Firm Innovation

Firm Innovation

Previous lectures have focused on static efficiency where we saw that maximizing societal welfare required setting price equal to marginal cost.

Innovation, or equivalently Research and Development ("R&D"), is the production of knowledge which in turn can deliver "better" goods.

- Firms invest to reduce costs, improve quality of products, or come up with new products.
- Consumers gain utility from new products.
- Therefore, costs and demands are changing over time.

In discussing innovation and R&D, we need to think in terms of dynamic efficiency.

Example

- Recall Q3 from PS4 where two firms are competing to introduce a new product (e.g., a new drug). Define $T(p)$ as the benefit consumers get from the new product, then welfare is

$$W(p, C) = \underbrace{\mathcal{P}\Big(C\Big) \times T(p)}_{\substack{\text{Expected benefit} \\ \text{of product if} \\ \text{innovation successful}}} - \underbrace{\sum_{i=1}^{N=2} C_i}_{\substack{\text{Total R\&D} \\ \text{Costs} \equiv \text{``}C\text{''}}}$$

where $\mathcal{P}(C) \times T(P)$ is the expected benefit from the good[1] and C_i is the money spent in R&D by Firm i.

[1] "$\mathcal{P}(C) \times T(p)$" is short-hand for four scenarios: Both firms are successful, Firm 1 is successful but Firm 2 is not, Firm 2 is successful but Firm 1 is not, and neither firm is successful though R&D costs are incurred nonetheless. Whether one or both firms are successful impacts the (Nash) equilibrium price and therefore $T(p)$.

Example (cont'd)

- Maximizing welfare then is a function of two things:
  1. Equilibrium price, p. When $p = mc$ we have "static efficiency."
  2. The probability the innovation occurs: $\mathcal{P}(\text{product invented}; \sum_{i=1}^{N=2} C_i)$ which depends on the research efforts of the firms $\{C_i\}_{i=1}^{N=2}$. An increase in $\mathcal{P}$ improves the economy's "dynamic efficiency."

- In Q3, competition
  1. decreased R&D effort per firm from 2 to 1.08,
  2. but total R&D increased leading to the likelihood the product is introduced (drug discovered) to increase from 67% to 77%.

Is Static or Dynamic Efficiency More Important?

The above conclusion is consistent with Joseph Schumpeter's view of the role of competition in dynamic efficiency:

"It is not price competition which counts but competition from the new commodity, the new technology, the new source of supply, the new type of organization... competition which commands a decisive cost or quality advantage and which strikes not at the margins of the profits and outputs of existing firms but their foundations and very lives."

- Joseph Schumpeter (1942) "Capitalism, Socialism and Democracy"

Main Questions

1. (Positive) What incentives do firms have to "innovate" and how are these incentives affected by market structure and institutional arrangements?

2. (Normative) If the amount of R&D is inefficient, can government policy improve upon the free market equilibrium? What does efficient policy look like?

A Role for Government Intervention?

Goals of Public Policy

1. Provide firms with incentives to innovate (dynamic efficiency).
2. Encourage the spread of innovation (static efficiency).

An Example: Patents

- Monopoly power conferred by patents provides the incentive to innovate.
- But patents prevent the innovation from spreading, resulting in static inefficiencies.

The optimal patent duration is our attempt to balance these two goals.

- In the U.S., patents used to last 17 years, but this has recently been increased to 20 years.
- In U.K., it used to be 14 years, but now has dropped to 5 years with annual renewal fee to continue the patent up to a maximum of 16 years.

Other policies

1. Entry subsidies.
   e.g., Venture Capital firms are taxed at 20% leading to greater start-up liquidity.
2. On-going R&D subsidies.
   e.g., $25 billion in loans to US automobile manufacturers to support development of "green car" technologies.
3. Demand subsidies.
   e.g., a consumer receives $2,500 to $7,500 credit for buying an electric vehicle.

The Incentive to Innovate

Timing:

- Today, firm "invests" in R&D.
- Tomorrow, the firm uses the output of its R&D to earn profits.

Two kinds of innovations:

1. **Process innovation:** lower production cost (or higher quality).
2. **Product innovation:** new product.

A new product or process often makes the old one obsolete.

Joseph Schumpeter called this "creative destruction".

- "Drastic" innovation: gives the firm monopoly profits (Arrow, 1962). Today, we would call this a "disruptive" innovation.
- "Non-drastic" innovation: old technology constrains the pricing and profits of the innovator.

Optimality

A Simple Model of Innovation

Motivating Questions:

1. Does the fee market deliver the efficient level of R&D?
2. Are all projects which "should" are undertaken actually undertaken?

Consider a process innovation which costs $K > 0$ to make.

- Prior to innovation, production cost is c_0 per unit.
- After the innovation, cost is c_1 per unit where $c_1 < c_0$.

An innovation is drastic if $p^M(c_1) < c_0$ and non-drastic if $p^M(c_1) > c_0$.

Q. Does the market operating under a patent system generate the efficient level of R&D?

Social Value of the Innovation

Suppose $P(Y) = A - BY$. Then consumer surplus at c_0 and c_1 are given by

$$CS(c_0) = (A - c_0)^2/2B$$

$$CS(c_1) = (A - c_1)^2/2B$$

The social value of the innovation per period is given by

$$\begin{aligned} v^s &= CS(c_1) - CS(c_0) \\ &= (c_0 - c_1) \times \left(\frac{2A - c_0 - c_1}{2B} \right) \end{aligned}$$

Define r as the market interest rate.

Consumers gain v^s in all future periods so the social present value of the innovation is

$$V^s = v^s/(1-R); \text{ where } R = 1/(1+r)$$

Thus, all innovations such that $V^s > K$ should be undertaken. This will serve as our benchmark.

Value of Innovation in Competitive Market

Suppose the market today is perfectly competitive ($p = mc$) and an innovator auctions/licenses the innovation to only one firm. That firm will buy it so long as it gets net profit ≥ 0.

The inventor can therefore profit from the innovation by setting the sale price equal to the value of the acquiring firm.

Q: What is the value of the innovation to the acquiring firm?

Case 1: If the innovation is non-drastic, the owner of the innovation charges price slightly below c_0.

The per period value of the innovation to the acquiring firm (and therefore th price at which the innovation is sold by the inventor) is

$$v^c = \underbrace{(c_0 - c_1)}_{\text{price - cost}} \times \left(\frac{A - c_0}{B} \right)$$

and the PV of the innovation is

$$V^c = v^c/(1 - R)$$

Case 2: If the innovation is drastic, the owner of the innovation charges the monopoly price and the per period value of the innovation is

$$v^c = \Pi^M(c_1) - \underbrace{\Pi^{\text{PC}}(c_0)}_{=0}$$

$$\Rightarrow v^c = \frac{(A - c_1)^2}{4B}$$

In either case, the DWL implies that $V^s > V^c$.

Intuition: Innovator (or the owner of the innovation) can't extract all of the surplus associated with the innovation.

Value of Innovation to Monopoly

The per period value of an innovation is

$$v^M = \Pi^M(c1) - \Pi^M(c_0)$$
$$\Rightarrow v^M = (c_0 - c_1)(2A - c_0 - c_1)/4B$$

The present value is $V^M = v^M/(1 - R)$.

$\Rightarrow$ For the monopolist, profits from the innovation replace existing profits, reducing the net gain.

This effect is called the *replacement* effect or *cannibalization* effect. It implies

$$v^c = \Pi^M(c1)$$
$$v^M = \Pi^M(c1) - \Pi^M(c_0)$$
$$\Rightarrow v^c > v^m$$
$$\therefore\ V^c > V^M$$

Is the Level of Innovation Optimal?

- The value of an innovation is:
  - Perfect Competition: $V^s > V^c$
  - Monopoly: $V^s > V^c > V^M$
- Working backwards, an innovator who knows K and $\{V^c, V^M\}$ and is deciding whether to spend the effort (K) to create the innovation will only do so if
  - Perfect Competition: $V^c > K$
  - Monopoly: $V^M > K$
- Low value ideas (i.e., ideas with $\{V^c, V^M\}$ close to K) will not be adopted though they may be still socially-optimal: $V^s > K$.

