Summary

International Policy Coordination to Promote Innovation and Production Capacity

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1 Introduction

While most new drugs are invented by pharmaceutical companies in developed countries, many firms in the developing world have the potential capability to produce these drugs at low prices and in large quantities. However, the collaboration between northern innovators and southern production facilities faces various impediments, which can lead to underinvestment in both innovative activities and capacity development. Our objective in this paper is to shed light on how policy competition and policy coordination could shape the incentive for innovation and capacity building and the resulting geographical distribution of production and consumption.

The relationship between innovation, production capacity, and patent protection is central to understanding the deployment of new technologies across industries. Innovation does not occur in isolation; its success depends on the ability of industries to integrate these developments into their production processes. The concept of "deployment" emphasizes that innovation extends beyond the creation of new products or ideas and involves their broad integration into existing systems. Investment in capacity development is a critical factor in this process. Inadequate production capacity can limit the effective deployment of innovations, even when the underlying technological advancements are significant.

The example of Covid-19 vaccine production is revealing: The main producers of mRNA vaccines (Pfizer and Moderna) contained their supply chain mostly to the US and Europe [4]. Other parts of the world, however, had the potential capacity to contribute to the production of these life-saving products. Nevertheless, the sourcing decisions of these companies left the potential capacity of production in the rest of the world largely unexplored.

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An important concern of northern innovators about outsourcing to the South is the potential loss of control over production and sales decisions. In the example of mRNA Covid-19 vaccines, western companies (and governments) were primarily concerned with providing these products in their countries. Had they expanded their supply chain to the South, these pharmaceutical firms and their respective governments would have lost their tight control over production and distributional decisions.

Pharmaceutical companies have rejected the notion that the fear of losing control over production and sales was a factor in determining the geography of their supply chain. They have instead attributed their decision to a lack of production capacity in the rest of the world [3]. Using a model of innovation and production in an international environment with incomplete contracts, we show that both of the aforementioned reasons for the containment of the Covid-19 supply chain in the developed world could be equilibrium features that occur simultaneously. In particular, the belief that pharmaceutical companies will avoid joint ventures with southern companies reduces the ex-ante incentive to invest in capacity building by potential southern producers.

We depart from the current literature by noting that the degree of intellectual property right protection affects not only the incentive to innovate, but also the incentive to develop production capacity by potential producers. In our model, production capacity is a choice that must be made in advance of production. We analyze a two-country model where an innovating North engages in R&D to innovate new pharmaceuticals that can be produced in either the North or South. The essence of our model could be described using a two-period scenario. In the first period, potential producers all over the world could make a sunk investment to draw a productivity parameter, after which they could choose their capacity by making a sunk investment in capacity. Production capacity is fungible: it can be used to produce a generic or a patented product. Independently, a potential innovator makes R&D investments and obtains a new design with a probability that is increasing in the level of R&D investment. Our basic tenet is that investment in innovation and production capacity may be undertaken by independent entities, and it is possible that the innovator of a product may not be its most efficient producer.

In period two, the patent-holder chooses a subset of facilities and negotiates a production license with them. The technology transfer involves a fixed resource cost by the patent holder, with the distribution of returns between patent holder and licensee determined by a Nash bargaining solution. The facilities that are not chosen (and those that fail to reach an agreement with the patent holder) will produce a generic drug that has a perfectly competitive market. The facilities that successfully obtain a license from the patent-holder could produce the patented drug. The output of the patented product is then sold at prices that are determined by the North and South governments in their respective countries.

Our model focuses on the complementarity between capacity investments and innovation: the profitability of the innovation depends on the availability of capacity and the incentive to invest in capacity depends on the likelihood that a patent holder will be willing to negotiate a license. Government policies can influence these decisions in several ways. One concerns the commitment ability of the governments to pricing policies. If the South government cannot commit to a price policy, then the North patent holder will be reluctant to negotiate with owners of production capacity in the South, reducing the incentive to invest in South capacity.

A second policy concerns the strength of patent protection. Strict patent protection may reduce the likelihood that the patent holder will negotiate with licensees in the North and South, which will reduce the incentives for capacity investments by independent producers. In this light, we reevaluate the efficacy of Compulsory Licensing laws that are incorporated in the TRIPS agreement [2, 1] taking into account their effect on capacity building in developing countries.

