Patent Licensing and Optimality

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1 Introduction

This short paper considers the impact of patent licensing on investment (and innovation). Scope for patent licensing occurs when an individual has a patent protected discovery that may be licensed to others. The patent holder may be a producer who can benefit from application of the discovery or a inventor who develops and patents innovations with a view to selling them to willing buyers.

The primary motivation for establishing a patent system is the promotion of innovation.[1] That view has a long history. The Venetian Senate voted a patent law governing all classes of invention into existence in 1474, giving patent protection for 10 years, with free access to the government. According to the preamble to the law [4]: "We have among us men of great genius, apt to invent and discover ingenious devices... Now, if provisions were made for the works and devices discovered by such persons, so that others who may see them could not build them and take the inventors honor [sic] away, more men would then apply their genius, would discover, and would build devices of great utility to our commonwealth."

However, it was also recognized that the existence of a patent system created incentive issues. The United States Constitution, ratified in 1789, states (in Article I, section 8) that "Congress shall have power .... To promote the progress of science and useful arts, by securing for limited times to authors and inventors the exclusive right to their respective writings and discoveries; ....". However, the monopoly power granted by a patent gave the holder the right to assert ownership of ideas which could be used to prevent competition directly. See, for example [1], for a discussion of patent history and such issues. These concerns were present in the US from the earliest times. At the time of drafting the constitution, Jefferson expressed concern to Madison in a letter dated July 31, 1788 [5]:

> "...... The saying there shall be no monopolies lessens the incitements to ingenuity, which is spurred on by the hope of a monopoly for a limited time, as of 14 years; but the benefit even of limited monopolies is too doubtful to be opposed to that of their general suppression."

Madison replied:

> "With regard to monopolies they are justly classed among the greatest nuisances in government. But is it clear that as encouragements to literary works and ingenious discoveries, they are not too valuable to be wholly renounced? Would it not suffice to reserve in all cases a right to the public to abolish the privilege at a price to be specified in the grant of it? Is there not also infinitely less danger of this abuse in our governments than in most others? Monopolies are sacrifices of the many to the few. Where the power is in the few it is natural for them to sacrifice the many to their own partialities and corruptions. Where the power, as with us, is in the many not in the few, the danger can

[1] There are plenty of other reasons one may use to argue for patents: (1) to induce disclosure of discovery and dissemination of ideas; (2) provide incentives for investors — ideas awaiting development; (3) provide a framework for the development and commercialization of discovery [3].

not be very great that the few will be thus favored. It is much more to be dreaded that the few will be unnecessarily sacrificed to the many."

The prevalence of patent systems indicates a belief that the gains from spurred invention outweigh the costs associated with temporary monopoly power over the innovation, restricting its application or use. Even though the outcome is not efficient, the absence of a patent system would lead to even greater inefficiency.

Furthermore, a patent is a right, and like any property right it may be sold, assigned, licensed or otherwise managed. The ability to trade patent rights suggests there is scope for eliminating or reducing the inefficiency associated with patents. According to the Coase theorem, under suitable circumstances, regardless of the initial property rights, people will trade to an efficient outcome (which may well depend on the initial rights allocation.) Since trade in patent rights is widespread (many acquire patents for the purpose of trade), one might expect the presence of patent licensing to improves allocative efficiency.

In what follows, this viewpoint is considered through a number of examples. The main conclusions from the discussion to follow are:

- Sharing of patented discovery is easier (in the sense of mutually beneficial licensing) when discoveries of different firms are similar in economic impact.
- With very valuable innovations there may be no feasible license agreement — because the payment required by the innovation owner exceeds what the potential licensee could profitably pay.
- When firms have discoveries of similar economic impact, it is more difficult and may be impossible to *reach* a licensing agreement.
- With patenting by firms that do not operate in the market (independent inventors):
  - Welfare is improved when the cost of innovation is low (relative to the case where there is no licensor).
  - When innovation cost are high, welfare is lowered by the presence of the independent innovator as a licensor.

`Comment 1.` *All this depends on very specific modeling assumptions.*

2 The Model

A market with n firms had demand given by:

$$P(Q) = a - bQ.$$

Firm i has cost function $c_i(q_i) = c_i q_i$. With Cournot competition, equilibrium output of firm i is:

$$q_i = \frac{a - nc_i + \sum_{j \neq i} c_j}{(n+1)b}. \tag{1}$$

Aggregate output and equilibrium price are:

$$Q = \frac{\sum(a - c_i)}{(n+1)b} = \frac{na - \sum c_i}{(n+1)b} \tag{2}$$

$$P(Q) = \frac{(n+1)a - na + \sum c_i}{(n+1)} = \frac{a + \sum c_i}{(n+1)} \tag{3}$$

Profit of firm i is

$$\pi_i = (P(Q) - c_i)q_i = \frac{a - nc_i + \sum_{j \neq i} c_j}{(n+1)} \cdot \frac{a - nc_i + \sum_{j \neq i} c_j}{(n+1)b} \tag{4}$$

$$= \frac{1}{(n+1)^2 b}(a - nc_i + \sum_{j \neq i} c_j)^2 \tag{5}$$

Throughout, assume that $b = \frac{1}{n^2}$ to reduce notation and assume that $a - nc_i + \sum_{j \neq i} c_j \geq 0$ so that all firms in the market produce over the range of possible costs. Thus, the profit of firm i is:

$$\pi_i = (a - nc_i + \sum_{j \neq i} c_j)^2 \tag{6}$$

Each firm can incur an investment cost, ρ, or undertake no investment. Investment leads to an improvement in the marginal cost, with the improvement drawn from a distribution F_i.

