

Innovation, Imitation and Competition*

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Abstract

In a general equilibrium framework, it is known that imitation may actually promote innovation (Aghion et al., 1997). The same effect is demonstrated with a standard oligopoly model in which one firm has the ability to develop technologies while all other firms imitate and obtain a fraction of it for free. Competition is shown to dampen innovation, while imitation may stimulate it if imitation is strong and competition moderate. The findings have implications for policy toward intellectual property rights protection, as weak protection may promote rather than impede technology innovation.

KEYWORDS: innovation, imitation, competition, intellectual property protection

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1 Introduction

Endogenous growth theory regards technological innovation as the engine of economic growth. Since a firm's innovations may be imitated by other firms, an important question is whether imitation will hinder or strengthen the incentive to innovate. One argument, which can be traced to Schumpeter, is that imitation reduces the reward for developing new technologies and therefore must dampen innovation. However, another argument, commonly attributed to Arrow (1962), is that the effect is not so clear. Imitation (or more generally, product market competition) reduces a firm's profit if it does not innovate. Thus, imitation may serve as a "stick" in stimulating innovation.

Aghion et al. (1997) demonstrated that indeed such a stimulation may prevail and, as a result, imitation can be growth-enhancing. They suggest that the incentive to innovate is related to the difference between a firm's pre-innovation and anticipated post-innovation profits. When imitation is stronger, a firm's profits are reduced both before and after any innovation. If the pre-innovation profits are reduced more than the post-innovation profits, the difference will rise and, as a result, the firm may engage in more innovation. Intuitive and powerful as the argument is, alone it is not enough to generate Aghion et al.'s anticipated result because, in that model, any single firm's innovation is still reduced by imitation. The positive effect of imitation on growth is through a "composition effect"—imitation pushes more industries into neck-and-neck competition, which generates more innovation activity than when one firm in an industry is lagging behind the other. In other words, imitation stimulates innovation only in a general equilibrium framework. One wonders whether such an effect can be found in a partial equilibrium framework. This study applied a standard industrial organization model in an attempt to show that indeed imitation may stimulate innovation.

In the model, several firms produce a homogeneous product and engage in Cournot competition. Firms' costs can be reduced by technologies developed before they compete in the product market. Only one firm has the ability to innovate; all the other firms are imitators. Innovation is modeled as developing a technology at some cost, while imitators obtain some fraction of the innovator's technology for free. In a two-stage game, the innovator first chooses the level of technology, which is imitated by its competitors instantly. Then all firms engage in Cournot competition in the product market. The study investigates how the technology chosen by the innovator is affected by the intensity of imitation and competition.

In choosing its technology level, the innovator faces the following tradeoff. A more advanced technology reduces its own cost, which is beneficial. This

is the direct effect. Due to imitation, however, the technology also reduces its competitors' costs, which is detrimental to the innovator. This is the indirect effect. The optimal level of technology therefore balances the two effects against the cost of developing technologies.

As imitation becomes stronger, the direct effect is weakened because imitators are now stronger and therefore more aggressive in competition. The residual demand faced by the innovator becomes smaller, reducing his marginal benefit from any cost reduction. The indirect effect, on the other hand, may be strengthened or weakened by stronger imitation, depending on the current level of imitation. When imitation is already strong, further strengthening imitation will weaken the indirect effect both because the technology reduces imitators' costs at a decreasing rate, and because imitators' strength reduces the innovator's profit at a decreasing rate. It is possible that the weakening of the indirect effect might outweigh the weakening of the direct effect, leading the innovator to choose a higher level of technology when imitation is stronger. This happens when imitation is already strong and competition (as measured by the number of imitators) is moderate. The impact of competition has been analyzed in a similar way, and the conclusion is that competition always dampens innovation.