Finally, it is notable that our analysis primarily applies to industries where the lead time for capacity building is long, making rapid scaling challenging. In these sectors, the slow pace of capacity development creates a substantial barrier to innovation, as potential developers may see the market as unready to support new products. For instance, pharmaceutical manufacturing requires not only specialized equipment and facilities but also highly trained human capital, which can take years to develop and train to meet industry standards. This stands in contrast to industries with quick, adaptable capacity expansion, such as textiles, where production can be scaled more readily by adding new machinery or shifting production lines in existing facilities, allowing innovation to be more easily integrated and adopted. For industries with lengthy lead times in capacity development, the inability to scale quickly can create bottlenecks that hinder the effective deployment of new technologies. Our model, therefore, suggests that an optimal patent system should be more relaxed in industries with long capacity development lead times, as this can better support investment in capacity building and ultimately enhance innovation adoption.

2 Model

A manufacturer in this industry has a limited capacity denoted by q. The production capacity is fungible: it could be used to produce either a generic or a patented good. Production of a high-quality product requires advanced knowledge, which can be obtained through a license from a patent holder or through imitation of an existing patent.

The are potentially several patent-holders in the market, each of which has exclusive rights to license the production of its patented good, subject to the possibility of successful imitation by manufacturers.

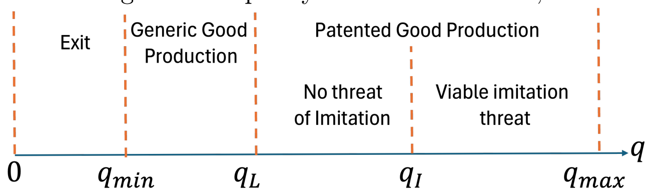
Product Market We consider a product market in which several high-quality (patented) products and generic varieties are supplied. The price of the generic good is fixed and normalized to 1. Demand for the patented product is downward-sloping, and the inverse demand function for the patented product is given by $p(Q)$, where, $Q \equiv Q_L + Q_I$, is the total supply of a specific patented good, which is the sum of production by licensed manufacturers, Q_L, and imitators, Q_I.

Manufacturing Capacity A manufacturer in this industry has a limited capacity denoted by q. Investors could sink a fixed cost of F to draw of a capacity q from a distribution function $G(q)$. This function is continuous and differentiable with density function $g(q)$ and support $[0, q_{max}]$. This investment creates a facility that requires an overhead cost of f to operate, in which case q units could be produced at zero marginal cost. A positive marginal costs does not change the analysis. Therefore, for simplicity we assume that once production capacity is in place and the overhead cost of production is incurred, production could take place without additional costs.

The production capacity is fungible: it could be used to produce either a generic or a patented good. Production of a high-quality product requires advanced knowledge, which can be obtained through a license from a patent holder or through imitation of an existing patent. Production of the generic good does not involve any additional costs.

Innovation There are N potential innovators. If an innovator invests k dollars in R&D, it will innovate a new drug and obtain a patent with a probability of $\gamma(k)$,where $(\gamma' > 0, \gamma'' < 0)$. The demand for a newly invented product is given by the inverse demand curve $p(Q)$, where Q is the total output of the patented

Figure 1: Capacity thresholds for exit, imitation, and licensing



product. Given that all potential innovators are identical, they all choose the same investment level, k, in equilibrium and there will be $\gamma(k) N$ patent holders.

Licensing If an innovating firm has successfully innovated, it can can contract with manufacturing firms The patent-holder, **P**, may produce the output in-house at a marginal cost of $\bar{c}$, or it can outsource production to independent facilities that have entered in stage 1 and have a marginal cost of of zero. Licensing production incurs a fixed technology transfer cost of f_L to each firm that the patent holder licenses with. In licensing negotiations, the patent holder makes a take it or leave it offer to the firm. If a manufacturer does not receive a license, it will have to decide between imitation and generic good production (next stage.) We assume that each patent holder is matched with an equal fraction of the distribution of manufacturers. In particular, if M is the mass of manufacturers in the market with a capacity distribution of g(q), a given patent-holder faces a mass of $m = \frac{M}{\gamma(k)N}$ manufacturers with the same distribution, $g(q)$.