2.1 Licensing Major Innovations.

Consider the case of two firms, $i = 1, 2$, so that profit of firm i is given be:

$$\pi_i(a, c_i, c_j) = \frac{1}{3^2 b}[a - 2c_i + c_j]^2 = [(a - c_i) + (c_j - c_i)]^2$$

Recall that a firm's investment options are $i \in \{0, \bar{i}\}$, with investment level $\bar{i}$ costing ρ and no investment costing 0. Suppose that a firm's current cost is currently $c_i = 1$. Next period, without investment by either firm, unit cost will continue to be 1 for each. If firm i invests, next period unit cost will be x_i, a random variable uniformly distributed on $[0, 1]$, giving cost function cost $c_i(q) = x_i q$. If firms both invest and allow use of each others innovation (cross-license), the cost function of firm i will be $c_i(q) = x_i x_j q$. With investment and subsequent cost parameters $\tilde{c}_i$, profit is

$$\pi_i(a, \tilde{c}_i, \tilde{c}_j) = [(a - \tilde{c}_i) + (\tilde{c}_j - \tilde{c}_i)]^2$$

Provided $a > 2$, output and profit of each firm is always positive.

Comment 2. *In this context, innovation occurs in terms of a reduction of a parameter (c_i). Alternatively one could write $\pi_i(a, \alpha_i, \alpha_j)$ where $\alpha_i = 1 - c_i$. Formulated this way, the key properties of the profit functions are:*

$$(1)\ \frac{\partial \pi_i}{\partial \alpha_i} \geq 0 \qquad (2)\ \frac{\partial^2 \pi_i}{\partial \alpha_i^2} \geq 0 \qquad (3)\ \frac{\partial^2 \pi_i}{\partial \alpha_j \partial \alpha_i} \leq 0$$

2.2 Incentives after innovation.

There are four possible situations that a firm may find itself: neither it or its competitor invested; one or other invested; both invested.

NEITHER FIRM INVESTS.

Profit for each firm is: $\pi_i(a, 1, 1) = (a-1)^2$.

ONE FIRM INVESTS.

Say that firm i alone invests. The profits for i and j respectively are:

$$\begin{aligned} \pi_i(a, x_i, 1) &= [(a - x_i) + (1 - x_i)]^2 \\ \pi_j(a, 1, x_i) &= [(a-1) + (x_i - 1)]^2 \end{aligned}$$

And, if firm j can use i's technology, then the profit to both is $\pi_i(a, x_i, x_i) = (a - x_i)^2$. From these:

$$\pi_i(a, x_i, 1) > \pi_i(a, x_i, x_i) > \pi_i(a, 1, x_i)$$

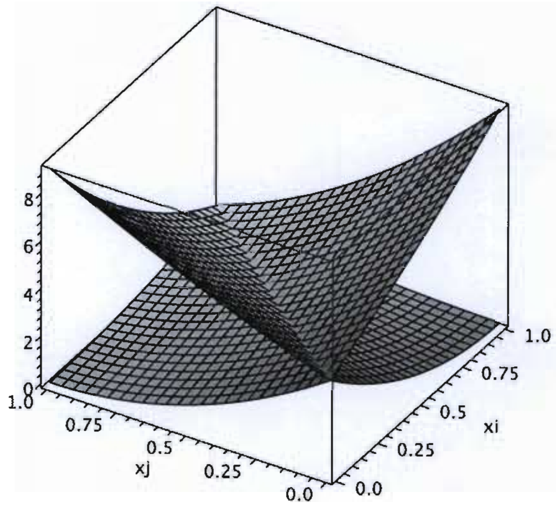
These have expectations:

$$\begin{aligned} E\{\pi_i(a, x_i, 1)\} &= \int_0^1 \pi_i(a, x_i, 1) dx_i = a^2 + \frac{1}{3} \\ E\{\pi_i(a, 1, x_i)\} &= \int_0^1 \pi_j(a, 1, x_i) dx_i = a^2 - 3a + \frac{7}{3} \\ E\{\pi_i(a, x_i, x_i)\} &= \int_0^1 \pi_i(a, x_i, x_i) dx_i = a^2 - a + \frac{1}{3} = a(a-1) + \frac{1}{3} \end{aligned}$$

Since $\delta = E\{\pi(a, x_i, 1)\} - \pi(a, 1, 1) = 2(a - \frac{1}{2}) > 0$, it pays to invest as long as investment cost is no greater than δ. Since $E\{\pi_i(a, x_j, x_i)\} - E\{\pi(a, 1, x_i)\} = a^2 - 3a + \frac{7}{3} - a(a-1) + \frac{1}{3} = 2(a-1) > 0$, it pays to invest when the other firm does (and $(a-1) > 0$).

BOTH FIRMS INVEST. In this case, provided neither firm can use the discovery of the other (there is no cross licensing), the profits of i and j respectively are:

$$
\begin{aligned}
\pi_i(a, x_i, x_j) &= [(a - x_i) + (x_j - x_i)]^2 \\
\pi_j(a, x_i, x_j) &= [(a - x_j) + (x_i - x_j)]^2
\end{aligned}
$$