Conclusion

As with monopoly and market power more generally, the free market equilibrium does not maximize welfare; i.e., it delivers less innovation than what is socially-optimal.

The policy implication is that, in theory, there is a case to be made for a corrective government policies (e.g., R&D subsidies, demand subsidies) to encourage R&D. Most countries have such subsidies.

Threat of Entry

Q: How does the threat of entry impact incumbent innovation?

Suppose the innovator sells the innovation. Is an incumbent or entrant willing to pay more for the innovation?

– Equivalently, "who is willing to spend more on R&D: the incumbent or entrant?"

Let $\Pi^D(c_1, c_0)$ denote the profit of a firm with cost c_1 who faces another firm with cost c_0 and $c_1 < c_0$. Goods are homogenous.

In **Bertrand** game, if innovation is non-drastic,

$$\Pi^D(c_1, c_0) = \underbrace{(c_0 - c_1)}_{\text{price - cost}}(A - c_0)/B$$

$$\Pi^D(c_0, c_1) = 0$$

If drastic, then $\Pi^D(c_1, c_0) = \Pi^M(c_1)$.

In **Cournot** game, a non-drastic technology implies:

$$\Pi^D(c_1, c_0) = (A + c_0 - 2c_1)^2/9B$$

$$\Pi^D(c_0, c_1) = (A + c_1 - 2c_0)^2/9B$$

If drastic, then $\Pi^D(c_1, c_0) = \Pi^M(c_1)$.

In either case,

$$\Pi^M(c_1) \geq \Pi^D(c_1, c_0) + \Pi^D(c_0, c_1)$$

with strict inequality holding for non-drastic innovation.
Intuition: competition in duopoly dissipates profits.

The incumbent monopolist's willingness to pay for the innovation is

$$\Pi^M(c_1) - \Pi^D(c_0, c_1)$$

The entrant's willingness to pay is its duopoly profits less its outside option (assumed to be zero):

$$\Pi^D(c_1, c_0) - 0$$

Conclusion

The monopolist under threat of entry is willing to pay more for the innovation than the entrant. (Efficiency effect)

$\rightarrow$ Competition from entrant spurs the monopolist to invest in more R&D since

$$\underbrace{\Pi^M(c_1) - \Pi^D(c_0, c_1)}_{\text{Net Profit, Entry Threat}} > \underbrace{\Pi^M(c_1) - \Pi^M(c_0)}_{\text{Net Profit, No Entry Threat}}$$

Remarks:

- If the old technology is offered for sale and the innovation is non-drastic, the monopolist would like to buy it in order to prevent entry, though it would not use it.
- This is clearly sub-optimal as society would like the innovation to be used (dynamic efficiency) and the firm faces less competition so can charge high markups (static efficiency).

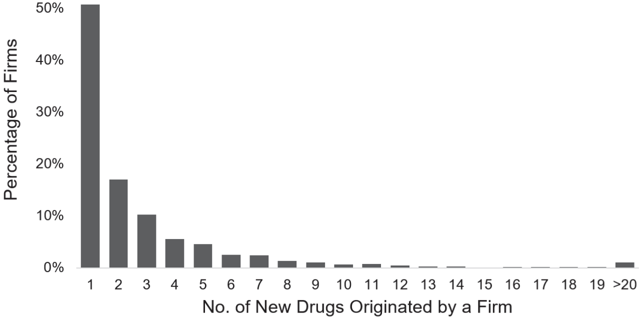
Q: Is this strategic behavior empirically relevant?

Empirical Example:
Cunningham, Ederer, & Ma (2018) "Killer Acquisitions"

- Authors use pharmaceutical data to test whether incumbent firms may acquire innovative targets solely to discontinue the target's innovation projects and preempt future competition. They call such acquisitions "Killer Acquisitions."
- Data:
  1. **Drug development data.**
     - A comprehensive dataset on drug development that tracks drug projects from early stage development through to launch or discontinuation. Data collected directly from pharmaceutical companies and researchers.
     - Data include information about each drug's intended therapeutic market (e.g., "hypertension") and mechanism of action (e.g., "calcium channel antagonist").
  2. **Acquisition data.**
     - Announced and completed M&As (*i.e.*, complete information on acquirer and target firms) and announced and effective dates from Thomson Reuters SDC Platinum.
     - Thomson Reuters RecapIQ which documents deals in the biotechnology industry using information from company press releases, SEC filings, and company disclosures.
     - SDC VentureXpert database, which covers mainly VC-backed, early stage startups to identify small entrepreneurial firms which exited via acquisition.

Empirical Example:
Cunningham, Ederer, & Ma (2018) “Killer Acquisitions”

Figure: Firm Size Distribution



This graph plots the distribution of the number of new drugs originated by a company between 1989 and 2010. We assign a drug to a company if the company was the first to own the drug development project, but we do not assign the drugs that were obtained through acquisitions. The drug origination data are from the Pharmaprojects database.

Empirical Example: Cunningham, Ederer, & Ma (2018) "Killer Acquisitions"

Figure: Descriptive Statistics of Drug Development Acquisitions

	N	Non-Acquired	Non-overlap Acquired	Overlap Acquired
Whole Sample	16,015	78%	17%	5%
By Time Period				
Beginning-1995	1,605	60%	31%	9%
1996-2000	1,933	68%	25%	7%
2001-2005	3,739	79%	16%	4%
2006-2010	5,208	90%	8%	2%
By High-level Disease Group (top 5)				
Anti-cancer (13 therapeutic classes; 783 ThC/MoA)	2,579	80%	16%	4%
Neurological (27 therapeutic classes; 986 ThC/MoA)	2,573	77%	19%	4%
Anti-infectives (28 therapeutic classes; 452 ThC/MoA)	1,946	77%	16%	7%
Biotechnology (26 therapeutic classes; 209 ThC/MoA)	1,493	79%	16%	5%
Alimentary/Metabolism (24 therapeutic classes; 498 ThC/MoA)	1,380	81%	15%	4%

- "Overlap" occurs when the target's drug project is in the same therapeutic class (e.g., "antihypertensive") and uses the same mechanism of action (e.g., "calcium channel antagonist") in which the acquirer has a drug.
- 22% of drugs acquired during the sample and 5% are acquired by a firm with a rival product.
- What happens to these acquisitions? Is there a systematic pattern based on whether there is overlap?

Empirical Example: Cunningham, Ederer, & Ma (2018) "Killer Acquisitions"

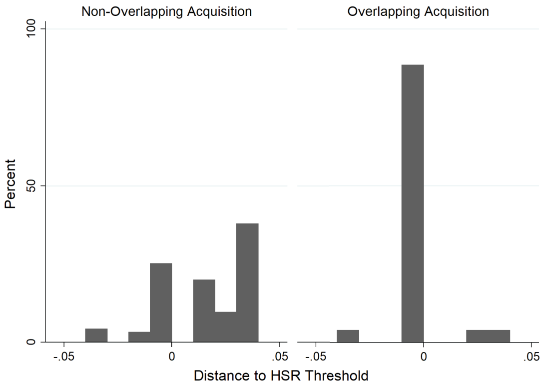
- **Hart-Scott-Rodino Antitrust Improvements Act of 1976** (*i.e.*, the "HSR Act") requires that parties must not complete certain mergers, acquisitions or transfers of securities or assets, including grants of executive compensation, until they have made a detailed filing and received approval with the U.S. Federal Trade Commission and Department of Justice.

  1. Deals with a target valuation under $50 million are not required to submit filings for pre-merger review.
  2. For deals between $50 million and $200 million, the "size-of-the-person" test is conducted: If the larger party has less than $100 million in assets or sales or the smaller party has less than $10 million in assets, the deal does not need to be reviewed by the FTC.

- The relevant HSR condition here is that acquisitions below $200 million will usually not be investigated since in the pharmaceutical industry size-of-the-person test is typically not satisfied for the smaller (target) party.