Investigating how imitation affects innovation is important because it has policy implications about intellectual property rights (IPR) protection. The conventional wisdom is that innovators' profits must be protected, usually through a legal monopoly, for them to have enough incentive to develop technologies. In such a world, imitation discourages innovation because it reduces its rewards, hence the rationale for enforcing IPR. This view has been challenged by several researchers. Aghion et al. (2001) and Aghion et al. (2005) argue that stronger imitation may lead to more innovation because incumbents suffer more if they do not innovate. Helpman (1993) has shown how, by affecting the North-South division of labor, weak IPR protection in the South can improve world welfare. Imitation allows southern firms to concentrate on production using northern technologies, which in turn allows northern firms to concentrate on innovation. Bessen and Maskin (2007) stress the importance of market failure in understanding the role of IPR enforcement. They demonstrate that if technologies display externalities which cannot be internalized through contracts, strong IPR protection can slow down rather than facilitate technological progress. Finally, Che et al. (2009) have shown that, when a country suffers from some forms of market failure, weak IPR enforcement allows copycats to fill market vacancies left by multinationals. The increased social surplus can then be shared by the multinationals, which ultimately leads to more innovation.

This study arrives at the same conclusion—that imitation may stimulate innovation—but for a different reason: When imitation is strong, the innovator derives a smaller benefit from its own cost reduction, but it also suffers less damage from imitators' cost reductions. The second effect may dominate so that the incentive to innovate is enhanced. This explanation is related to, but distinct from, that developed by Aghion et al. (1997), Aghion et al. (2001) and Aghion et al. (2005), for it is demonstrated in a typical industrial organization setting. The conclusion has a clear policy implication: Weak IPR protection may not only increase *ex post* social surplus by encouraging product market competition, but it may also increase *ex ante* social surplus by encouraging innovation.

In this study, technology imitation was modeled as a free transfer of part of the innovator's technology to non-innovators. Such a setting is similar to that adopted in industrial organization studies of R&D cooperation (D'Aspremont and Jacquemin, 1988). Nevertheless, the objective of this study and the driving force behind the conclusions were both very different. The connection of this study to the literature as well as the robustness of the findings will be discussed in the concluding remarks.

2 The Model

A set, N , of firms produce a homogenous product and compete *à la* Cournot. Demand is linear: $p = a - bQ$ with $Q = \sum_{i \in N} q_i$ and $a, b > 0$. Following Perry and Porter (1985) and McAfee and Williams (1992), I assume that firm i 's production cost is $C_i = C(q_i, k_i) \equiv \frac{q_i^2}{2k_i}$, where q_i is the production quantity and k_i measures the firm's technology level (or knowledge capital). Innovation is modeled as an improvement in k_i . Unlike most models in growth and R&D cooperation that assume constant marginal costs, this one assumes that marginal costs increase with production quantity. Such a cost structure is a natural way to model technology innovation that affects production costs because it can be derived as a short-run cost from a Cobb-Douglas production function with a variable input such as labor and a fixed input in the form of technology represented by k_i .¹ In fact, the analysis will show that the results still hold when marginal costs are constant with respect to quantity.

¹Suppose that all firms possess the same constant-returns-to-scale production function $q = (kl)^{\frac{1}{2}}$, in which k is technology (or alternatively knowledge capital) as an input, and l is labor input. In the short run when its technology is fixed at k_i , firm i 's variable cost is $C_i \equiv \min_{l_i} w l_i$ subject to $q_i = (k_i l_i)^{\frac{1}{2}}$, in which w is the wage rate. The minimum cost is $\frac{w}{k_i} q_i^2$. If $w = \frac{1}{2}$, the assumed cost function obtains.

Given the vector of technologies, $\mathbf{k} \equiv \{k_i\}_{i \in N}$, the Cournot equilibrium can be derived as follows (see McAfee and Williams, 1992). Let $g_i = \frac{bk_i}{1+bk_i}$ and $G = \sum_{i \in N} g_i$. Thus, g_i represents the (competitive) strength of firm i . It is increasing and concave in i 's technology level, k_i , with $\lim_{k_i \rightarrow \infty} g_i = 1$. Firm i 's Cournot profit is then

$$\pi_i = \frac{a^2 g_i (1 + g_i)}{2b(1 + G)^2}.$$

It is evident that normalizing $a \equiv 1$ does not entail any loss of generality. Furthermore, because b is a fixed coefficient in π_i and it always appears together with k_i in g_i , we can also normalize $b \equiv 1$ by appropriately choosing the measurement unit of k_i . Note that $\frac{\partial \pi_i}{\partial g_i} > 0$ while $\frac{\partial \pi_i}{\partial g_j} < 0$ for $j \neq i$. That is, a firm's profit increases with its own strength and decreases with its competitors' strengths.