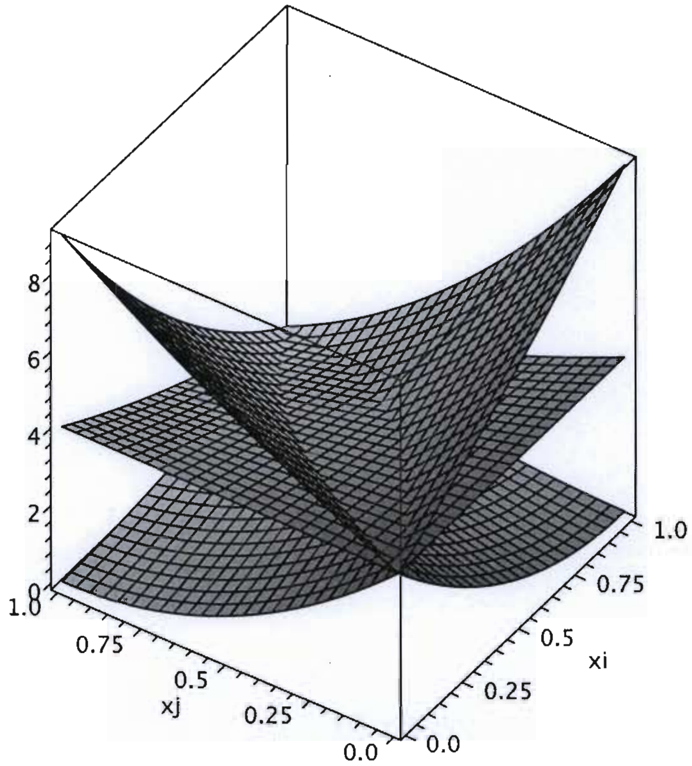


If innovations are cross-licensed, then for each profit becomes:

$$\pi_i(a, x_ix_j, x_ix_j) = \pi_i(a, x_ix_j, x_ix_j) = (a - x_ix_j)^2$$

Graphing all three functions:

$$
\begin{aligned}
\pi_i(a, x_i, x_j) &= [(a - x_i) + (x_j - x_i)]^2 \\
\pi_j(a, x_i, x_j) &= [(a - x_j) + (x_i - x_j)]^2 \\
\pi_i(a, x_ix_j, x_ix_j) &= (a - x_ix_j)^2
\end{aligned}
$$



Considering $\pi_i(a, x_i, x_j)$ and $\pi_i(a, x_i x_j, x_i x_j)$, these functions are equal when:

$$[(a - x_i) + (x_j - x_i)]^2 = (a - x_i x_j)^2 \tag{7}$$

or

$$x_i = \frac{x_j}{2 - x_j}. \tag{8}$$

(The other root of the quadratic is $x_i = \frac{x_j + 2a}{x_j + 2} > 1$.)

Thus, $\pi_i(a, x_i x_j, x_i x_j) > \pi_i(a, x_i, x_j)$ on the region where $x_i < \frac{x_j}{2 - x_j}$. Likewise $\pi_j(a, x_i x_j, x_i x_j) > \pi_i(a, x_i, x_j)$ on the region where $x_j < \frac{x_i}{2 - x_i}$.

REMARK 1. *When innovations are of similar value — (x_i, x_j) satisfy:*

$$x_i > \frac{x_j}{2 - x_j} \quad \textit{and} \quad x_j > \frac{x_i}{2 - x_i} \tag{9}$$

then cross-licensing is mutually beneficial without payment of a license fee by either party.

Outside this region, achieving cross-licensing requires a net payment from one firm (with the lesser innovation) to the other.

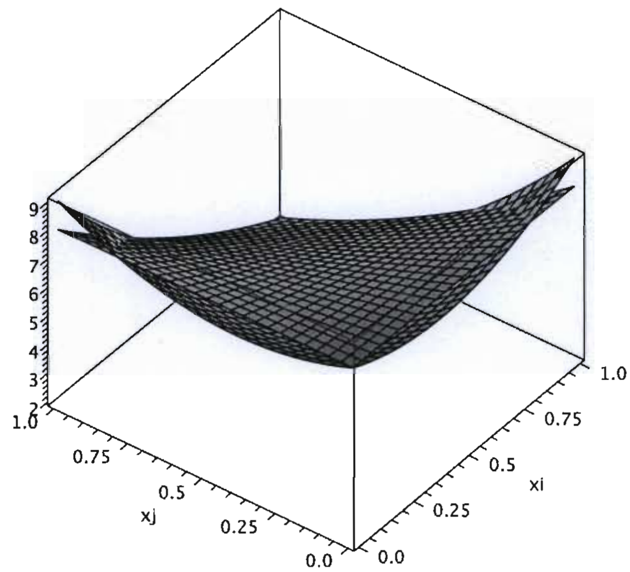
Overall profit for both firms without sharing innovation is:

$$\pi_i(a, x_i, x_j) + \pi_j(a, x_i, x_j) = [(a - x_i) + (x_j - x_i)]^2 + [(a - x_j) + (x_i - x_j)]^2. \tag{10}$$

If technology is shared, overall profit is:

$$2 \cdot \pi_i(a, x_i x_j, x_i x_j) = 2(a - x_i x_j)^2 \tag{11}$$

Plotting these:



So, for example, when $x_i = x_j = x \in (0, 1)$,

$$\pi_i(a, x_i, x_j) + \pi_j(a, x_i, x_j) = 2(a - x)^2 < 2(a - x^2)^2 = 2 \cdot \pi_i(a, x_i x_j, x_i x_j) \tag{12}$$

In this case, total profit after cross-licensing exceeds the sum of profits in the pre-license environment. Cross-licensing with a suitable division of total profit (through differential license payments) can make both parties better off relative to having no license agreement.

Conversely, if $x_i = 0$ and $x_j = 1$ then $2(a - x_i x_j)^2 = 2a^2$ and

$$\begin{aligned} [(a - x_i) + (x_j - x_i)]^2 + [(a - x_j) + (x_i - x_j)]^2 &= [(a + 1)]^2 + [(a - 2)]^2 \\ &= 2a^2 - 2a + 5 \\ &= 2a(a - 1) + 5 \end{aligned} \tag{13}$$

Since $[2a^2 - 2a + 5] - 2a^2 = 5 - 2a$, is strictly positive for $a < \frac{5}{2}$, for $a = 2$:

$$\pi_i(a, x_i, x_j) + \pi_j(a, x_i, x_j) < 2 \cdot \pi_i(a, x_i x_j, x_i x_j) \tag{14}$$

In this case, there is no license fee that j could profitably pay i, that is profitable for i. Note that here, the value of the innovations is highly asymmetric.

