left[ e (h/n)^{\gamma_d} (\ell/n)^{1-\gamma_d} \right]^{\phi} \]

- The Poisson arrival rate of incremental innovation is

\[ X_m = z_m n \left[ \frac{1}{\phi} \right] \left( (1 - e) h^{\gamma_m} \ell^{1-\gamma_m} \right)^{\phi} \]  

- 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
- Entry
- Human capital accumulation
- We focus on equilibrium featuring a balanced growth path, where the average productivity of the economy, $\bar{q}(t)$, grows at a constant rate $g$. 
Equilibrium: the Quantity-Quality Trade-off

The ratio between radical and incremental innovation intensities satisfies

\[
\frac{x_d}{x_m} \propto \frac{A(1 + \lambda) + B}{A(1 + \bar{\eta}) + B} \times \left( \frac{w^h}{w^\ell} \right)^{-(\gamma_d - \gamma_m)}.
\]

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

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

\( \bar{\eta} \) 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

\[ \Delta g = \Delta \delta \times \left[ \frac{\delta_d}{\delta} \lambda + \left( 1 - \frac{\delta_d}{\delta} \right) \bar{\eta} \right] \]

(i) quantity-creative destruction

\[ + \delta \times \left[ \Delta \frac{\delta_d}{\delta} \times (\lambda - \bar{\eta}) \right] + \delta \times \left[ \left( 1 - \frac{\delta_d}{\delta} \right) \times \Delta \bar{\eta} \right] . \]

(ii) quality-composition

(iii) quality-crowding

- The last “quality-crowding” channel exists because \( \bar{\eta} \) is endogenously decreasing in \( \delta_m/\delta \).
### Calibration I

**Table:** Externally Calibrated Parameters

<table>
<thead>
<tr>
<th>Para</th>
<th>Value</th>
<th>Meaning</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \rho )</td>
<td>0.02</td>
<td>time discount rate</td>
<td>literature</td>
</tr>
<tr>
<td>( \nu )</td>
<td>3</td>
<td>intertemporal elasticity of substitution</td>
<td>literature</td>
</tr>
<tr>
<td>( \epsilon )</td>
<td>0.22</td>
<td>E.o.S. in final good production</td>
<td>profitability</td>
</tr>
<tr>
<td>( L )</td>
<td>1</td>
<td>total population</td>
<td>normalization</td>
</tr>
<tr>
<td>( d )</td>
<td>0.03</td>
<td>death rate of the population</td>
<td>years of working</td>
</tr>
</tbody>
</table>

**Aggregate Economy**

- \( \rho \) - time discount rate
- \( \nu \) - intertemporal elasticity of substitution
- \( \epsilon \) - E.o.S. in final good production
- \( L \) - total population
- \( d \) - death rate of the population

**R&D Sector**

- \( \phi \) - innovation elasticity w.r.t. R&D
- \( \eta \) - initial step-size of incremental inno.

\( \phi \) - innovation elasticity w.r.t. R&D
- \( \eta \) - initial step-size of incremental inno.
## Calibration II

### Table: Internally Calibrated Parameters

<table>
<thead>
<tr>
<th>Para</th>
<th>Value</th>
<th>Meaning</th>
<th>Target</th>
<th>Data(%)</th>
<th>Model(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td><strong>R&amp;D Sector</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\tilde{z}_{Hd}$</td>
<td>1.029</td>
<td>H-type’s radical productivity</td>
<td>share of radical innov.</td>
<td>8.01</td>
<td>8.01</td>
</tr>
<tr>
<td>$\tilde{z}_{Hm}$</td>
<td>1.038</td>
<td>H-type’s incremental productivity</td>
<td>H-type’s R&amp;D intensity</td>
<td>17.78</td>
<td>17.49</td>
</tr>
<tr>
<td>$\tilde{z}_{Lm}$</td>
<td>1.016</td>
<td>H-type’s incremental productivity</td>
<td>L-type’s R&amp;D intensity</td>
<td>15.02</td>
<td>15.02</td>
</tr>
<tr>
<td>$\gamma_d$</td>
<td>0.796</td>
<td>skill intensity in radical innov.</td>
<td>H-type’s skill intensity</td>
<td>34.12</td>
<td>34.08</td>
</tr>
<tr>
<td>$\gamma_m$</td>
<td>0.453</td>
<td>skill intensity in incremental innov.</td>
<td>L-type’s skill intensity</td>
<td>25.42</td>
<td>25.41</td>
</tr>
<tr>
<td>$b_n$</td>
<td>0.029</td>
<td>quantity-based subsidy</td>
<td>subsidy-to-R&amp;D ratio</td>
<td>20.42</td>
<td>20.44</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Other Sectors</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\lambda$</td>
<td>0.158</td>
<td>step-size of radical innovations</td>
<td>TFP growth rate</td>
<td>1.97</td>
<td>1.97</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>0.862</td>
<td>quality decay</td>
<td>average citation ratio</td>
<td>33.28</td>
<td>33.27</td>
</tr>
<tr>
<td>$\xi$</td>
<td>0.035</td>
<td>education productivity</td>
<td>wage premium</td>
<td>243</td>
<td>243</td>
</tr>
<tr>
<td>$x_E$</td>
<td>0.068</td>
<td>entry rate</td>
<td>entrants’ patent share</td>
<td>21.00</td>
<td>20.98</td>
</tr>
<tr>
<td>$\chi$</td>
<td>0.138</td>
<td>cost of becoming H-type</td>
<td>fraction of H-type firms</td>
<td>26.98</td>
<td>26.99</td>
</tr>
</tbody>
</table>
The size of subsidy, $b_n$, sums up to about 3% of the value-added and 15% of the profit.