N consists of $n + 1$ firms. One of them is the innovator, and all the other n ($n \geq 0$) firms are imitators. For any level of the innovator's technology, k , assume each of the imitators obtains a fraction, β , of the technology for free. The coefficient $\beta \in [0, 1]$ measures the degree of technology imitation, while n measures the degree of competition.² There is no time delay in imitation, so if an innovation reduces the innovator's cost, the costs of all its competitors are also reduced instantly.

Given k , the innovator's profit in the product market is

$$\pi(k) = \frac{g(1 + g)}{2(1 + g + nh)^2},$$

where $g = g(k) = \frac{k}{1+k}$ is the innovator's strength, and $h = h(\beta, k) = \frac{\beta k}{1+\beta k}$ is each imitator's strength.

The innovation game is played as follows. The innovator chooses its technology level k at cost $r(k)$, with $r'(\cdot) \geq 0$, $r'(0) = 0$ and $r''(\cdot) \geq 0$. The chosen technology is immediately imitated by the n imitators, after which all the $n + 1$ firms play a Cournot game in the product market. The innovator therefore solves the following problem:

$$\max_{k \geq 0} \pi(k) - r(k).$$

The optimal level of technology, k^* , is solved from the first-order condition:

$$\pi'(k^*) - r'(k^*) = 0,$$

²In the growth literature, the intensity of competition is usually measured by the substitutability between two firms' products, which is a taste parameter (Aghion et al., 2001).

as the second-order condition is always satisfied: $\pi''(k) < 0$ whenever $\pi'(k) \geq 0$, while $r''(\cdot) \geq 0$. Note that $\pi'(0) = \frac{1}{2}$ so $\pi'(0) - r'(0) > 0$, and $\lim_{k \rightarrow \infty} \pi'(k) = 0$. As a result, k^* exists and is unique.

Denote $\pi(k)$ by $\pi(g(k), h(\beta, k), n)$. Then,

$$\pi'(k) \equiv \frac{d\pi}{dk} = \frac{\partial \pi}{\partial g} g'(k) + \frac{\partial \pi}{\partial h} \frac{\partial h}{\partial k}.$$

It has been noted above that $\frac{\partial \pi}{\partial g} > 0$ and $\frac{\partial \pi}{\partial h} < 0$, while $g'(k) = \frac{1}{(1+k)^2} > 0$ and $\frac{\partial h}{\partial k} = \frac{\beta}{(1+\beta k)^2} > 0$. Thus, the innovator faces the following tradeoff in choosing its technology level. On one hand, innovation reduces its own cost and should therefore increase its profit. This is the direct effect (when the imitators' costs are fixed), which is captured by the term $\frac{\partial \pi}{\partial g} g'(k)$, which is positive. On the other hand, imitation means the innovator's technology also reduces its competitors' costs, which tends to decrease the innovator's profit. This is the indirect effect, which is captured by the term $\frac{\partial \pi}{\partial h} \frac{\partial h}{\partial k}$, which is negative. Because the two effects work in opposition, the net effect depends on the parameter values.