REMARK 2. *When an innovation is "big" (leads to a dramatic improvement in profit), it may not be possible to license profitably.*

> *Watt's Steam engine:* James Watt obtained a patent in 1769 for improvements to the steam engine currently in use at that time (the "Newcomen" engine). The main feature was the addition of an external condenser to create a vacuum *outside* the piston chamber, thus preventing the cooling of steam on the outward piston cycle. Over the next six years he worked developing and improving the mechanical features to complete a functioning machine. The Watt engine gave a dramatic performance improvement — using a quarter the amount of steam the Newcomen engine required on each cycle. At this time, the length of a patent was 14 year. Afraid of patent expiry before return from manufacture of the new engine, Watt successfully arranged an extension of the patent to 1800 through an act of Parliament (with the help of powerful friends). During the period from 1785 to 1800, Watt had numerous struggles with other inventors but steadfastly refused to either license his patent discovery or license the patents of others (such as the crank patent held by James Pickard, which he circumvented with the sun and planet gear system.) [2, 6]

`Comment 3.` *In the model, ex-ante licensing does raise both firms payoffs. The ex-ante expected payoffs are, with sharing:*

$$E\{\pi_i(a, x_i x_j, x_i x_j)\} = \int_0^1 \int_0^1 \pi_i(a, x_i x_j, x_i x_j) dx_i dx_j \quad = \quad a^2 - \frac{1}{2}a + \frac{1}{9}$$

and without sharing:

$$E\{\pi_i(a, x_i, x_j)\} = \int_0^1 \int_0^1 \pi_i(a, x_i, x_j) dx_i dx_j \quad = \quad a^2 - a + \frac{2}{3}$$

So, ex-ante, a cross-licensing agreement is possible since:

$$E\{\pi_i(a, x_i x_j, x_i x_j)\} > E\{\pi_i(a, x_i, x_j)\} \tag{15}$$

2.3 Surplus

Recall, in this model the price and quantity are determined as:

$$P(a, x_i, x_j) = \frac{a + x_i + x_j}{2+1}; \quad Q = \frac{2a - x_i - x_j}{(2+1)b}$$

So, $a - P = \frac{2a - x_i - x_j}{3}$, and consumer surplus is:

$$CS = \frac{1}{2}(\frac{2a - x_i - x_j}{3})(\frac{2a - x_i - x_j}{3b})$$

Recalling that $b = \frac{1}{9}$, this is:

$$CS(a, x_i, x_j) = \frac{1}{2}(2a - x_i - x_j)^2 \tag{16}$$

Total surplus is:

$$TS = CS(a, x_i, x_j) + \pi_i(a, x_i, x_j) + \pi_j(a, x_i, x_j) = \\ \frac{1}{2}(2a - x_i - x_j)^2 + (a - x_i + x_j - x_i)^2 + (a - x_j + x_i - x_j)^2 \tag{17}$$

Without cross-licensing, comparing the total surplus at $(x_i, x_j) = (0, 1)$ with the total surplus at when cross-licensing occurs gives:

$$TS(a, 0, 0) - TS(a, 0, 1) = \frac{11}{2} + 4a > 0 \tag{18}$$

So, total welfare would be higher in this case, if cross-licensing were to occur: but firm i will not cross-license to firm j for any fee that j would be willing to pay.

REMARK 3. *For some innovation profiles, (x_i, x_j), no licensing scheme can achieve efficiency.*

3 Licensing Stability

Suppose there are three firms, i, j, k and the market structure is the same as before.

$$\pi_i(a, b, c_i, c_j, c_k) = \frac{1}{3^2 b}[a - 3c_i + c_j + c_k]^2 = \frac{1}{16b}[(a - c_i) + (c_j - c_i) + (c_k - c_i)]^2$$

Now, with $b = \frac{1}{16}$ and $a \geq 3$ to ensure that all firms can profitably operate in the market, the profit of i with no sharing is:

$$\pi_i(a, x_i, x_j, x_k) = [(a - x_i) + (x_j - x_i) + (x_k - x_i)]^2$$

No firm invests: The expected payoff to each player when no one invests is:

$$\pi(3:0) = (a - 1)^2$$

Exactly one firm invests: The expected payoff to a single player investing, with the others not investing is:

$$\pi(1:1) = \int_x [(a - x_i) + 2(1 - x_i)]^2 dx_i = a^2 + a + 1$$

And to each of the two non-investing firms:

$$\pi(2:1) = \int_x [(a-1) + (1-1) + (x_i - 1)]^2 dx_i = \int_x [(a-1) + (x_i - 1)]^2 dx_i = a^2 - 3a + \frac{7}{3}$$

Exactly two firms invests: The expected payoff to each player investing when just one player does not invest.

$$\pi(2:2) = \int_{x_i} \int_{x_j} [(a - x_i) + (x_j - x_i) + (1 - x_i)]^2 dx_i\, dx_j = \frac{5}{6} + a^2$$

And to the non-investing player:

$$\pi(1:2) = \int_{x_i} \int_{x_j} [(a-1) + (x_j - 1) + (x_i - 1)]^2 dx_i\, dx_j = \frac{25}{6} + a^2 - 4a$$

All firms invest: The expected payoff to each player when all invest is:

$$\pi(3:3) = \int_{x_i} \int_{x_j} \int_{x_k} [(a - x_i) + (x_j - x_i) + (x_k - x_i)]^2 dx_i\, dx_j\, dx_k = \frac{7}{6} + a(a-1)$$

Provided $\pi(1:1) - \pi(3:0) = 3a > \rho$ (in the no investment regime one firm has an incentive to invest); $\pi(2:2) - \pi(2:1) = 3a - \frac{9}{6} > k$ (when just one firm is investing each other firm has an incentive to follow); $\pi(3:3) - \pi(1:2) = 3a - 3 > k$ the only (ex-ante) equilibrium is one where all invest (and no licensing anticipated subsequently).