Imitation and Patent Protection An entity seeking to imitate a patented product may invest a cost f_I in imitation efforts. The success of these efforts is probabilistic: with a probability α the imitation is successful, and the imitator avoids legal repercussions. However, with a probability of $1-\alpha$ the imitation is deemed to infringe upon the patent, and the imitated products are confiscated and destroyed. f_I and $1-\alpha$ reflect the scope (or breadth) of patent protection and the effectiveness of patent enforcement, respectively. We will assume that the cost of imitation is greater than the cost of knowledge transfer through licensing, namely, $f_I > f_L$.

Lemma 1. *Capacity thresholds for Exit, Imitation and Licensing:*

(i) There is a threshold of capacity, $q_{\min}$, *such that a manufacturer exits the market if* $q < q_{\min}$.

(ii) There is a capacity threshold, q_I, such that all manufacturers with $q \geq q_I$ prefer imitation and licensing to generic good production.

(iii) There is a capacity threshold, q_L, such that all manufacturers with $q \geq q_L$ will receive a license to produce the patented product.

The imitation threshold, q_I, may be larger, smaller or equal to the licensing threshold, q_L. If $q_I > q_L$, for $q > q_L$ licensing is a Pareto-improvement over imitation. Therefore,

Corollary 2. *Imitation is attempted by a manufacturer only if $q_I \leq q < q_L$.*

3 Backward Induction

We assume that the sequence of events is as follows.

- **Stage 0: Patent Policy** The government determines the strength of patent protection (denoted by α) and sets the imitation cost (f_I).
- **Stage 1: Capacity Building** Manufacturers choose whether to enter the market by investing in capacity. Each manufacturer incurs a fixed entry cost F and draws its production capacity q from a distribution $G(q)$.
- **Stage 2: Innovation** Innovators invest in R&D to develop a new patented good. The probability of a successful innovation depends on the level of investment, denoted by $\gamma(k)$.
- **Stage 3: Licensing and Imitation** Patent holders offer licenses to manufacturers for a fee (f_L), or manufacturers attempt to imitate the patented good at cost f_I.
- **Stage 4: Production and Sales** Manufacturers choose whether to produce generic goods, licensed patented goods, or imitated patented goods.

We solve for the equilibrium by backward induction.

3.1 Stage 4: Production and sales

At the time of production and sales, the predetermined variables are $q_I, q_L, m \equiv \frac{M}{N\gamma}, \alpha$.

Licensed manufacturers and successful imitators will use all of their capacity to produce the patented product. The price of a patented good is determined by $p(\tilde{Q})$, where

$$\widetilde{Q}(m,\alpha,q_L,q_I) = Q_L + Q_I = \left[\int_{q_L}^{q_{max}} qg(q)dq + \alpha \int_{\min(q_I,q_L)}^{q_L} qg(q)dq\right] m. \quad (1)$$

Generic good producers will use all of their capacity for generic goods production. Unsuccessful imitators will have no production (or their production is confiscated and destroyed).

We have:

$$\frac{\partial \widetilde{Q}}{\partial m} = \frac{Q}{m}, \; \frac{\partial \widetilde{Q}}{\partial \alpha} = \int_{\min(q_I,q_L)}^{q_L} qg(q)dq \quad (2)$$

$$\frac{\partial \widetilde{Q}}{\partial q_L} = \begin{cases} -\left(1-\alpha\right) q_L g(q_L)m, & \text{if } q_I < q_L \\ -q_L g(q_L) m & \text{if} q_I \geq q_L \end{cases} \quad (3)$$

3.2 Stage 3: Potential Imitation

The predetermined variables in this stage are $q_L, m \equiv \frac{M}{N\gamma}, \alpha$. Potential imitators also take the equilibrium supply of patented product, $\widetilde{Q}$, as given.