Our estimate of $\alpha$ 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.
Effects of Quantity-Based Subsidies I

- In the data, compared to the pre-2008 trend, we estimate:
  - 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

<table>
<thead>
<tr>
<th>Variable</th>
<th>Meaning</th>
<th>B.M.</th>
<th>C.F.</th>
<th>$\Delta_{\text{Model}}$</th>
<th>$\Delta_{\text{Data}}$</th>
<th>$\frac{\Delta_{\text{Model}}}{\Delta_{\text{Data}}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\delta$</td>
<td>creative destruction</td>
<td>25.53%</td>
<td>23.18%</td>
<td>10.14%</td>
<td>34.57%</td>
<td>29.33%</td>
</tr>
<tr>
<td>$\delta_d/\delta$</td>
<td>radical share</td>
<td>8.01%</td>
<td>10.39%</td>
<td>-22.91%</td>
<td>-40.89%</td>
<td>56.03%</td>
</tr>
<tr>
<td>$\bar{\eta}/\lambda$</td>
<td>step-size ratio</td>
<td>33.27%</td>
<td>39.27%</td>
<td>-15.28%</td>
<td>-20.27%</td>
<td>75.38%</td>
</tr>
</tbody>
</table>
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:

<table>
<thead>
<tr>
<th>$\Delta_{\text{Growth}}$</th>
<th>(i) quantity</th>
<th>(ii) quality-composition</th>
<th>(iii) quality-crowding</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.0019</td>
<td>0.0017</td>
<td>-0.0007</td>
<td>-0.0026</td>
</tr>
<tr>
<td>-89.47%</td>
<td>36.84%</td>
<td>136.84%</td>
<td></td>
</tr>
</tbody>
</table>

- Negative quality effects, especially the quality-crowding effect, dominate.
Quantity-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 ↑ from 1.97% to 5.51%, and welfare ↑ 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