3.1 The Post Investment period

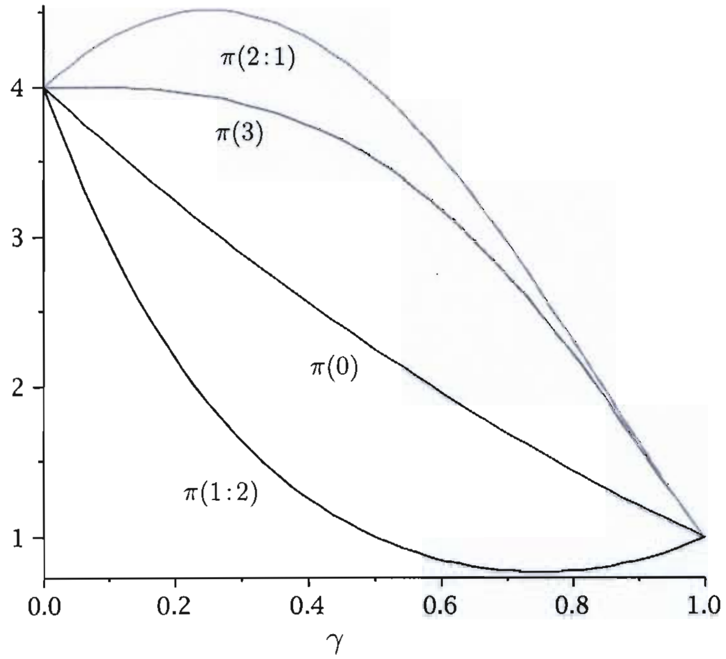
After the realization of technologies, $\boldsymbol{x} = (x_i, x_j, x_k)$, if technology is shared, the profit of each firm i is $\pi(3)(\boldsymbol{x}) = (a - x_i x_j x_k)^2$. With i, j sharing technology and not sharing with k, the profit of i and j is

$$\pi(2{:}1)(\boldsymbol{x}) = [(a - x_i x_j) + (x_k - x_i x_j)]$$

and the profit of k is

$$\pi(1{:}2)(\boldsymbol{x}) = [(a - x_k) + (x_i x_j - x_k) + (x_i x_j - x_k)].$$

In the special case where all firms have the same level of discovery, $\boldsymbol{x}_\gamma = (x_i, x_j, x_k) = (\gamma, \gamma, \gamma)$. The payoff when all three share technology is: $\pi(3)(\boldsymbol{x}_\gamma) = (a - \gamma^3)^2$. When two share the payoff to each is $\pi(2{:}1)(\boldsymbol{x}_\gamma) = [(a - \gamma^2) + (\gamma - \gamma^2)]^2 = [(a - \gamma^2) + \gamma(1-\gamma)]^2$ and the payoff to the outsider is $\pi(1{:}2)(\boldsymbol{x}_\gamma) = [(a - \gamma) + 2(\gamma^2 - \gamma)] = [(a - \gamma^2) - 2\gamma(1-\gamma)]$. Finally, the payoff with no sharing is $\pi(0) = (a - \gamma)^2$.



3.1.1 Core allocations

For (π_i, π_j, π_k) to be a stable payoff allocation in the post investment environment, we require:

$$\begin{aligned} \pi_i + \pi_j &\geq 2\pi(2:1) \\ \pi_i + \pi_k &\geq 2\pi(2:1) \\ \pi_j + \pi_k &\geq 2\pi(2:1) \end{aligned}$$

or

$$\pi_i + \pi_j + \pi_k \geq 3\pi(2:1)$$

This is impossible.

REMARK 4. *When different firms have similar levels of innovation, it may be impossible to achieve stability in licensing agreements: there is an incentive for unstable subcoalitions to form. Given remark 1, obtaining license agreements may be mutually beneficial, but also unstable.*

> *Wi-Fi:* In 2007, WiLAN (an Ottawa based company) has sued 22 IT companies for patent infringement of Wi-Fi and DSL patents. The Commonwealth Scientific and Industrial Research Organization had refused to commit not to sue firms as the Institute for Electronic Engineering (IEEE) seeks to develop standard for Wi-Fi standard 802.11n. (This standard is capable of doubling the range and increasing the speed by a factor of 5 over standard 802.11g.) As a result, the 802.11n standard, under development for a number of years is stalled.