Denote $\pi'(k)$ by v . Given the expression for $\pi(k)$,

$$\begin{aligned} v &= \frac{\partial \pi}{\partial g} g'(k) + \frac{\partial \pi}{\partial h} \frac{\partial h}{\partial k} \\ &= \frac{(1+g) + nh(1+2g)}{2(1+g+nh)^2} \frac{1}{(1+k)^2} - \frac{ng(1+g)}{(1+g+nh)^3} \frac{\beta}{(1+\beta k)^2} \\ &= \frac{(1+\beta k) \{n\beta k[(k+3k^2)\beta - (4k^2+3k+1)] + (1+\beta k)^2(1+2k)\}}{2[(1+\beta k)(1+2k) + n\beta k(1+k)]^3}. \end{aligned}$$

Note that, for a given β and k , $v \geq 0$ if and only if $n \leq n_1$, where

$$n_1 \equiv \frac{(1+2k)(1+\beta k)^2}{\beta k[(4-3\beta)k^2 + (3-\beta)k + 1]} > 0.$$

Also note that k should be endogenous, but whenever $v(k^*) \geq 0$, there is an $r(k)$ function that yields the particular k^* as the k that is optimally chosen. Thus, $n \leq n_1$ is a necessary condition at the optimal k^* because $v(k^*) \geq 0$ must be satisfied.

3 How Imitation Affects Innovation

We are interested in how imitation affects the innovator's optimal choice of technology, i.e., how β affects k^* . The optimal technology k^* is determined

from the first-order condition: $v(k^*(\beta, n), \beta, n) - r'(k^*(\beta, n)) = 0$. Taking derivative with respect to β yields $(\frac{\partial v}{\partial k} - r'') \frac{\partial k^*}{\partial \beta} + \frac{\partial v}{\partial \beta} = 0$. Because $\frac{\partial v}{\partial k} - r'' < 0$ (the second-order condition), the sign of $\frac{\partial k^*}{\partial \beta}$ is the same as the sign of $\frac{\partial v}{\partial \beta}$.

To determine the impact of β , we are interested in the sign of $\frac{\partial v}{\partial \beta}$ when $v \geq 0$. It has already been established that $v \geq 0$ if and only if $n \leq n_1$. Similarly, $\frac{\partial v}{\partial \beta} \geq 0$ if and only if $n \geq n_2$, where

$$n_2 \equiv \frac{(1+2k)(1+\beta k)[-2\beta k^3 + (2-3\beta)k^2 + 3k+2]}{\beta k(1+k)(2\beta k^3 + 4k^2 + 3k+1)}.$$

When $\beta \geq \frac{4k^2+3k+1}{k(4k^2+9k+3)}$, $n_1 \geq n_2$ and therefore the set $[n_2, n_1]$ is not empty. Figure 1 shows v as a function of β when $n = 1$ and $k = 3$. It is clear that v decreases with β when β is small, but increases with β when β is large. Thus, *when imitation is weak, imitation dampens innovation; when imitation is strong and competition moderate, imitation may stimulate innovation.*

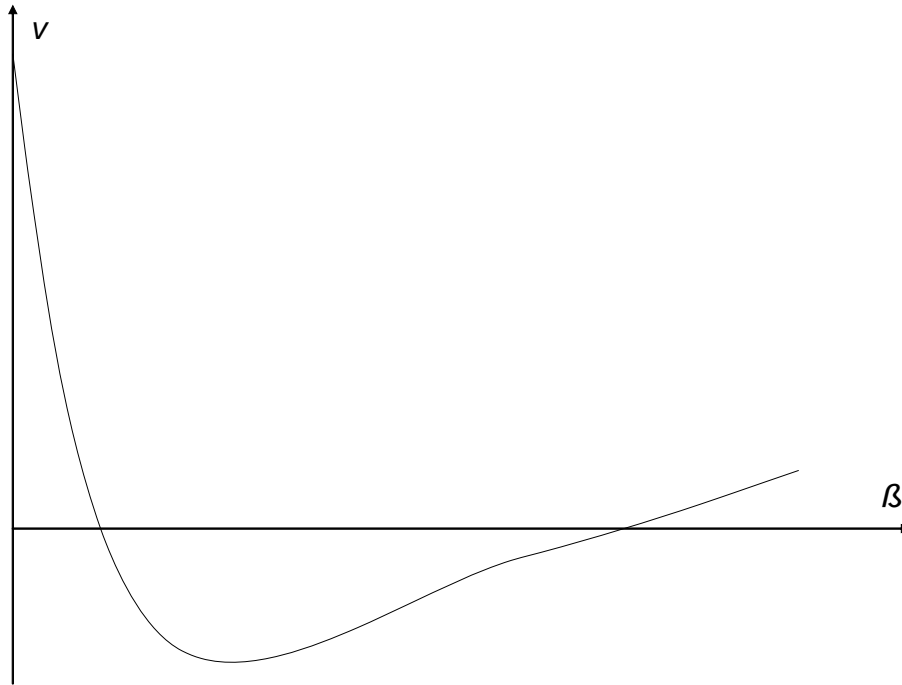


Figure 1: v as a function of β ($n = 1$, $k = 3$)