<table>
<thead>
<tr>
<th>Variable</th>
<th>Meaning</th>
<th>B.M.</th>
<th>$b_n+5%$</th>
<th>$b_e+5%$</th>
<th>$b_h+5%$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R(x)/V_{add}$</td>
<td>avg R&amp;D intensity</td>
<td>15.84%</td>
<td>16.02%</td>
<td>15.73%</td>
<td>15.75%</td>
</tr>
<tr>
<td>$\delta_d/\delta$</td>
<td>radical share</td>
<td>8.01%</td>
<td>7.91%</td>
<td>8.63%</td>
<td>8.51%</td>
</tr>
<tr>
<td>$w^h/w^l$</td>
<td>skill premium</td>
<td>2.43</td>
<td>2.44</td>
<td>2.38</td>
<td>2.39</td>
</tr>
<tr>
<td>$g$</td>
<td>TFP growth rate</td>
<td>1.97%</td>
<td>1.96%</td>
<td>2.07%</td>
<td>2.05%</td>
</tr>
<tr>
<td>$U$</td>
<td>social welfare</td>
<td>100%</td>
<td>99.80%</td>
<td>101.14%</td>
<td>100.93%</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Variable</th>
<th>Meaning</th>
<th>Model</th>
<th>C.F.</th>
<th>$\Delta_{\text{Model}}$</th>
<th>$\Delta_{\text{Data}}$</th>
<th>$\frac{\Delta_{\text{Model}}}{\Delta_{\text{Data}}}$</th>
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</thead>
<tbody>
<tr>
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<td>creative destruction</td>
<td>25.43%</td>
<td>23.16%</td>
<td>9.80%</td>
<td>34.57%</td>
<td>28.35%</td>
</tr>
<tr>
<td>$\delta_d/\delta$</td>
<td>radical share</td>
<td>7.37%</td>
<td>9.52%</td>
<td>-22.58%</td>
<td>-40.89%</td>
<td>55.22%</td>
</tr>
<tr>
<td>$\bar{\eta}/\lambda$</td>
<td>step-size ratio</td>
<td>31.45%</td>
<td>37.20%</td>
<td>-15.46%</td>
<td>-20.27%</td>
<td>76.27%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$\Delta_{\text{Growth}}$</th>
<th>(i) quantity</th>
<th>(ii) quality-composition</th>
<th>(iii) quality-crowding</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.0018</td>
<td>0.0015</td>
<td>-0.0006</td>
<td>-0.0024</td>
</tr>
<tr>
<td>-83.33%</td>
<td>33.33%</td>
<td>133.33%</td>
<td></td>
</tr>
</tbody>
</table>
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 accrues in doing increasing innovation promotes ability in doing radical ones.
Motivation: Researchers per Million Inhabitant

Table: Researchers per Million Inhabitants, 2013

<table>
<thead>
<tr>
<th></th>
<th>China</th>
<th>US</th>
<th>Europe</th>
<th>Japan</th>
<th>France</th>
<th>Germany</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)</td>
<td>1071.1</td>
<td>3984.4</td>
<td>2941.9</td>
<td>5194.8</td>
<td>4124.6</td>
<td>4355.4</td>
</tr>
<tr>
<td>(2)</td>
<td>0.2%</td>
<td>1.5%</td>
<td>1.8%</td>
<td>1.2%</td>
<td>1.7%</td>
<td>2.7%</td>
</tr>
</tbody>
</table>

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

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

- Innography Patent Database: provides information on patent ID, patent class, forward and backward citations, legal status and etc, from 1985 onwards.
- 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

- **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

![Graph showing share of radical patents over years]

**Figure**: Share of Radical Patents under Alternative Definitions
Figure: Quality Decline: Domestic vs. Foreign Firms
Quality Decline: Entrants vs. Incumbent Firms

Figure: Quality Decline: Entrants vs. Incumbent Firms
Two-Stage Bidding Game

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

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

<table>
<thead>
<tr>
<th>Period</th>
<th>No. of external patents</th>
<th>No. of patents</th>
<th>Share of external patents</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998-2013</td>
<td>279,800</td>
<td>296,254</td>
<td>94.45%</td>
</tr>
<tr>
<td>2011-2013</td>
<td>159,490</td>
<td>167,823</td>
<td>95.03%</td>
</tr>
</tbody>
</table>

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

Figure: Radical Patent Share among External Patents
### Table: Skill Intensity for Firms of Different Types

<table>
<thead>
<tr>
<th></th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skill intensity of high-type firms</td>
<td>34.91%</td>
<td>34.53%</td>
<td>33.02%</td>
<td>34.12%</td>
</tr>
<tr>
<td>Skill intensity of low-type firms</td>
<td>26.83%</td>
<td>25.19%</td>
<td>24.69%</td>
<td>25.42%</td>
</tr>
</tbody>
</table>

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

- 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.
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 $\theta$ 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 $s = \xi h^{\text{teacher}}$. 
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

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

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

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

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

\[ rV_H(Q, \bar{q}) - \dot{V}_H(Q, \bar{q}) = \max_{x_d, x_m} \sum_{q \in Q} \left\{ \pi q \omega + \delta \left[ V_H(Q \setminus \{q \omega\}, \bar{q}) - V_H(Q, \bar{q}) \right] \right\} \]

profit loss from creative destruction

\[ + n \times x_d \left[ \mathbb{E}_{\omega'} V_H(Q \cup \{q \omega' + \lambda \bar{q}\}, \bar{q}) - V_H(Q, \bar{q}) \right] \]

return from radical innovations

\[ + n \times x_m \left[ \mathbb{E}_{\omega'} V_H(Q \cup \{q \omega' + \eta \alpha^{\tau} \omega'^{-1} \bar{q}\}, \bar{q}) - V_H(Q, \bar{q}) \right] \]

return from incremental innovations

\[ - n \times R(x_d, x_m) + n \times b_n \bar{q} \]