Empirical Example:
Cunningham, Ederer, & Ma (2018) "Killer Acquisitions"

Figure: Acquisitions and Antitrust Scrutiny



This graph plots the distribution of acquisition size near the Hart-Scott-Rodino review threshold. Acquisitions that fall into the [-5%,5%] around the threshold are kept, and the horizontal axis represents the distance to the review threshold (from -5% to 5%). The non-overlapping acquisitions are reported on the left panel, and overlapping acquisitions are reported on the right panel.

Empirical Example: Cunningham, Ederer, & Ma (2018) "Killer Acquisitions"

- **Research Question:** Do incumbent firms acquire innovative targets solely to discontinue the target's innovation projects and preempt future competition?
- **Results:** Authors find that
  1. 6% of acquisitions in the sample are "Killer Acquisitions" and that
  2. such acquisitions typically just occur below levels which would typically attract scrutiny from antitrust authorities.

Patents as Entry Deterrent

Table: How Firms Use Patents

Firm Type	**Internal Use**	Licensing	Cross Licensing	Licensing & Use	**Blocking Competitors**
Large companies	**49.93%**	3.03%	3.03%	3.22%	**21.72%**
Medium sized companies	**65.62**	5.38	1.20	3.59	**13.90**
Small companies	**55.78**	14.97	3.89	6.90	**9.62**
Private Research Inst.	**16.67**	35.42	0.00	6.25	**18.75**
Public Research Inst.	**21.74**	23.19	4.35	5.80	**10.87**
Universities	**26.25**	22.50	5.00	5.00	**13.75**
Other Governm. Inst.	**41.67**	16.67	0.00	8.33	**8.33**
Other	**34.04**	17.02	4.26	8.51	**12.77**
Total	**50.53%**	6.17%	3.06%	3.92%	**18.83%**

Source: EU Commission. Remainder are "Sleeping Patents" (i.e., patents which have not been used in any way) not shown (17.5% of total).

1. Only 63.68% of patents are used in a commercial process (columns 2-5). Most are used by the original assignee (i.e., "Internal Use" column).

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2. The residual have either not been used (17.50%) or are used strategically to block the competition's R&D efforts (18.83%).

Q: Does Competition Promote or Inhibit Innovation?

Joseph Schumpeter (1883-1950) believed that innovation rates are higher in less competitive markets:

"A shocking suspicion...big business may have more to do with creating our standard of life than keeping it down"

- Joseph Schumpeter (1942) "Capitalism, Socialism and Democracy"

Theory: Dasgupta and Stiglitz (1980)

Consider the following game due to Dasgupta and Stiglitz (1980).

- N firms simultaneously choose R&D expense and quantities.
- Each firm i's profit is given by

$$\pi_i(y_i, y_{-i}, x_i, x_{-i}) = P(Y)y_i - c(x_i)y_i - x_i$$

- The cost function is differentiable in x and we assume

$$\frac{dc(x)}{dx} < 0, \;\; e.g., \; c(x_i) = \beta x_i^{-\alpha} \text{ for } \alpha, \beta > 0$$

Equilibrium Concept: Nash Equilibrium

Equilibrium Conditions

1. Differentiating profits with respect to output holding R&D investment fixed, equilibrium outputs satisfy the symmetric FOC

$$\frac{P^{\star} - c(x_i^{\star})}{P^{\star}} = \frac{1}{N} \times \frac{1}{\epsilon(P^{\star})},\ i = 1, .., N$$

   where $\epsilon(P)$ is the elasticity of demand.

2. Differentiating profits with respect to R&D holding output fixed, equilibrium R&D levels must satisfy

$$-y_i^{\star} \times \frac{dc(x_i^{\star})}{dx_i^{\star}} = 1$$

   Interpretation: LHS is the marginal benefit of spending a dollar of R&D, which is equal to the level of output times the reduction in cost. The RHS is the marginal cost of increasing R&D.

   *Note: (2) holds b/c $y \geq 0$ and $\frac{dc(x)}{dx} < 0$ by assumption.

Comparative Statics

What happens to R&D as N increases?

- As N increases, we know from (1) that $y^\star$ decreases but $Y^\star = Ny^\star$ increases.
- It then follows from (2) that $x^\star$ decreases if $\frac{d^2c(x)}{dx^2} > 0$.

Increased entry reduces profits which in turn leads firms to reduce their R&D investment. More firms leads to higher costs and less output (relative to original R&D expenditure).

What about total R&D expenditure, $X^\star = Nx^\star$?

- Unclear: N goes up, $x^\star$ goes down.

The net effect depends upon the elasticity of demand.

But suppose we impose a zero-profit entry condition to determine $N^\star$.

$$P(Y^\star)y^\star - c(x^\star)y^\star = x^\star$$

Multiplying through by $N^\star$, we obtain

$$P(Y^\star)Y^\star - c(x^\star)Y^\star = N^\star x^\star$$

and dividing by $P(Y^\star)Y^\star$ we get

$$\underbrace{1 - \frac{c(x^\star)}{P^\star}}_{=\frac{p^\star - c^\star}{p^\star}} = \frac{N^\star x^\star}{P^\star Y^\star}$$

Finally use the equilibrium condition (1) to generate

$$\frac{N^\star x^\star}{P^\star Y^\star} = \frac{1}{N^\star} \times \frac{1}{\epsilon(P^\star)}$$

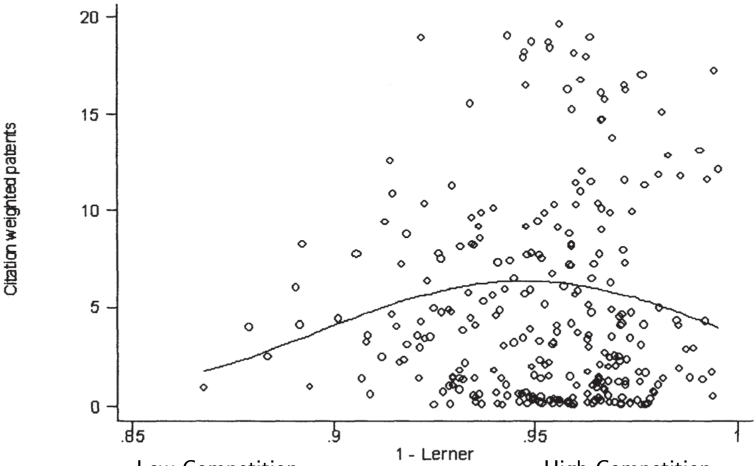
Conclusions:

1. The LHS is the industry R&D to sales ratio.
2. For two industries with the same equilibrium demand elasticity, the R&D to sales ratio is lower in the industry with more firms (i.e., the more competitive one)

   $\Rightarrow$ less competition means more research and lower costs!

Testing Theory: Does Competition Increase Innovation?

Figure: Aghion et al (2005) "Competition and Innovation: An Inverted-U Relationship"



Low Competition High Competition

Testing Theory: Does Competition Increase Innovation?

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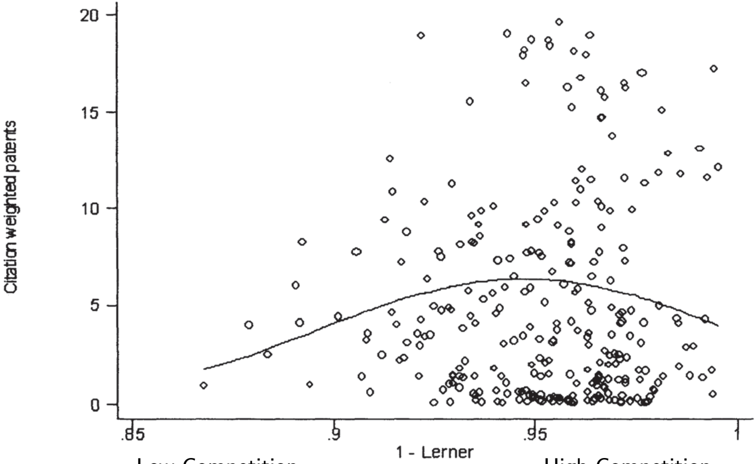


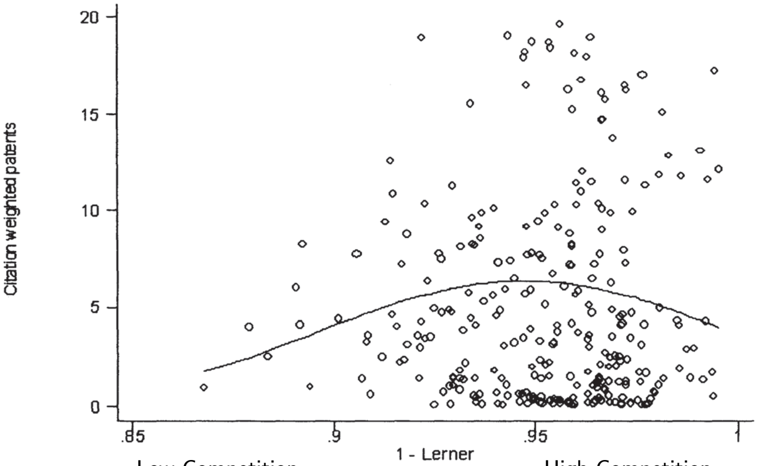
Low Competition — High Competition

Result 1. Little competition (LHS) leads firms to rest on their laurels.