A manufacturer could imitate the patented product by incurring a fixed cost f_I. Therefore, the expected surplus from imitation (gross of overhead costs) are

$$\pi_I(q) = \alpha p(\widetilde{Q})q - f_I, \quad (4)$$

Moreover, the expected surplus from producing the generic good (gross of overhead costs) is

$$\pi_G(q) = q. \quad (5)$$

Therefore, imitation is preferred to generic good production iff $\alpha p_P(\widetilde{Q}) > 1$, and

$$q > q_I(p,\alpha) = \frac{f_I}{\alpha p(\widetilde{Q}) - 1}. \quad (6)$$

This threshold (q_I) is increasing in $\tilde{Q}$ and decreasing in α. There will exist an α_{min}, which is the solution to $\left(\alpha p(\widetilde{Q}) - 1\right) q_{max} = f_I$, such that there will be no potential imitators for $\alpha < \alpha_{min}$.

3.3 Stage 2: Licensing

The predetermined variables in this stage are m, α. At this stage, each patent holder is matched with $m = \frac{M}{N}$ manufacturing firms with a capacity distribution identical to the distribution of the manufacturers in the market, namely, $g(q)$. The licensing thresholds, q_L is determined at this stage.

The patent-holder will make a take-or-leave offer to firms to produce the product under license. The patent holder's offer will make the firm indifferent between accepting the offer and choosing its best outside option (in stage 4).

Assuming that f_L is borne by the licensee, the licensing fee, $T(q)$, that makes the manufacturer indifferent between licensing and its best outside option will be given by

$$T(q) = \min[(1-\alpha)p_P(\tilde{Q}_P)q + f_I - f_L, \left(p_P(\tilde{Q}) - 1\right) q - f_L]. \tag{7}$$

This may be also written as

$$T\left(q\right) = \begin{cases} \left(p(\tilde{Q}) - 1\right) q & \text{if } q \leq q_I \\ (1-\alpha)p(\tilde{Q})q + f_I & if q > q_I \end{cases}$$

$$R = m \int_{q_L}^{q_I} \left(p(\tilde{Q}) - 1\right) qg\left(q\right) dq + m \int_{q_I}^{q_{\max}} \left[(1-\alpha)p(\tilde{Q})q + f_I\right] g\left(q\right) dq$$

$$C = m \int_{q_L}^{q_{\max}} f_L g\left(q\right) dq$$

where $\widetilde{Q}(m, \alpha, q_L, q_I)$ is given by (1).

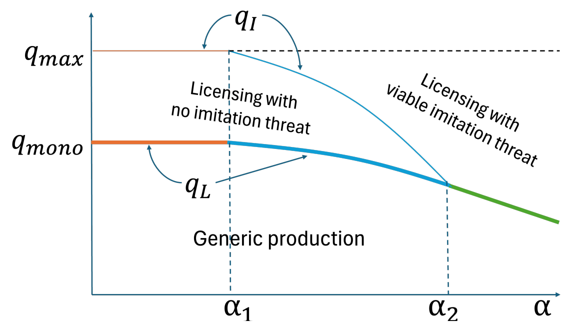
$T(q)$ is the licensing fee that the patent-holder would charge if it decides to grant a license to a manufacturer. Since the return to the patent holder from a license is increasing in q, the patent holder will choose to license all firms whose capacity exceeds a threshold value q_L. The threshold value will be chosen to yield the maximum profit for the patent holder

$$\tilde{\Pi}_P(M, \alpha) = max_{q_L} \Pi_P(q_L) = max_{q_L} \left[\int_{q_L}^{q_{max}} T\left(q\right) g(q) dq\right] m. \tag{8}$$

This is based on the assumption that patent holders recognize the effect of their licensing decisions on q_I.

Lemma 3. *For a given m and f_I, there are thresholds of α, namely, α_1 and α_2, such that*

Figure 2: Thresholds of licensing, imitation, and generic good production



For $\alpha < \alpha_1$, the innovator receives all the monopoly rents and, thus, it sets a licensing threshold to achieve the monopoly outcome.
For $\alpha \in [\alpha_1, \alpha_2]$, a marginal increase in production has a negative externality on infra-marginal manufacturers that is not taken into account by the innovator. Therefore, in this range, total output will be greater than the monopoly output.
Moreover, licensing threshold, q_L, is declining in α, because larger α implies that a greater share of the rent goes to the infra-marginal licensed manufacturers and, thus, the innovator has less motivation to limit production.