4 External Innovation

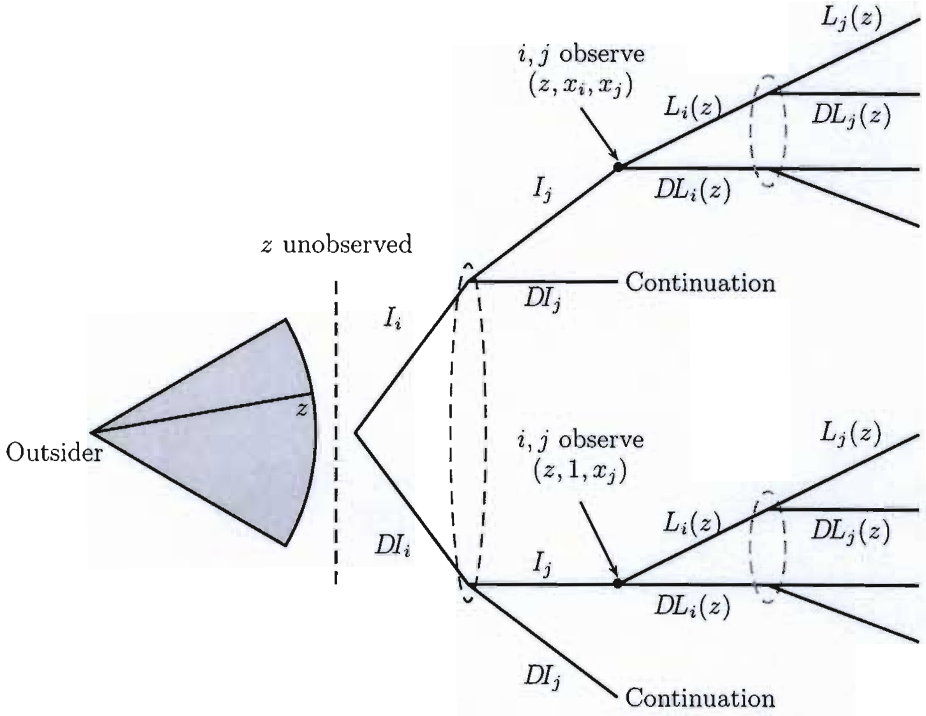
This section considers the impact that an "outside" innovator has on investment in innovation. The outside innovator is not involved in production but instead licenses discovery to active firms. It is assumed that the external innovator faces the same R&D costs (ρ), and has the same probability of success. As before, denote the innovations of the two firms i, j by x_i, x_j and let z denote the innovation of the external innovator.

Assume the innovator innovates before the firms do; the innovation is unknown to the firms but is legally protected. The firms are aware that they may be challenged by the innovator: the innovator may have a "blocking" innovation or not. Say that z blocks x_i if $z \leq x_i$; otherwise i's innovation "jumps" that of the innovator and the innovation $x_i < z$ may be used without paying any license fee to the innovator.

> *Automobile Patent:* In 1769 Nicolas-Joseph Cugnot built a self-propelled carriage driven by a steam engine; Richard Trethwick also built a steam propelled vehicle in 1803. The first gasoline powered car was built around 1860 in France by Jean Joseph Lenoir. Over 100 years after Cugnot, George B. Selden, a Rochester lawyer obtained a patent for a road engine (US patent 549,160). Selden filed the patent application in 1879, recognizing the potential of the auto industry. However, he also realized that a patent with a life of 17 years was likely to expire before the auto industry achieve volume in production where a patent would be most valuable. Strategically filing amendments to the patent over time, he delayed the granting of the patent until 1895, while maintaining priority with the 1879 date. Thus his patent ran from 1895. The patent was carefully written and covered the main features of a car. As a result, all manufacturers were forced to pay royalties on his patent. Eventually Henry Ford challenged the Selden patent and although the validity of the patent was upheld Ford was found not guilty infringing the Selden patent (because Ford used a four-stroke engine whereas the Selden patent specified a two-stroke engine). In the course of the lawsuit, Selden did build a car according to the patent specification but it was almost unable to function. However, by this time the patent was within one year of expiry. Selden, who had contributed little if anything to the development of the automobile, became rich by skilful exploitation of the patent system.

Two models of firm behavior are considered. In the first, firms do not block competitors use of their own technology — even if it would be considered infringing. Firms never litigate. If licenses are issues, they are issued only by the external licensor, and only because the licensor owns a technology superior to that of the potential licensee. The potential licensee is blocked from use of own discovery and must either license from the external innovator or use pre-investment technology.

A second model allows innovating firms to block usage by other firms of innovation. In either case, the structure of strategic interaction is described by the game form:



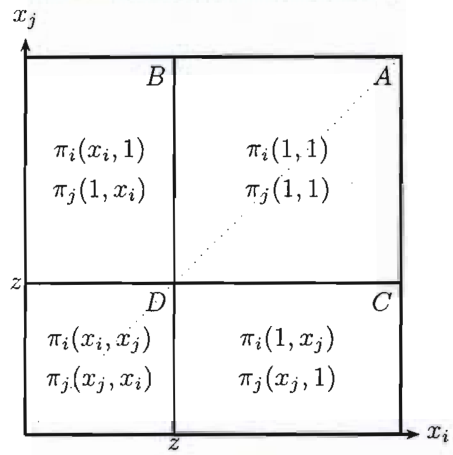
4.1 Non-blocking firms

Initially, the external innovator invests in R&D but the outcome is unknown to both firms. Firms may choose to invest or not (for i, I_i and DI_i) and they make the decisions simultaneously. Subsequently, the innovations of both firms become know and then firms have the option of licensing the outside innovator's discovery if it is a blocking discovery. (To simplify the calculations, it is assumed that firms do not cross license or seek to block the other firm from using its own innovation.)

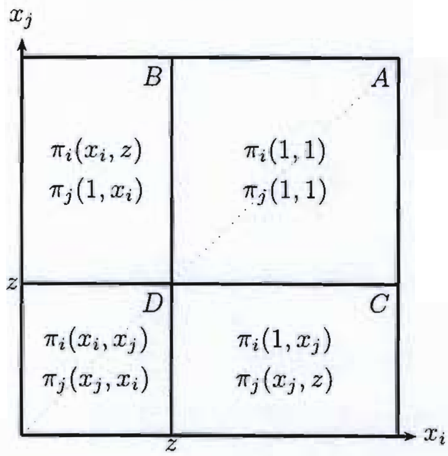
There are four sub-games following the investment phase. These are considered in turn.

Consider the upper branch of the tree where both firms invest. This results in a pair of innovations (x_i, x_j) which along with the outsider's innovation z lead to a sub-game for the licensing of z. There, firms may choose to license z or not depending on whether or not it is blocking; and on its value to the firm. The outside innovator is assumes to license at the most favorable terms possible — extracting all the "rent" from the value of the innovation z.