Result 2. A lot of competition (RHS) erodes profits and ability to innovate.

Testing Theory: Does Competition Increase Innovation?

Figure: Aghion et al (2005) "Competition and Innovation: An Inverted-U Relationship"



Low Competition   High Competition

Result 3. There exists a sweet-spot where competition maximizes innovation.

Result 4. This point seems to vary widely across industries (points in figure).

In Summary

- The Dasgupta & Stiglitz (1980) model predicts that more competition ($N^\star \uparrow$) decreases not only a single firm's R&D ($x^\star \downarrow$) but also the equilibrium R&D intensity in the industry ($\frac{N^\star x^\star}{P^\star Y^\star} \downarrow$).
- We want to test this theoretical prediction to see if it is indeed true in the data.
- If theory is correct, we should observe a negative correlation as we compare industry R&D intensity (i.e., $\frac{N^\star x^\star}{P^\star Y^\star}$) to number of firms in the industry.
- A Challenge:
  - R&D expense (numerator) is often poorly measured in data so measurement of R&D to sales is also poor.

In Summary (cont'd)

- We saw that Aghion, et al (2005) test the relationship between competition and innovation but instead look for a relationship between market power (Lerner index) and patents as a proxy for innovation.
  - Competition (or equivalently lack of competition) is no panacea for generating innovation.
  - Instead, they find that there exists a sweet-spot where innovation and competition co-exist.
  - Unfortunately, this sweet-spot seems to vary by industry suggesting that a one-size-fits-all innovation policy will be inefficient.
  - Plus, we have already observed that patents are often used strategically so are a poor metric for innovation.

Spillovers

Spillovers

We have derived equilibrium R&D levels when R&D spending only benefited the firm that made the investment. However, in many cases, the information generated by the R&D benefits other firms.

Q. How will this spillover affect R&D investment?

We return to Cournot duopoly model with linear demand $P = A - BY$. Costs for the two firms are

$$c_1 = c - x_1 - \beta x_2$$

$$c_2 = c - x_2 - \beta x_1$$

where $\beta \in (0, 1)$ modulates the research spillover. There are two stages to the game:

1. Firms simultaneously choose R&D $\Rightarrow$ marginal costs.
2. Firms simultaneously choose output conditional on marginal costs.

Equilibrium Concept: SPNE

Cournot Equilibrium as a Function of R&D

Work backwards and begin at Cournot. Firm i solves

$$\max_{y_i} \left[P(y_i + y_j) - c_i \right] \times y_i - \frac{x_i^2}{2}$$

Recall that, given c_1 and c_2, equilibrium outputs are

$$y_1 = (A - 2c_1 + c_2)/3B$$

$$y_2 = (A - 2c_2 + c_1)/3B$$

Substituting for costs,

$$y_1 = (A - c + (2 - \beta)x_1 + (2\beta - 1)x_2)/3B$$

$$y_2 = (A - c + (2 - \beta)x_2 + (2\beta - 1)x_1/3B$$

Conclusion

Output is increasing in own R&D but effect of rival R&D depends upon whether β is greater or less than $1/2$.

A similar result holds for profits. Recall that

$$\pi_1 = (A - 2c_1 + c_2)^2/9B - x_1^2/2$$

$$\pi_2 = (A - 2c_2 + c_1)^2/9B - x_2^2/2$$

Substituting for the costs,

$$\pi_1 = (A - c + (2-\beta)x_1 + (2\beta - 1)x_2)^2/9B - x_1^2/2$$

$$\pi_2 = (A - c + (2-\beta)x_2 + (2\beta - 1)x_1)^2/9B - x_2^2/2$$

- When spillovers are low ($\beta < .5$) a firm's output and profits are decreasing in rival R&D.
- When spillovers are high ($\beta > .5$) a firm's output and profits are increasing in rival R&D.

Subgame Perfect Nash Equilibrium

Move to the R&D game where firm i solves

$$\max_{x_i} \left[\left(A - c + (2-\beta)x_i + (2\beta - 1)x_j \right)^2 / 9B - x_i^2/2 \right]$$

Differentiate to find the best responses, then the symmetric equilibrium for R&D is

$$x^\star = \frac{2(A-c)(2-\beta)}{9B - 2(2-\beta)(1+\beta)}$$

and profits are

$$\pi^\star = \frac{(A-c)^2[9B - 2(2-\beta)^2]}{[9B - 2(2-\beta)(1+\beta)]^2}$$

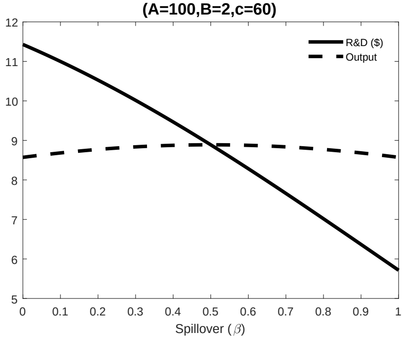
Note: Both R&D and profits may be increasing or decreasing in β.

$$\beta = 1 : x^\star = 2(A-c)/(9B-4)$$

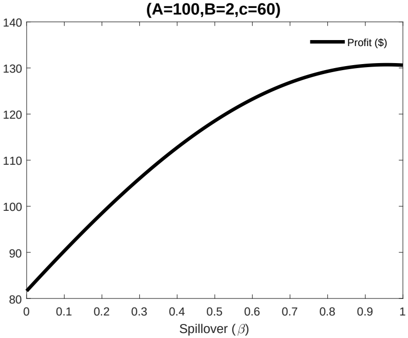
$$\beta = 0 : x^\star = 4(A-c)/(9B-4)$$

So R&D investment is higher when spillovers are low. However, profits are lower.

Equilibrium Duopoly Results as a Function of β



(a) R&D Expense ($x^{\star}$) and Output ($y^{\star}$)



(b) Profit ($\pi^{\star}$)

The Trade-Off

Basic social tradeoff here is between duplication and free-riding.

- If spillovers are low, then each firm invests to steal the business from its rival and the market may produce too much R&D.
- If spillovers are high, then each firm has an incentive to free-ride on the investment of the other firm and the market may produce too little R&D.

Joint-Ventures

- Competition between Firms 1 and 2 in both the R&D and Cournot stages reduces firm profits:
  1. Lack of coordination in R&D leads an inefficient level of R&D and therefore costs.
  2. Lack of coordination in the Cournot game leads to greater output and lower margins.
- Whereas competition in Cournot is socially-efficient, lack of coordination in (1) is socially-inefficient b/c it increases costs.
- The firms would be better off to coordinate, solving

$$\max_{x_1,x_2} \underbrace{\left[\frac{\left(A-c+(2-\beta)x_1+(2\beta-1)x_2\right)^2}{9B}-\frac{x_1^2}{2}\right]}_{\pi_1(y_1^\star,y_2^\star)}+\underbrace{\left[\frac{\left(A-c+(2-\beta)x_2+(2\beta-1)x_1\right)^2}{9B}-\frac{x_2^2}{2}\right]}_{\pi_2(y_1^\star,y_2^\star)}$$

where $(y_1^\star, y_2^\star)$ are the Nash equilibrium outputs in the second stage. Note that the firms are not colluding when they choose output but rather are competing.