R&D cost quantity-based subsidy

The value function takes the form

\[ V(Q, \bar{q}) = \sum_i Aq_i + nB\bar{q}. \]
The value function for a potential entrant

\[ rV_E = x_E \left[ \max_p \left\{ pV_H + (1 - p)V_L - K(p) \right\} - V_E \right], \]

where

\[ V_H \equiv \mathbb{E}_\omega' \ V_H (\{q_{\omega'} + \eta\alpha^{\tau_{\omega'}^{-1}}\bar{q}\}, \bar{q}), \]

\[ V_L \equiv \mathbb{E}_\omega' \ V_L (\{q_{\omega'} + \eta\alpha^{\tau_{\omega'}^{-1}}\bar{q}\}, \bar{q}), \]

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 \( \delta_d \) and \( \delta_m \) the creative destruction rates due to radical and incremental innovations.

\[
\delta_d = \sum_{n} \mu_{H,n} \times nx_{Hd}; \quad \delta_m = \sum_{j} \sum_{n} \mu_{j,n} \times nx_{jm} + x_E,
\]

where \( x_H = x_{Hd} + x_{Hm} \) and \( x_L = x_{Lm} \).

The economy-wide creative destruction rate is simply \( \delta = \delta_d + \delta_m \).
Under a stationary step-size distribution of incremental innovations, the expected step-size is

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

- $\bar{\eta}$ decreases under a faster decay rate, i.e., a smaller $\alpha$.
- As the fraction of incremental innovations in the economy, $\delta_m/\delta$, increases, $\bar{\eta}$ also decreases, that is, quality-crowding.
Proposition 1: Definition of the creative destruction rate $\delta$ guarantees that

$$\sum_j \sum_n \mu_{j,n} \times n = 1.$$
For the unskilled workers,

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

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,

\[
C + x_E \times K(p^*) = Y.
\]
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.
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.
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.

Our (extended) model generates a 26.55% decline in its share of radical innovations once a high-type firm receives HTE recognition.
Table: Size Ratio between High- and Low-Type Firms in the Data and Model

<table>
<thead>
<tr>
<th></th>
<th>Employment</th>
<th>Revenue</th>
<th>Profit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data</td>
<td>1.139</td>
<td>1.249</td>
<td>1.420</td>
</tr>
<tr>
<td>Model</td>
<td>1.332</td>
<td>1.332</td>
<td>1.332</td>
</tr>
</tbody>
</table>

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.
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.
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

- 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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Margin</th>
<th>$\Delta_\delta$</th>
<th>$\Delta_\delta_{d/\delta}$</th>
<th>$\Delta_{\eta/\lambda}$</th>
<th>$\Delta_g$</th>
<th>$\Delta_{\text{welfare}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e$</td>
<td>research time</td>
<td>6.36%</td>
<td>-0.24%</td>
<td>-0.06%</td>
<td>0.21 p.p.</td>
<td>0.29%</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>quality decay</td>
<td>9.34%</td>
<td>-41.58%</td>
<td>0.00%</td>
<td>-0.05 p.p.</td>
<td>-1.92%</td>
</tr>
<tr>
<td>$\gamma_d$, $\gamma_m$</td>
<td>skill intensity</td>
<td>8.77%</td>
<td>-12.49%</td>
<td>-8.36%</td>
<td>-0.04 p.p.</td>
<td>-1.79%</td>
</tr>
<tr>
<td>baseline results</td>
<td></td>
<td>10.14%</td>
<td>-22.91%</td>
<td>-15.28%</td>
<td>-0.19 p.p.</td>
<td>-3.31%</td>
</tr>
</tbody>
</table>

Note: $\Delta$ 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 $\Delta_g$ in absolute percentage point (p.p.) changes, while the others are presented in relative percentage changes (%).
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 $\theta_{SP}^*$, policymakers face a linear trade-off between $b_e$ and $b_h$;
2. when the talent threshold $\theta_{SP}^*$ is low enough, the set $\mathcal{G}$ does not contain $(0, b_h)$ or $(b_e, 0)$.
Implementing the Socially Optimal $\theta_{SP}^*$ II

To implement the socially optimal $\theta_{SP}^*$ 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 $\theta_{SP}^* = 2.6$. 