The intuition works as follows. Re-write v as

$$v = \overbrace{\frac{\partial \pi}{\partial g}(g(k), h(\beta, k))g'(k)}^{\text{direct effect}} + \overbrace{\frac{\partial \pi}{\partial h}(g(k), h(\beta, k))\frac{\partial h}{\partial k}(\beta, k)}^{\text{indirect effect}}$$

$(+)$ $(+)$ $(-)$ $(+)$

to highlight how β affects various terms in the expression. Recall that v is the innovator's marginal benefit of technology. It consists of two effects. The first term represents the direct effect, which is the benefit of innovation when imitators' costs are fixed. The second term is the indirect effect, which is the damage to the innovator arising from the reduction in the imitators' costs. For the impact of β on k^* , take the derivative with respect to β :

$$\frac{\partial v}{\partial \beta} = \overbrace{\frac{\partial^2 \pi}{\partial g \partial h} \frac{\partial h}{\partial \beta} g'(k)}^{\text{direct effect}} + \overbrace{\frac{\partial^2 \pi}{\partial h^2} \frac{\partial h}{\partial \beta} \frac{\partial h}{\partial k} + \frac{\partial \pi}{\partial h} \frac{\partial^2 h}{\partial k \partial \beta}}^{\text{indirect effect}}$$

$(-)$ $(+)$ $(+)$ $(+)$ $(+)$ $(-)$ $(?)$

The first term in the expression describes how β affects the direct effect. It is related to $\frac{\partial^2 \pi}{\partial g \partial h} = -\frac{n[1-g^2+nh(1+2g)]}{(1+g+nh)^4} < 0$. When imitators are stronger (h is larger), they compete more aggressively in the product market. As a result, the residual demand faced by the innovator is smaller, reducing his benefit from the technology. So stronger imitation weakens the direct effect.

The second and third terms in the expression for $\frac{\partial v}{\partial \beta}$ capture how β affects the indirect effect, and the impact is reflected in how the imitators' strengths damage the innovator (the second term) and how technology strengthens the imitators (the third term). For the second term, note that $\frac{\partial^2 \pi}{\partial h^2} = \frac{3g(1+g)n^2}{(1+g+nh)^4} > 0$, which means that although the imitators' strengths reduce the innovator's profit ($\frac{\partial \pi}{\partial h} < 0$), they do so at a diminishing rate. When imitation is stronger, h is higher, so the negative impact on the innovator's profit diminishes. For the third term, $\frac{\partial^2 h}{\partial k \partial \beta} = \frac{1-\beta k}{(1+\beta k)^3}$, which can be positive or negative depending on the value of βk . Note that $h = \frac{\beta k}{1+\beta k}$ is the strength of each imitator, and $\frac{\partial h}{\partial k} > 0$ measures how the innovator's technology enhances him. When the imitator's current level of technology (βk) is low, the enhancement increases with β ; when the imitator's technology is already high, the enhancement decreases with β . To see the net effect, note that the second term is proportional to βk . So when βk is very small, the second term is close to zero while the third term is negative. As a result, stronger imitation exacerbates the indirect effect. Conversely, when βk is large, the terms reinforce each other, and stronger imitation lessens the indirect effect.