Joint-Ventures (cont'd)

- We call this kind of arrangement a "joint-venture."
- Joint-ventures can improve dynamic and static efficiency so are often socially beneficial (and therefore legal) but are tricky to implement in practice as it's unclear how firms manage any intellectual property which results.
- Foreign firms wishing to invest in China are required to partner with a domestic firm in order to set up operations in the country. This "quid pro quo" policy promotes technology transfers as the domestic Chinese firm learns from (imitates?) the more advanced foreign firm.
- Holmes, et al (2015) show that China's quid pro quo policy had a significant impact on global innovation and welfare.
  - Unlike a tariff or tax, under a quid pro quo requirement management of a technology is reallocated to domestic firms, and this result can have significant effects on productivity.
  - Authors find that advanced economies (e.g., US) lose the equivalent of about 0.3–0.5% in consumption ($\approx$ welfare) because of China's quid pro quo policy.
  - China benefits significantly from the policy – consumption increases approximately 5%.

An Example

Suppose $P = 100 - 2Y, c = 60, x = \{7.5, 10\}$

- If spillovers are low ($\beta = .25$), the payoff matrix to the R&D game is

	Firm II low R&D	high R&D
Firm I low R&D	(107.31, 107.31)	(100.54, 110.5)
high R&D	(110.50, 100.54)	(103.13, 103.13)

SPNE: (H, H) but (L, L) is more profitable. Competition leads firms to **over-invest** in R&D.

- If spillovers are high ($\beta = .75$), the payoff matrix to the R&D game is

	Firm II low R&D	high R&D
Firm I low R&D	(128.67, 128.67)	(136.13, 125.78)
high R&D	(125.78, 136.13)	(133.68, 133.68)

SPNE : (L, L) but (H, H) is more profitable. Competition leads firms to **under-invest** in R&D.

Application: OCS Oil and Gas leases

- The US government sells leases to drill in sectors of the Gulf of Mexico. This area is called teh "Outer Continental Shelf" or OCS.
- They sell the leases via an auction format.
- R&D is exploration and drilling while extracting the oil amounts to Cournot output.
- Interesting conditions:
  - Seismic studies were private information but drilling outcomes are more or less observable and informative.
  - Pools of oil cross lease boundaries.
  - Drilling is expensive.
  - Extracting oil is least expensive when you first hit oil.
- Pre-auction: firms were not permitted to drill.
- Post-auction: when to drill is a war of attrition.
  - Each firm wants its neighbor to drill first to find out if there's oil in the leased area.
  - Conditional on beginning to drill, each firm wants to be the first to strike oil.

Results

- In the equilibrium, firms delay drilling.
- Since the private value of information is less than social value $\rightarrow$ too little drilling in unexplored areas.
- When an oil pool is discovered, the resulting "oil rush" leads to too much drilling due to lack of coordination of information.
- Government permitted joint ventures. However, in 1976, the seven largest oil firms were prohibited from forming joint ventures with each other due to concerns about lack of competition in bidding.

Licensing of Innovations

Licensing of Innovations

Licensing arrangement that have been studied consist of different combinations of fixed fees and royalties.

A. Drastic Innovation:

- If inventor is a member of industry, it will not license it.
- If inventor is not active in the industry and it can charge a fixed fee, then the innovation will be licensed to only one firm at per period fee equal to the monopoly profits.

Intuition: when two or more firms have the license, they will dissipate some of the profits, thereby reducing the amount that the inventor can obtain.

However, if inventor is restricted to royalties, then it may want to license to more than one firm.

Example: $c_1 = 0, c_0 = .9$, and $P = 1 - Y$.

If only one firm gets a license at royalty rate s, the monopolist

$$\max_y \left\{(1 - s - y)y\right\}$$

Differentiating and solving for optimal output and price yields

$$y^M = (1 - s)/2, P^M = (1 - s)/2$$

Its profits are

$$\Pi^M = (1 - s)^2/4$$

The inventor chooses its optimal royalty rate to

$$\max_s \left\{s(1 - s)/2\right\}$$

which implies

$$s^\star = 1/2$$

The inventor earns $1/8$ and the monopolist earns $1/16$.

Now suppose the inventor licenses to two firms.

1. If they compete as Bertrand players, then

$$p = s, y_1 = y_2 = (1 - s)/2$$

Thus, the inventor maximizes royalty revenue by

$$\max_{s} \left\{ s(1 - s) \right\}$$

$$\Rightarrow s^{\star} = 1/2$$

But, now it earns $1/4$ rather than $1/8$.

2. If the two licensed firms compete as Cournot, then each firm i

$$\max_{y_i} \left\{(1 - y_i - y_j - s)y_i\right\}$$

The symmetric solution is

$$y_1 = y_2 = (1 - s)/3$$

The inventor chooses s to

$$\max_{s} \left\{2s(1 - s)/3\right\}$$

Differentiating and solving for s yields an optimal royalty of $1/2$ and revenues of $1/6$.

We see the inventor should license its innovation to more than one firm.

Q: Why? What's the underlying mechanism?

When licensing a product and collecting royalties, the innovator wants to promote production since its profits are tied to quantity.

Competition drives down equilibrium price(s) and since demand is downward-sloping, quantity produced increases.

B. Non-drastic innovation

Suppose the firm with the innovation is active and the industry is a Cournot duopoly. In this case,

$$\Pi^D(c_1, c_0) = (A + c_0 - 2c_1)^2/9B$$

$$\Pi^D(c_0, c_1) = (A + c_1 - 2c_0)^2/9B$$

The innovator can always license the technology to its rival at royalty rate of $c_0 - c_1$. The rival's marginal costs become

$$c_1 + (c_0 - c_1) = c_0$$

Hence, equilibrium behavior and profits stay the same but the innovator earns additional royalty revenue.

Patent Races

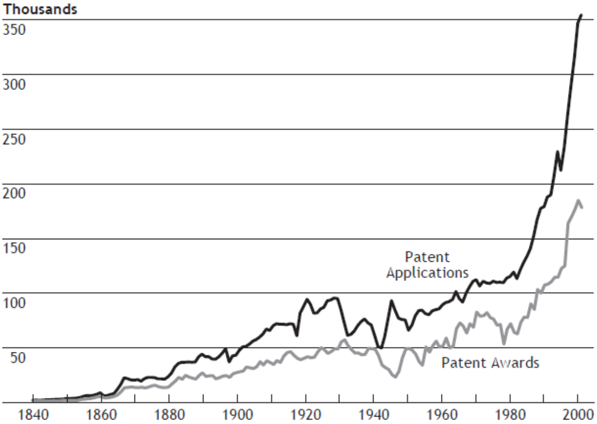
Are Patents Efficient?

- Patents are often used as evidence of innovation (technological advancement) in both popular culture and in empirical research.
- But patents confer market power and can prevent innovation of others.

Questions:

1. Are patents a good indicator of innovation?
2. Are patents good for dynamic efficiency and welfare?

Data Fact 1: Patent Filings Have Increased Significantly



Source: Jaffe and Lerner (2004)

Q: Does the increase in patents correspond to real technological progress … or just more pieces of paper?