(i) For $\alpha < \alpha_1$, we have $q_I > q_{\max}$, which implies that the threat of imitation is not viable in equilibrium. In other words, all manufacturers strictly prefer generic-good production to imitation.

(ii) For $\alpha_1 \leq \alpha < \alpha_2$, we have $q_I > q_L$, and imitation is an off-equilibrium outcome. All manufactures with $q > q_I$ receive a licensing offer that makes them indifferent between imitation and licensing, which they accept. All manufacturers with $q \in (q_L, q_I)$ receive a licensing offer that makes them indifferent between imitation and generic good production. Manufacturers with $q < q_L$ do not receive any licensing offer and produce the generic good.

(iii) For $\alpha > \alpha_2$, we have $q_I = q_L$ and all manufacturers with $q \geq q_I = q_L$ receive a license.

There are three possible types of equilibria as related to imitation and licensing. First, if the cost of imitation is sufficiently high, we will have $q_I > q_{\max}$, in which case there will be no threat of imitation and, thus, the patent holder chooses licensing to produce the monopolistic quantity. A second type of equilibrium is one in which the threat of imitation is credible but imitation does not take place because all potential imitators receive a license to produce the patented product. Finally, we consider the possibility of an equilibrium where some manufacturers receive a license, some imitate, and some produce the generic good. This latter case will not occur if demand is elastic.

Equilibrium with off-equilibrium imitation Without loss of generality, suppose that the patent-holder pays for the licensing costs and charges the amount of quasi-rent that the manufacturer earns by obtaining a license. We then find the optimal licensing decision of the patent holder by setting its marginal revenues from licensing equal to its marginal cost of licensing.

The revenues that accrue to the patent-holder are given by

$$R = \int_{q_L}^{q_I} (p-1)\, qmg(q)\, dq + \int_{q_I}^{q_{\max}} \left((1-\alpha)\, pq + f_I\right) mg(q)\, dq$$

Assuming uniform distribution, $g(q) = \frac{1}{q_{\max}-q_{\min}}$, the revenues of the patent holder may be written as

$$R = \frac{m}{q_{\max}-q_{\min}} \left((p-1)\frac{q_I^2-q_L^2}{2} + (1-\alpha)\, p \frac{q_{\max}^2-q_I^2}{2} + f_I\left(q_{\max}-q_I\right) \right),$$

or, equivalently, as

$$R = (p-1)\, Q - \frac{m}{q_{\max}-q_{\min}} \left((\alpha p - 1)\frac{q_{\max}^2-q_I^2}{2} - f_I\left(q_{\max}-q_I\right) \right),$$

where we used $Q = \frac{m}{2}\frac{q_{\max}^2-q_L^2}{q_{\max}-q_{\min}}$ to simplify the expression.

Therefore, noting that $q_I = \frac{f_I}{\alpha p-1}$, $MR \equiv \frac{dR}{dQ}$ is given by

$$MR = MR_M - \alpha \frac{m}{q_{\max}-q_{\min}} \frac{q_{\max}^2-q_I^2}{2}\frac{dp}{dQ}$$

where, $MR_M = p\left(1-\frac{1}{\epsilon}\right)-1$ is the marginal revenue of a pure monopolist. The second term in the above expression is positive. Moreover, the second term is increasing in α because q_I is decreasing in α. On the other hand, marginal cost for the patent holder is given by

$$MC = \frac{f_L}{q_L}.$$

which is increasing in Q and independent of α. Therefore, an increase in α increases Q, or equivalently, reduces q_L in equilibrium.

For further use, we write the patent-holder's optimality condition ($MR =$

MC) as follows:

$$p\left(1-\frac{1}{\epsilon}\right)-1+\alpha\frac{mg}{2}\left(q_{\max}^2-q_I^2\right)\frac{p}{Q}\frac{1}{\epsilon}=\frac{f_L}{q_L}. \tag{9}$$

where, $g=\frac{1}{q_{\max}-q_{\min}}$.