In summary, β affects an innovator's choice of technology through both direct and indirect effects. A larger β always weakens the direct effect, and it weakens the indirect effect when β is high. It is possible that the impact on the indirect effect dominates so that the net benefit of innovation increases when imitation is strong, leading to a higher level of technology. This happens when competition is neither too strong nor too weak. When competition is strong (i.e., n is large), the marginal benefit of technology is negative. There are so many competitors waiting to imitate the technology that a wise innovator will refuse to adopt any technology even if it is free. When competition is weak (i.e., n is small), the impact of β on the direct effect dominates, so stronger imitation leads to lower levels of technology.

4 How Competition Affects Innovation

For the impact of competition on innovation, i.e., how n affects k^* , the same method can be applied to show that the sign of $\frac{\partial k^*}{\partial n}$ is the same as the sign of $\frac{\partial v}{\partial n}$. It has been explained that $v \geq 0$ if and only if $n \leq n_1$. It can also be shown that $\frac{\partial v}{\partial n} \geq 0$ if and only if $n \geq n_3$, where

$$n_3 \equiv \frac{(1+2k)(1+\beta k)[2k^2 + (3+\beta)k + 2]}{\beta k[(4-3\beta)k^2 + (3-\beta)k + 1]}.$$

It is straightforward to verify that $n_1 < n_3$. Therefore, whenever $v > 0$, $\frac{\partial v}{\partial n} < 0$. That is, *competition always dampens innovation*. A typical graph of v as a function of n is shown in Figure 2.

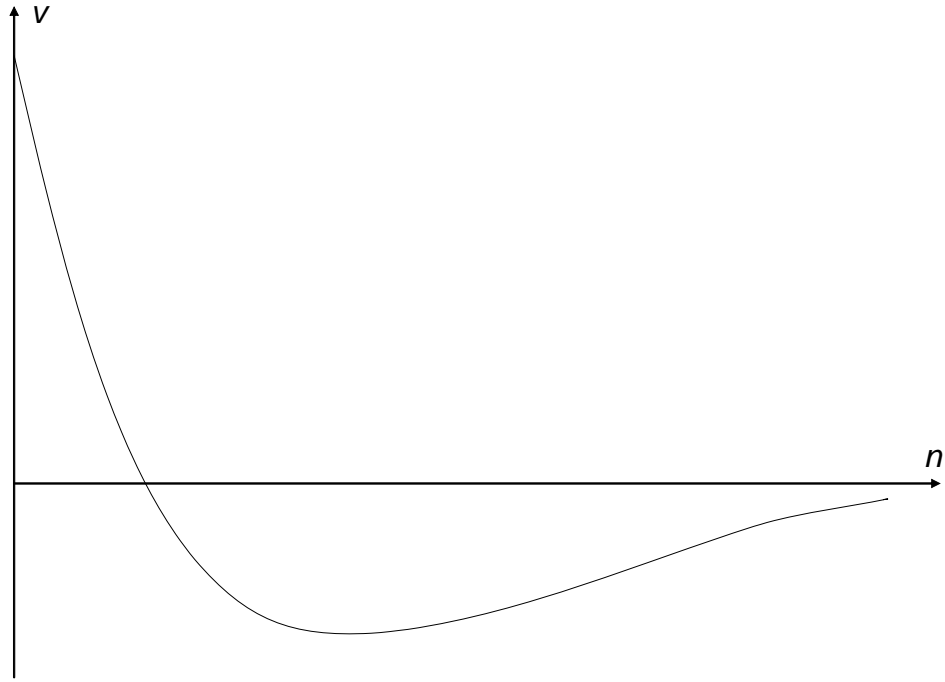
To understand the intuition, re-write v as

$$v = \frac{\partial \pi}{\partial g}(g(k), h(k), n)g'(k) + \frac{\partial \pi}{\partial h}(g(k), h(k), n)\frac{\partial h}{\partial k}(k).$$

Then

$$\frac{\partial v}{\partial n} = \underbrace{\frac{\partial^2 \pi}{\partial g \partial n} g'(k)}_{(-)} + \underbrace{\frac{\partial^2 \pi}{\partial h \partial n} \frac{\partial h}{\partial k}}_{(+)}.$$