Data Fact 2: Patents are Often Used Strategically to Block a Competitor's Innovation

Table: How Firms Use Patents

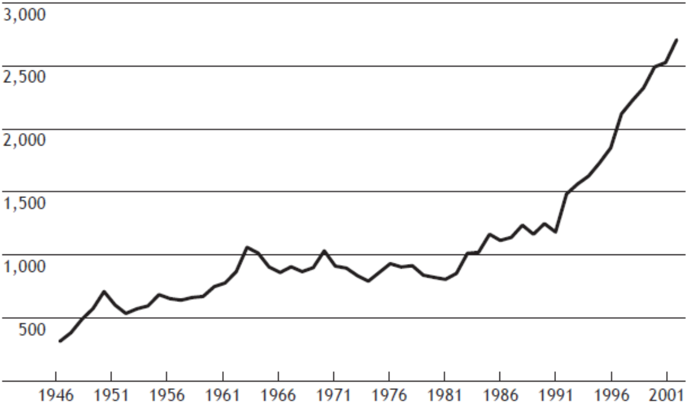
Firm Type	**Internal Use**	Licensing	Cross Licensing	Licensing & Use	**Blocking Competitors**
Large companies	**49.93%**	3.03%	3.03%	3.22%	**21.72%**
Medium sized companies	**65.62**	5.38	1.20	3.59	**13.90**
Small companies	**55.78**	14.97	3.89	6.90	**9.62**
Private Research Inst.	**16.67**	35.42	0.00	6.25	**18.75**
Public Research Inst.	**21.74**	23.19	4.35	5.80	**10.87**
Universities	**26.25**	22.50	5.00	5.00	**13.75**
Other Governm. Inst.	**41.67**	16.67	0.00	8.33	**8.33**
Other	**34.04**	17.02	4.26	8.51	**12.77**
Total	**50.53%**	6.17%	3.06%	3.92%	**18.83%**

Source: EU Commission. Remainder are "Sleeping Patents" (i.e., patents which have not been used in any way) not shown (17.5% of total).

- As we saw before, patents are often not used or are used to prevent competition from rival firms.
- The former could be because the firm hasn't figured out how to best use the idea underlying the patent. In this case, the patent represents a future option value to the firm.
- In the latter case, patenting is sub-optimal as it limits innovation and competition.

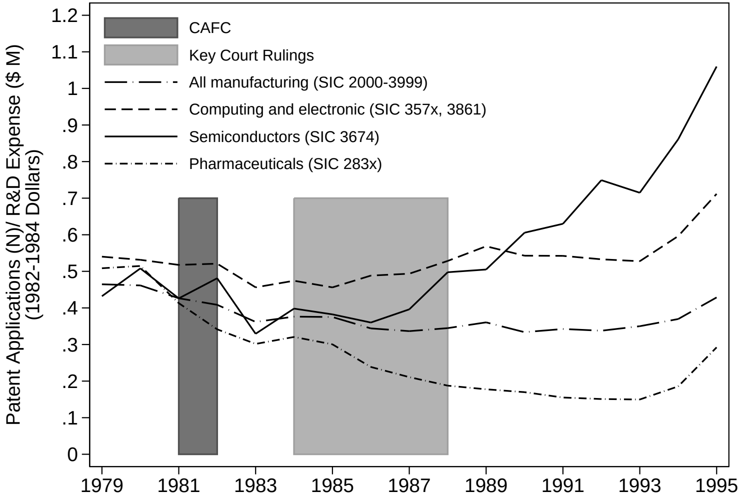
Data Fact 3: Patent Litigation Has Increased Significantly

Figure: **Increasing Role of Litigation (# initiated by year)**



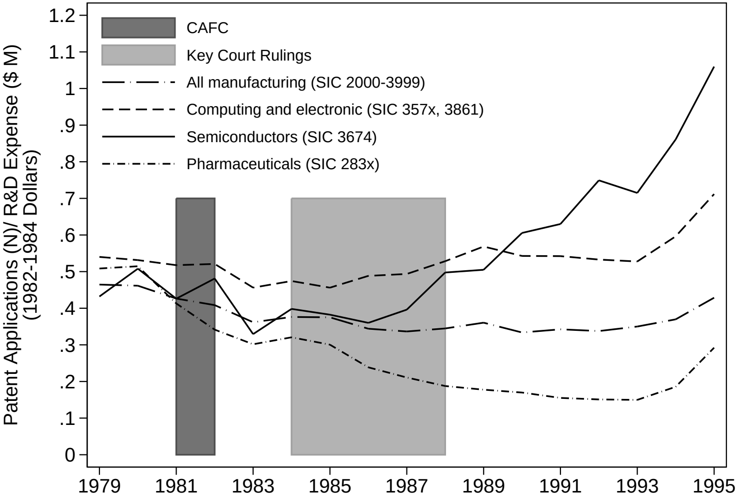
Source: Jaffe and Lerner (2004)

Case Study: The Semiconductor Industry



Data Fact 1: Harmonization of patent law in 1982 results in several key rulings which increased the value of patents.

Case Study: The Semiconductor Industry



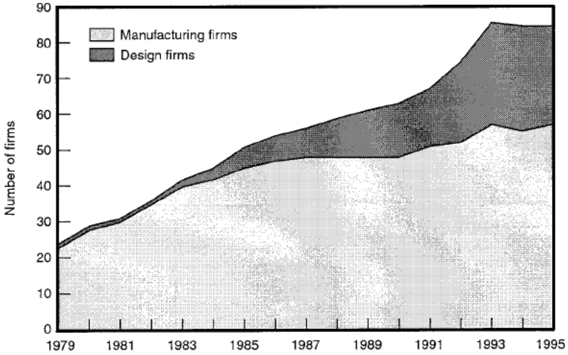
Data Fact 2: Firms in the semiconductor patent intensely and this behavior has increased over time.

The Patent Paradox

- Semiconductor firms such as AMD, Intel, Qualcomm, & Texas Instruments introduce new products each year.
- Each new product amounts to a significant innovation over the predecessor.
- The industry moves fast (Moore's Law) so there is an inherent first-mover advantage.
- Why patent at all then?

The Patent Paradox Resolved

Figure: **Specialization in the Semiconductor Industry**



Source: Hall and Ziedonis (2001)

Hall & Ziedonis (2001) document the motivations behind the patent race:

- Large firms like Intel patent to prevent getting their next innovation held up in court over a patent dispute.
- Small "design" firms patent to protect the IP underlying their products from imitation.

Imitation

International Protection of Intellectual Property

- The U.S. Chamber of Commerce estimates that piracy costs the U.S. economy between $200 and $250 billion each year.

  – Myron Brilliant. *"Testimony before the US-China Economic and Security Review Commission."* 2005.

- Between one to eight percent of Chinese GDP is attributable to counterfeit goods (Asia Business Council, 2005).

- Are these numbers right? Hard to say but casual empiricism suggests imitation by Chinese firms is both effective and quantitatively important:

  – In 2011 Chinese authorities found 22 fake Apple stores in the Chinese town of Kunming. These "beautiful fakes" were so real that even the sales staff believed they worked for Apple.

  – In March 2018, the Trump administration announced tariffs on approximately $60 billion Chinese exports to the U.S. in retaliation for Chinese "theft" of US firm intellectual property.

International Protection of Intellectual Property

- Patent protection among countries are strategic substitutes ⇒ absent international coordination the levels of patent protection chosen countries is too low (Grossman and Lai, 2004).
  - Data: Countries in the "North" choose stronger patent rights than in the "South."
  - Why? "Innovative capacity" (e.g., human capital) and market size are larger in the North.

    Each increases the returns to investment so a benevolent government maximizes welfare by emphasizing dynamic efficiency (new goods) rather than static efficiency (low prices).

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    Each increases the returns to investment so a benevolent government maximizes welfare by emphasizing dynamic efficiency (new goods) rather than static efficiency (low prices).
- Patent protection was part of the 1995 Uruguay Trade Round, the Trade-Related Aspects of Intellectual Property Rights (TRIPS).
- Remains the most comprehensive international agreement on IPRs to date.

Imitation

- It's usually much less costly to imitate a technology than invent it in the first place.
- The cost of imitating a new technology is 65% the research & development cost originally required to develop it (Mansfield, Schwartz, and Wagner, 1981).
- 60% of *patented* technologies are imitated within four years of introduction indicating that patent protection alone is insufficient to protect a firm's intellectual property (Mansfield, Schwartz, and Wagner, 1981).

Question: What impact does imitation have on firm R&D?

Theory

- 2 firms: N, S.
- Firms have marginal cost $c_0 > 0$.
- Timing:
  1. Firm N can invest $\kappa > 0$ to reduce its costs to $c_1 < c_0$.
  2. Firm S observes Firm N choice (i.e., whether the "innovation" occurs) and can pay $\gamma = 0$ to imitate the technology (i.e., costless imitation).
  3. Firms simultaneously choose outputs given vector of marginal costs.