Equilibrium with on-equilibrium imitation Imitation in equilibrium will take place if and only if $q_L > q_I \equiv \frac{f_I}{\alpha p(Q)-1}$, where $Q = Q_L + Q_I$. Assuming uniform distribution, the patent-holder's revenues under this condition (*i.e.*, $q_L > q_I$) are given by

$$\begin{aligned} R &= mg\int_{q_L}^{q_{\max}}\left(\left(1-\alpha\right)pq+f_I\right)dq \\ &= \left(1-\alpha\right)pQ_L+\frac{m}{q_{\max}-q_{\min}}f_I\left(q_{\max}-q_L\right). \end{aligned}$$

It can be shown that

Lemma 4. *If demand is elastic, there will be no imitation in equilibrium.*

Proof. The marginal revenues may be written as

$$\begin{aligned} \frac{dR}{dQ_L} &= \left(1-\alpha\right)p+\left(1-\alpha\right)Q_L\frac{dp}{dQ}\frac{dQ}{dQ_L}-mgf_I\frac{dq_L}{dQ_L} \\ &= \left(1-\alpha\right)p\left(1-\frac{Q_L}{Q}\frac{1}{\epsilon}\left(1+\frac{dQ_I}{dQ_L}\right)\right)-mgf_I\frac{dq_L}{dQ_L} \end{aligned}$$

Noting $\frac{dQ_L}{dq_L}=-mgq_L$, we have

$$\frac{dR}{dQ_L}=\left(1-\alpha\right)p\left(1-\frac{Q_L}{Q}\frac{1}{\epsilon}\left(1+\frac{dQ_I}{dQ_L}\right)\right)+\frac{f_I}{q_L}$$

Noting that $\frac{Q_L}{Q}\frac{1}{\epsilon}\left(1+\frac{dQ_I}{dQ_L}\right)<1$ because $Q_L<Q$, $\epsilon>1$, and $-1<\frac{dQ_I}{dQ_L}<0$, in this region we have

$$\frac{dR}{dQ_L}>\frac{f_I}{q_L}>MC.$$

Therefore, a sufficient condition for the above expression to be less than the marginal cost, $\frac{f_L}{q_L}$, is $\epsilon>1$. Therefore, □

3.4 Stage 2: R&D decision

At this stage, the predetermined variables are m, α. Given (m, α), the innovator chooses the level of k to maximize,

$$\gamma(k)\tilde{\Pi}_P(m, \alpha) - k \tag{10}$$

Note that $m = \frac{M}{\gamma N}$ but we assume that innovators do not consider the effect of their innovation on m. The FOC for optimality of the R&D decision is

$$\gamma'(k)\,\tilde{\Pi}_P(m, \alpha) = 1. \tag{11}$$

We denote the optimal investment in innovation by $k(\tilde{m}, \alpha)$, where $\frac{dk}{dm} = -\frac{\gamma'}{\gamma"}\frac{d\tilde{\Pi}}{dm}$ and $\frac{dk}{d\alpha} = -\frac{\gamma'}{\gamma"}\frac{d\tilde{\Pi}}{d\alpha}$.

3.5 Stage 1: Firm entry decision

Given our assumption that each patent holder is matched with an equal fraction of the distribution of manufacturers, we can write the free entry condition for manufacturers using m, rather than M, as the equilibrium variable. The optimal R&D investment, k, and the number of innovators who successfully get a patent, $\gamma(k)N$, will then be determined as a function of m.

Given α, the measure of firms is determined as the value that makes the firm indifferent between bearing the fixed cost to enter and not entering. The expected return from entry will be

$$E\pi_F(m) \equiv \int_{\tilde{q}_I}^{q_{max}} (\alpha\tilde{p}_P q - f_I)\, g(q)dq + \int_{q_{min}}^{\tilde{q}_I} qg\,(q)\,dq - F.$$

Assuming uniform distribution, the zero-profit condition for manufacturers, $E\pi_F(m)$, may be written as

$$\alpha\tilde{p}\frac{\left(q_{\max}^2 - \tilde{q}_I^2\right)}{2} - f_I\left(q_{\max} - \tilde{q}_I\right) + \frac{\tilde{q}_I^2 - q_{\min}^2}{2} = \frac{F}{g}. \tag{12}$$

In equilibrium this must be zero. So the mass of entrants, M, in equilibrium will satisfy $E\pi_F(M) = 0$.