Payoffs with Innovation Blocking



Payoffs with licensing



A. Both firms license the innovation x, paying a license fee: $l(z) = \pi_i(z, z) - \pi_i(1, 1)$.

B. Firm j licenses the innovation, paying a license fee of $l(z, x_i) = \pi_j(z, x_i) - \pi_j(z, 1)$.

C. Firm i licenses the innovation, paying a license fee of $l(z, x_j) = \pi_i(z, x_j) - \pi_i(z, 1)$.

D. Neither firm licenses the innovation.

MOTIVATION: Consider region A. If i licenses z, license fee aside, the net benefit is $\pi(z, 1) - \pi(1, 1)$. (Note, payoff function symmetry: $\pi_i(a, b) = \pi_j(b, a)$.) If firm j responds, the resulting gain to j is $\pi(z, z) - \pi(1, z)$, again ignoring license cost. Suppose the firms both license z paying $l(z)$. This is the most that they will pay, and since profit is $\pi(z, z) - l(z) = \pi(1, 1)$ if a player deviates to not purchase a license the payoff becomes $\pi(1, z)$. Since $\pi(1, z) < \pi(1, 1)$, it pays to purchase the license.

Next, consider region B. Since $x_i < z$, i will not buy a license. For j, the benefit of purchasing a license is $l(z, x_i) = \pi_j(z, x_i) - \pi_j(1, x_i)$. Similarly, on region C, the license is $l(z, x_i) = \pi_i(z, x_j) - \pi_i(1, x_j)$. On region D, the license is 0.

Finally, from the licensor's viewpoint: $2[\pi(z, z) - \pi(1, 1)] > \pi(z, 1) - \pi(1, 1)$, so it is more profitable to license to 2 rather than 1 (at a higher license fee).

Considering the upper branch, the expected payoff to either firm conditional on z is $\varphi_1(a)$.[2] The

[2]The calculations are:

A. $pa(z, a) = (a-1)^1(1-z)^2$

B.

$$pb1(z, a) = \int_0^z \int_z^1 [a - x_i + z - x_i]^2 dx_j dx_i = (1-z)\int_0^z [a - x_i + z - x_i]^2 dx_i = a^2 z + \frac{1}{3}z^3.$$

$$\begin{aligned} pb2(z, a) &= \int_0^z \int_z^1 [a - 1 + x_i - 1]^2 dx_j dx_i \\ &= (1-z)\int_0^z [a - 1 + x_i - 1]^2 dx_i \\ &= (1-z)(a^2 z - 4az + az^2 + 4z - 2z^2 + \frac{1}{3}z^3) \end{aligned}$$

expected payoff to either player is:

$$\varphi_1(a) = \int_0^1 [pa(z,a) + pb1(z,a) + pc1(z,a) + pd(z,a)]dz = 1 - \frac{3}{2}a + a^2$$

Corresponding calculations for the licensor give the payoff as:

$$\varphi_1^L(a) = -\frac{34}{15} + \frac{7}{3}a$$

Summarizing, the payoffs when both firms invest are:

PAYOFFS: BOTH FIRMS INVEST	
Either investing firm	Licensor
$\varphi_1(a) = 1 - \frac{3}{2}a + a^2$	$\varphi_1^L(a) = -\frac{34}{15} + \frac{7}{3}a$

Next, considering the case where 1 firm invests (say i) and one does not, with similar calculations, the payoffs are:

PAYOFFS: ONE FIRM INVESTS		
Investing firm	Non-investing firm	Licensor
$\varphi_2(a) = \frac{7}{12} - a + a^2$	$\varphi_3(a) = \frac{23}{12} - \frac{8}{3}a + a^2$	$\varphi_{23}^L(a) = -\frac{25}{12} + 2a$

Finally, if neither invests, then the payoff to each firm is:

PAYOFFS: NEITHER FIRMS INVEST	
Either non-investing firm	Licensor
$\varphi_4(a) = (a-1)^2$	$\varphi_4^L(a) = -\frac{4}{3} + 2a$

Finally, recall that investment costs ρ. Summarizing these calculations, the investment decision

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C.

$$\begin{aligned} pc1(z,a) &= \int_0^z \int_z^1 [a - 1 + x_j - 1]^2 dx_i dx_j = (1-z)\int_0^z [a - 1 + x_j - 1]^2 dx_j \\ &= (1-z)(a^2 z - 4az + az^2 + 4z - 2z^2 + \frac{1}{3}z^3) \\ pc2(z,a) &= \int_0^z \int_z^1 [a - x_j + z - x_j]^2 dx_i dx_j = (1-z)\int_0^z [a - x_j + z - x_j]^2 dx_j \\ &= (1-z)(a^2 z + \frac{1}{3}z^3) \end{aligned}$$

D.

$$\int_0^z \int_0^z [a - x_i + x_j - x_i]^2 dx_j dx_i = \frac{2}{3}z^4 - z^3 a + a^2 z^2$$

strategically can be summarized by the matrix:

$$\begin{array}{cc} & \begin{array}{cc} I_j & DI_j \end{array} \\ \begin{array}{c} I_i \\ DI_i \end{array} & \begin{pmatrix} (\varphi_1(a) - \rho, \varphi_1(a) - \rho) & (\varphi_2(a) - \rho, \varphi_3(a)) \\ (\varphi_3(a), \varphi_2(a) - \rho) & (\varphi_4(a), \varphi_4(a)) \end{pmatrix} \end{array}$$

The equilibrium is described as ρ varies in figure 1 below.

4.1.1 Comparison with the "no investor" case.

In the absence of a potential external investor, firms make investment decisions depending on investment cost and the implications for competition after the investment decision is made.