The first term above captures the direct effect. $\frac{\partial \pi}{\partial g}$ is the innovator's marginal benefit from its own strength. When there is more competition (n is larger), the marginal benefit becomes smaller: $\frac{\partial^2 \pi}{\partial g \partial n} = -\frac{h[1-g^2+nh(1+2g)]}{(1+g+nh)^4} < 0$. The second term captures the indirect effect. $\frac{\partial \pi}{\partial h}$ measures how much the innovator suffers from the competition from imitators, and $\frac{\partial^2 \pi}{\partial h \partial n} = \frac{g(1+g)(2nh-1-g)}{(1+g+nh)^4}$ can be either positive or negative depending on n . When n is small, the innovator

Figure 2: v as a function of n ($\beta = \frac{1}{2}$, $k = 3$)

sustains a large share of the competitive pressure, so increased competition (due to a larger n) means the innovator suffers much of it. When n is large, however, the competition falls mainly on the imitators themselves and the innovator feels increased competition less.

So the direct effect (the innovator benefits from the technology through the drop in its own cost) is always weakened by increased competition, but the indirect effect (the innovator's reduced profits from the drop in its competitors' costs) may be either strengthened or weakened depending on the initial level of competition. In the context assumed here, the introduction of new technology indicates that competition must not be very strong, otherwise the innovator would not have chosen to implement new technology. It turns out that whenever a new technology is developed, the competition must have been so weak (i.e., n is small enough) that the incentive to innovate is reduced by increased competition. As a result, the innovator will choose a lower level of technology when competition intensifies.

5 Concluding Remarks

This analysis has shown that imitation may stimulate rather than dampen innovation. When imitation is easy, an innovator derives less benefit from its own cost reductions, but it may also suffer less damage from imitators' cost reductions. When imitation is strong and competition moderate, the second effect may dominate so that the marginal benefits from technology increases when imitation becomes stronger, leading to a higher level of technology.

Because the degree of imitation can be affected in part by the enforcement of intellectual property rights (IPR), the conclusion has implications for optimal IPR policy. Conventional wisdom advocates strong IPR protection because imitation is thought to damage innovation. Such thinking equates the innovator's profit with the incentive to innovate. As Arrow (1962) and Aghion et al. (1997) have pointed out and as has been shown in this analysis, the two can be very different. The innovator may suffer from stronger imitation, and yet at the same time the incentive to innovate may become stronger rather than weaker. Thus, if the government's goal is to stimulate innovation,³ Figure 1 suggests that the government should strengthen IPR protection when it is already strong. But, if IPR protection is weak, a government seeking to encourage innovation should weaken it further.

Of course, for such an IPR policy to be taken seriously, more thorough investigations are needed. This model is highly specific and merely points out a possibility. It may be useful, though, to ponder for a moment the robustness of the conclusions. In this model, there was only one innovator, all imitators were identical, imitation was instantaneous and free, and marginal costs were assumed increasing. None of these assumptions is crucial. If there were more than one innovator, the basic forces would still act as long as the firms fall into two distinctive groups: innovators and imitators. The symmetry of imitators is obviously a simplifying assumption; all the expressions can easily be modified to accommodate asymmetric imitators. Similarly, imitation costs can be incorporated into the model without changing the qualitative results.

As for the possibility of a time delay in imitation, note that imitation stimulates innovation when imitation weakens the indirect effect more than it weakens the direct effect. If imitation takes time, the direct effect is still instantaneous, but the indirect effect will not be felt immediately. This would tend to reduce the instantaneous marginal benefit of technology, but it is

³If the goal is dynamic social welfare combining *ex post* welfare from the product market and *ex ante* welfare from innovation, even weaker protection of IPR is called for, as the product market welfare decreases unambiguously with the degree of protection: a larger β always increases product market welfare at any given level of the innovator's technology.

unlikely that the forces identified in this analysis would disappear completely. In a dynamic model, although the marginal benefits of technology may be reduced at first, they may rise over time when imitation picks up strength. It is unclear how a time delay in imitation would alter the overall technology level. The purpose of this analysis is to highlight the possibility, in a standard industrial organization setting, that imitation may stimulate innovation, and to identify the driving force of the stimulus. Such a static model with its comparative static results should serve as the first step in understanding the relationship between imitation and innovation in a dynamic and more complete model.