Solution

- SPNE so solve by working backwards.
- Recall duopoly profits with (potentially) asymmetric costs:

$$\Pi^D(c_1, c_0) = (A + c_0 - 2c_1)^2/9B$$
$$\Pi^D(c_0, c_1) = (A + c_1 - 2c_0)^2/9B$$
$$\Rightarrow \Pi^D(c_1, c_0) > \Pi^D(c_0, c_1)$$

- Firm S will always imitate any advancement since

$$\Pi^D(c_1, c_1) - \gamma > \Pi^D(c_0, c_1).$$

Solution, cont'd.

Case 1: High κ

If

$$\Pi^D(c_1, c_0) - \kappa < \Pi^D(c_0, c_0) \; ,$$

Firm N does not invest even when it faces no imitation risk.

Case 2: Medium κ

If

$$\Pi^D(c_1, c_1) - \kappa \quad < \quad \Pi^D(c_0, c_0) \tag{1}$$

$$\Pi^D(c_1, c_0) - \kappa \quad > \Pi^D(c_0, c_0) \tag{2}$$

Firm N does not invest (expression 1) but would have without imitation (expression 2).

Case 3: Low κ

If $\Pi^D(c_1, c_1) - \kappa > \Pi^D(c_0, c_0)$, Firm N invests and Firm S imitates.

<u>Comments</u>

- In Case 2, the equilibrium is not dynamically efficient since the innovation is not undertaken due to imitation.
- In Case 3, we get both static and dynamic efficiency since the innovation occurs and competition reduces DWL.

Question: How can firms protect their innovations from imitation?

Application: Imitation in the Automobile Industry

- Paper: Thurk, Jeff (2018) "Sincerest Form of Flattery? Innovation and Imitation in the European Automobile Industry."
- In 1989 Volkswagen introduces its turbocharged direct injection (TDI) diesel engine in the Audi 100.
- New turbodiesel engines were significantly quieter, cleaner (no black smoke), and more reliable than their predecessors while maintaining superior fuel efficiency and torque relative to comparable gasoline models.
- Rival European firms (e.g., Fiat, Renault, Peugeot) quickly imitate the technology and introduce their own turbodiesels.
- Market penetration of diesels increases significantly.

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- Market penetration of diesels increases significantly.

Questions:

1. What was the impact of imitation on equilibrium prices and profits?
2. Did imitation of the TDI make this new technology an ex post poor investment?

Empirical Approach and Results

- Estimate demand for horizontally-differentiated automobiles.
  - Diesels accounted for 10.5% of VW profits in 1992
  - Diesels accounted for 61.1% of VW profits in 2000.
- Use estimated model to quantify the effects of imitation by simulating alternative equilibria:
  - Remove the TDI technology from all diesels, including VW.
  - Remove the TDI technology from diesels offered by rival firms.
- Find that imitation limited VW profits to 14% of potential:

$$\frac{\pi_t^{\text{Data}} - \pi_t^{\text{No TDI}}}{\pi_t^{\text{No Rival TDI}} - \pi_t^{\text{No TDI}}} \approx 14\%.$$

- Technology still generated between €2.1 to €2.6 billion of profit for VW in the Spanish market alone.
  - Technology was still a worthwhile ex post investment.

What We Learn

- Imitation is of a technology which may be easy-to-copy.
- But consumers consider the bundle of characteristics when they choose which product to purchase. The total package is hard-to-copy.
- Product differentiation specifically, or brands more generally, are therefore an important input for technological progress.
- New brands and firms may be the more important dimension of economic innovation than a specific technological progress or, in the case of multi-product firms, an increase in the quality of a specific product.
- Should think of product differentiation specifically, or brands more generally, as an important input for technological progress.

Application: Generic Drugs

- Paper: "Do Pharmacists Buy Bayer: Informed Shoppers and the Brand Premium?" by Bronnenberg, Dube, Gentzkow, & Shapiro.
- Products like aspirin and other generic drugs are biologically equivalent (by law) to the branded competition, yet we observe that consumers are willing to pay extra to buy the branded version. Why?
- Authors estimate the effect of information and expertise on consumers' willingness to pay for national brands in physically homogeneous product categories (e.g., aspirin).
- **Result 1:** Find more informed or expert consumers are less likely to pay extra to buy a branded aspirin product (e.g., Bayer aspirin rather than the generic aspirin), with pharmacists choosing them over store brands only 9 percent of the time, compared to 26 percent of the time for the average consumer.
- **Result 2:** Also true for food products but less stark.
- **Hypothesis:** Plausible mechanisms for the brand premium: asymmetric information. Uninformed consumers simply are not aware these products are exactly the same.
- **Implication:** In an uncertain world, firms can use their brand to increase the long-term profitability of their innovations since consumers may incorrectly infer these products are of higher "quality" than they actually are.

Application: Generic Drugs (Aspirin)

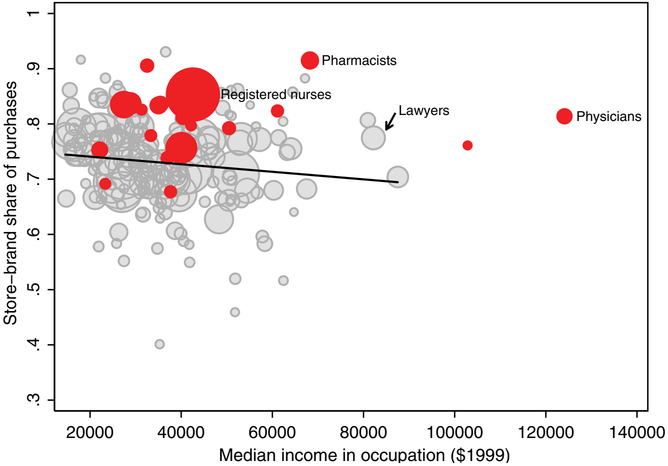
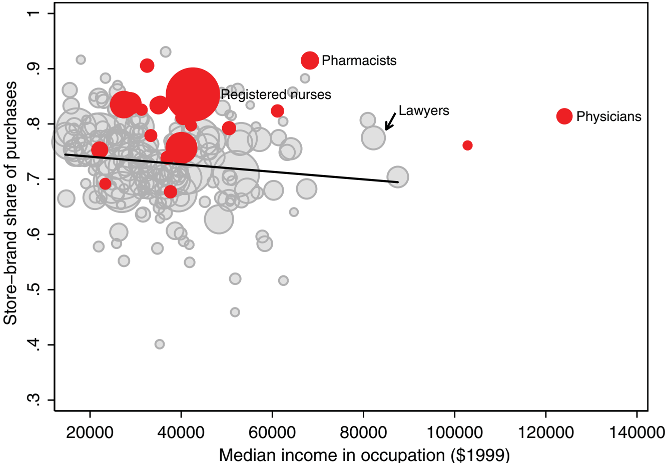


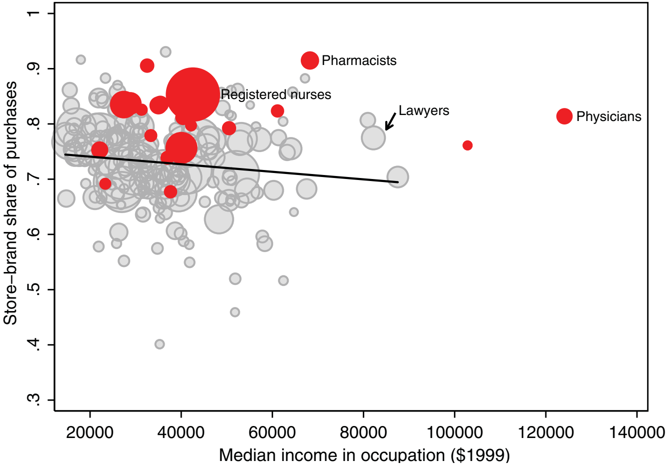
Figure shows store-brand share of headache remedy purchases by occupation (y-axis) and median earnings for full-time, full-year workers in 1999 by occupation (x-axis)

Application: Generic Drugs (Aspirin)



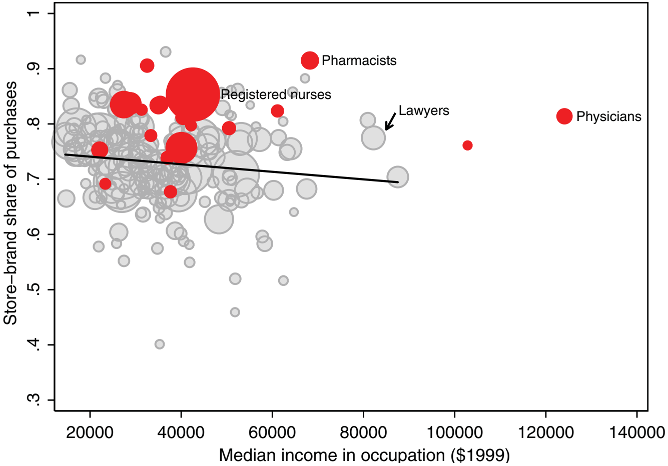
Area of circle is percent of shopping trips with that occupation in survey. Colored circles are healthcare-related.