When both invest, the expected profit to each (ignoring investment cost) is $bi(a)$; when just one invests, the payoff to the single investor is $s_i(a)$ and to the other firm $sni(a)$; finally, the payoff to each when neither invests is $n(a)$. These are

$$bi(a) = \int_0^1 \int_0^1 [a - x + y - x]^2 dydx = \frac{2}{3} + a^2 - a \quad (19)$$

$$si(a) = \int_0^1 \int_0^1 (a - x + 1 - x)^2 dydx = a^2 + \frac{1}{3} \quad (20)$$

$$sni(a) = \int_0^1 \int_0^1 (a - 1 + x - 1)^2 dydx = a^2 - 3a + \frac{7}{3} \quad (21)$$

$$ni(a) = (a-1)^2 \quad (22)$$

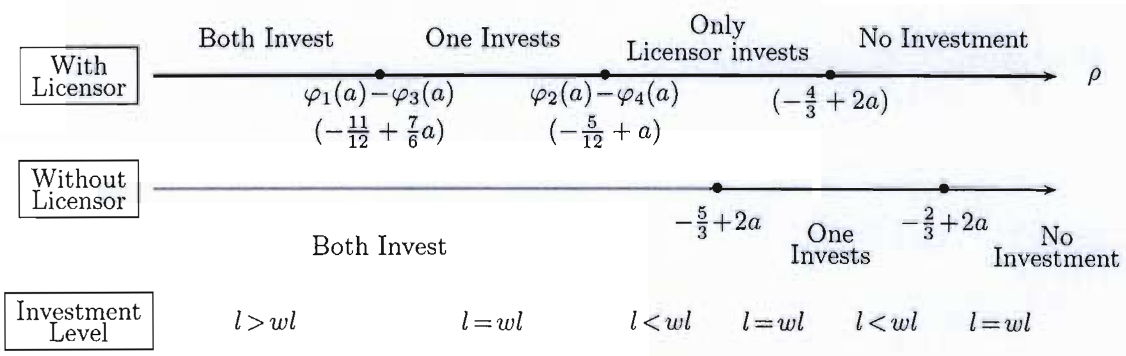
Thus, the investment decision is an equilibrium of:

$$\begin{array}{cc} & \begin{array}{cc} I_j & DI_j \end{array} \\ \begin{array}{c} I_i \\ DI_i \end{array} & \begin{pmatrix} (bi(a) - \rho, bi(a) - \rho) & (si(a) - \rho, sni(a)) \\ (sni(a), si(a) - \rho) & (ni(a), ni(a)) \end{pmatrix} \end{array}$$

For $\rho < -\frac{5}{2} + 2a$, both invest; for $-\frac{5}{2} + 2a < \rho < -\frac{2}{3} + 2a$ exactly one firm invests and for $-\frac{2}{3} + 2a$, neither firm invests.

Considering the impact of different investment costs gives the following below. The notation $l = wl$, $l < wl$, and $l > wl$ means that investment is the same; less; or greater; comparing the environments where the licensor operates with one where no licensor is present.

Figure 1: Equilibrium as investment cost varies

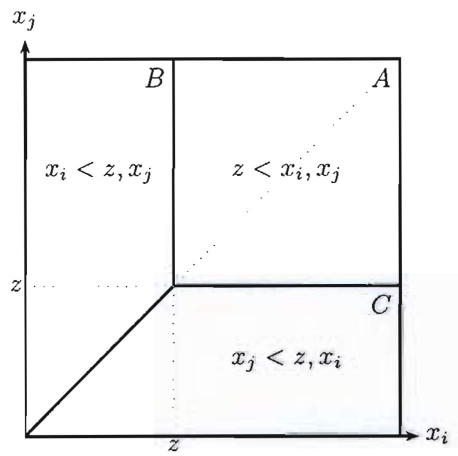


Remark 5. *When the cost of investment is low, the presence of a licensor raises overall investment. As investment cost increases, the presence of a licensor tends to reduce the overall level of investment.*

4.2 Blocking firms

With firms blocking competitors, and in the absence of an external licensor, similar computations give the following figure, depicting the decision to exit investment as the cost of investment increases.

Innovation Blocking



Payoffs

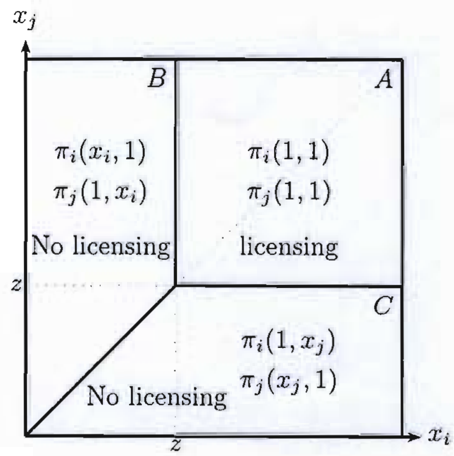
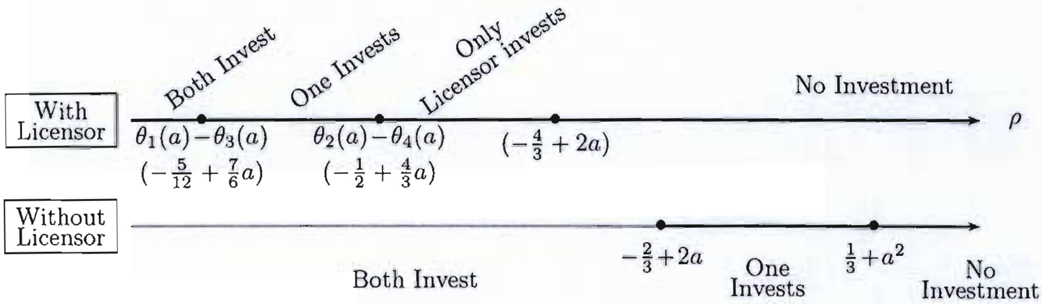


Figure 2: Equilibrium as investment cost varies, firms blocking



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