3.6 Equilibrium

Let's consider equilibrium for the case where there is no imitation in equilibrium. Equilibrium entry (m) and licensing threshold (q_L) is determined jointly by the optimal licensing condition 9 and the manufacturer's zero-profit condition 12, namely,

$$\alpha p \frac{\left(q_{\max}^2 - q_I^2\right)}{2} - f_I \left(q_{\max} - q_I\right) + \frac{q_I^2 - q_{\min}^2}{2} = \frac{F}{g},$$

and

$$p\left(1 - \frac{1}{\epsilon}\right) - 1 + \alpha \frac{mg}{2}\left(q_{\max}^2 - q_I^2\right)\frac{p}{Q}\frac{1}{\epsilon} = \frac{f_L}{q_L},$$

respectively. To interpret these conditions, recall that p is the inverse demand function, $Q = \frac{mg}{2}\left(q_{\max}^2 - q_L^2\right)$ is total production (of one patented product), $q_I = \frac{f_I}{\alpha p - 1}$.

The above conditions determine m and q_L. We can then find the equilibrium level of investment in R&D, k, by entering the equilibrium value of m into the optimal R&D condition,

$$\gamma'(k)\,\tilde{\Pi}_P(m,\alpha) = 1.$$

Note that the optimal R&D condition is decoupled from the other two equilibrium conditions.

4 Patent policy for maximum innovation

We now show that the rate of innovation is not monotonic in the strength of patent protection. In particular, we show that when patent protection is so strong that there is no threat of imitation, i.e., when $\alpha \leq \alpha_1$, then relaxing the patent enforcement slightly to allow for the possibility of imitation would increase the expected profits of the potential innovators. Formally,

Proposition 5. *At $\alpha = \alpha_1$, the expected profits of a potential patent-holders are increasing in α.*

Therefore, since $1-\alpha$ reflects the strength of patent protection, a reduction in patent protection improves the incentive to innovate in equilibrium. Intuitively, when $\alpha = \alpha_1$.

Proof. Recall that revenues of a patent-holder are given by □

$$R = (p-1)\frac{mg}{2}\left(q_{\max}^2 - q_L^2\right) - mg\left((\alpha p - 1)\frac{q_{\max}^2 - q_I^2}{2} - f_I\left(q_{\max} - q_I\right)\right)$$

and the associated costs are

$$\begin{aligned} C\left(q_L\right) &= mg\int_{q_L}^{q_{\max}} f_L dq \\ &= mg f_L\left(q_{\max} - q_L\right). \end{aligned}$$

Therefore, profits are given by

$$\pi_p = mg\left[\frac{(p-1)}{2}\left(q_{\max}^2 - q_L^2\right) - (\alpha p - 1)\frac{q_{\max}^2 - q_I^2}{2} + f_I\left(q_{\max} - q_I\right) - f_L\left(q_{\max} - q_L\right)\right].$$

where, $q_I = \frac{f_I}{\alpha p - 1}$.

Using envelope theorem, the derivative of the maximized profit with respect to α is given by

$$\begin{aligned} &\frac{dm}{d\alpha}g\left[\frac{(p-1)}{2}\left(q_{\max}^2 - q_L^2\right) - (\alpha p - 1)\frac{q_{\max}^2 - q_I^2}{2} + f_I\left(q_{\max} - q_I\right) - f_L\left(q_{\max} - q_L\right)\right] \\ &+ mg\left(-p\frac{q_{\max}^2 - q_I^2}{2} + \cancel{\left((\alpha p - 1)q_I - f_I\right)\frac{\partial q_I}{\partial \alpha}}\right) \end{aligned}$$

For $\alpha < \alpha_1$, profits are independent of α. For $\alpha = \alpha_1$, $q_I = q_{\max}$ and thus the above expression may be written as

$$\frac{dm}{d\alpha}g\left[\frac{(p-1)}{2}\left(q_{\max}^2 - q_L^2\right) - f_L\left(q_{\max} - q_L\right)\right].$$

Using the free-entry condition, we show that $\frac{dm}{d\alpha} > 0$. Therefore, profits are increasing in α at $\alpha = \alpha_1$. Since profits are the same for $\alpha \leq \alpha_1$, it follows that the patent holder's profits are maximized at an $\alpha > \alpha_1$.

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