Application: Generic Drugs (Aspirin)



Households whose primary shopper is a health care professional buy far more store brands than others of similar income. Pharmacists, physicians, and nurses buy more store brands than lawyers, who have high levels of schooling but different occupational expertise.

Application: Generic Drugs (Aspirin)



Only 8.5 percent of aspirin purchases made by pharmacists were national-brand, an amount small enough to be explained by the occasional stockouts of store brands, and the fact that some purchases are made by the nonpharmacist member of a pharmacist's household.

What We Learn

- Here, imitation is certain since patents have expired and the drug recipe is public-information, yet the innovating firms are still are able to charge higher margins.
- Firms can take seemingly homogenous products and make them differentiated by leveraging "brand." Here, that materializes in asymmetric information as poorly-informed consumers mistakenly buy the branded product (Bayer) in the belief that it will deliver superior benefits.
- Thus the value of an idea again depends critically on the ability of firms to differentiate it from the competition.

Innovation Direction

Is the Direction of Innovation Optimal?

- Most research on innovation asks: "Is research / innovation sufficient or excessive?"
- Now we ask: "Does it go in the right direction?"
- Intuition: heterogenous innovation races: hotter and cooler ideas.
- Equilibrium allocates scarce researchers to different areas.
- We'll show equilibrium and optimal allocation will rarely coincide.
- Under a plausible assumption, too many researchers in hot areas, though you could also get too few.

A Simple Model

- One period.
- Two research areas (1 and 2) with one potential discovery in each.
- Payoffs: value of a discovery is z where $z_1 < z_2$.
  $\rightarrow z_2$ is said to be a "hot" area.
- Discovery in area i occurs with probability $p(m_i) \in [0, 1]$. Assume $p(m)$ is concave (i.e., high likelihood of discovery with just a little research)
- M homogenous researchers.

Competitive Equilibrium

- Expected utility of participating in an R&D line with value z and a total of $m(z)$ researchers is given by:

$$U\big(z, m(z)\big) = \frac{p\big(m(z)\big)}{m(z)} \times z$$

- Interpretation: payoffs can be interpreted as a winner-take-all patent race where all participating researchers have equal probability of being first to innovate.

- No arbitrage implies the returns of each area equalize:

$$\underbrace{z_1 \frac{p(m_1)}{m_1}}_{\text{Utility from area 1}} = \underbrace{z_2 \frac{p(m_2)}{m_2}}_{\text{Utility from area 2}}$$

- In a competitive equilibrium, a marginal researcher contributes $p'(m)z$ ("external effect") to total value but receives only $p(m)z/m$ ("internal effect"). Since $p(m)$ is concave, $p(m)/m > p'(m)$ for $m > 0$.

Optimal Solution

- def: *A* **social planner** *is a decision-maker who attempts to achieve the best result for all parties involved. The planner therefore chooses the allocation which maximizes welfare (i.e., is optimal).*

- Planner solves

$$\max_{\tilde{m}_1, \tilde{m}_2} \left\{ z_1 p(\tilde{m}_1) + z_2 p(\tilde{m}_2) \right\}$$

which yields the following FONCs

$$z_1 \frac{\partial p(\tilde{m}_1)}{\partial m_1} = 0$$
$$z_2 \frac{\partial p(\tilde{m}_2)}{\partial m_2} = 0$$

- In equilibrium we get

$$z_1 \frac{\partial p(\tilde{m}_1)}{\partial m_1} = z_2 \frac{\partial p(\tilde{m}_2)}{\partial m_2}$$

Is the Direction of Innovation Optimal?

- Compare the competitive and optimal equilibria.

$$\text{(Competitive)} \qquad z_1 \frac{p(m_1)}{m_1} = z_2 \frac{p(m_2)}{m_2}$$
$$\text{(Optimal)} \qquad z_1 \frac{\partial p(\tilde{m}_1)}{\partial m_1} = z_2 \frac{\partial p(\tilde{m}_2)}{\partial m_2}$$

- And we have the following wedge between the competitive and optimal equilibria:

$$\frac{p(m)/m}{p'(m)} \equiv \frac{1}{\epsilon_{P_m}} - 1$$

- If LHS equals one, competitive solution is optimal. Otherwise, not.
- RHS demonstrates that whether or not an allocation is optimal depends upon the elasticity of the research process with respect to m (ϵ_{P_m}).
- The competitive equilibrium is efficient only in knife-edge cases where the elasticity of discovery ϵ_{P_m} is independent of m, e.g., $p(m) = Am^{\theta}$ for some constants (A, θ).

Results

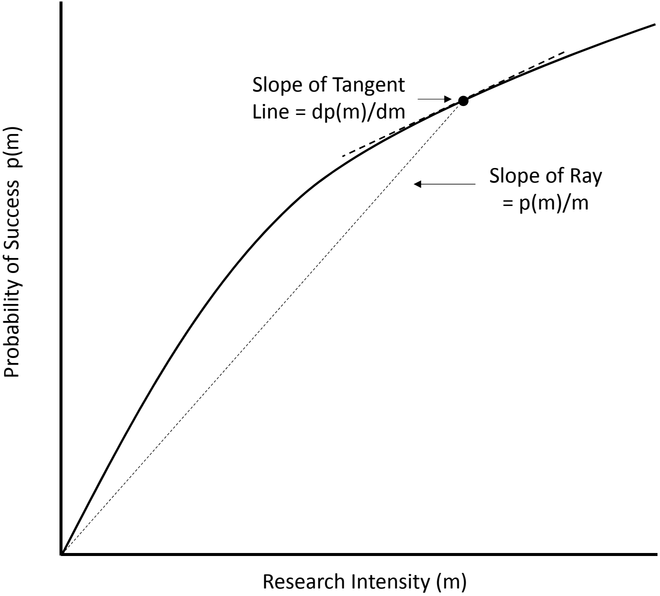
- When $\epsilon_{P_m} \neq 1$, the allocation is not optimal and the mis-allocation of resources depends on the curvature of the discovery function; i.e.,

$$p(m) > p'(m) \times m \ \text{(concave)}$$
$$p(m) < p'(m) \times m \ \text{(convex)}$$

- Intuitively, when the external effect (i.e., $p'(m)z$) is smaller than the internal effect (i.e., $p(m)z/m$), then the elasticity of discovery ϵ_{P_m} is small and the pay-off for a researcher particpating in the "hot" area is bigger than the social/ efficient value and too many researchers flock to this area.

- Thus, too much research is dedicated to the "hot" area if the elasticity of discovery ϵ_{P_m} is decreasing in m, or equivalently if $p(m)$ is concave.

Importance of the Curvature of p(m)



What We Learn

- Resources (e.g., your donations, time, effort, etc) may move to areas which are "hot" or "popular" but these resources are mis-allocated; i.e., it would be better to send them to less popular areas.

- Whether an area receives too little or too much investment depends on the curvature of the discovery function, or equivalently the returns to innovation early vs late in the discovery process.