In almost all industrial organization and growth models of R&D and innovation, marginal costs are assumed to be constant. It is therefore useful to consider whether the conclusions of this study still hold when marginal costs are constant. Assume that the innovator's marginal cost is $\frac{c}{k}$ while an imitator's marginal cost is $\frac{c}{\beta k}$, where c is a constant. For demand $p = a - bQ$, the innovator's Cournot profit $\pi = \frac{1}{b} \left(\frac{a + \frac{c}{k} + \frac{nc}{\beta k}}{n+2} - \frac{c}{k} \right)^2$. As previously, $v \equiv \frac{\partial \pi}{\partial k} \geq 0$ if and only if $n \leq n_1 \equiv \frac{\beta}{1-\beta}$, $\frac{\partial v}{\partial \beta} \geq 0$ if and only if $n \leq n_2 \equiv \frac{\beta}{2(1-\beta)} \left(2 - \frac{a}{c}k \right)$, and $\frac{\partial v}{\partial n} \geq 0$ if and only if $n \leq n_3 \equiv \frac{2\beta}{1-\beta} \frac{\frac{a}{c}k + \beta - 2}{\frac{a}{c}\beta k + 2\beta - 4}$. It turns out that $n_1 > n_2$, but $n_1 < n_3$. Thus, exactly the same conclusion is reached: While competition dampens innovation, imitation stimulates innovation when competition is moderate. So, if anything, assuming constant marginal costs makes the conclusion even stronger: For imitation to be conducive to innovation, imitation does not have to be strong to begin with. The conclusion holds for any level of imitation as long as competition is neither too strong nor too weak.

Although the assumption of increasing marginal costs is not crucial to the conclusions, it has several advantages over the setting in which marginal costs are constant. With the natural interpretation of k as knowledge, the cost structure is particularly suitable for studying innovation. Unlike in the case of constant marginal cost, there is no need to assume boundary conditions about how much knowledge a firm may possess.⁴ With knowledge as a stock, innovation as a flow, and imitation as delivering a fraction of the innovator's knowledge for free,⁵ the model can easily be extended to study the dynamics

⁴Since cost cannot be negative, there must either be an upper limit to the total amount of innovation, or the reduced cost must be non-linear and asymptotically approaching zero or some positive level.

⁵In this model, imitation yields a fraction of the stock (of knowledge), while Mookherjee and Ray (1991) considered diffusion as yielding a fraction of the flow (of cost reduction). That is why Mookherjee and Ray need dynamics (tomorrow's cost is a reduction of today's

of the accumulation, diffusion and erosion (i.e., forgetting) of knowledge.

This enquiry is closely related to industrial organization studies of R&D cooperation, which were pioneered by D'Aspremont and Jacquemin (1988) followed by Kamien et al. (1992), Suzumura (1992), and Ziss (1994), to name just a few. These scholars investigate whether the government should allow R&D cooperation between competing firms when their R&D investments spill over to one another. A common assumption in these studies (D'Aspremont and Jacquemin (1988) and many others) has been that a firm's investment reduces not only its own cost, but also its competitors' costs by a smaller amount, and that firms play a two-stage game in which R&D investment is followed by product market competition. Such a setting is almost identical to that assumed in this study. Spillover and imitation are just different names for the phenomenon whereby a firm obtains a fraction of its competitors' R&D output for free. One difference is that spillover is usually reciprocal while imitation is one-directional, but such a difference is not essential.⁶ More important differences lie in the motivation of the studies and forces driving the conclusions. This study was interested in how strongly to enforce IPR (i.e., to choose a value of β that would maximize the amount of innovation or social welfare), while studies of R&D cooperation have been interested in whether or not cooperation should be allowed (a binary choice for any given β , which is fixed regardless of cooperation). In this analysis, the basic tradeoff is between the direct and indirect effects. In R&D cooperation, the tradeoff (for social welfare) is the following: because of the R&D spillover, individual firms tend to underinvest in technology; because of competition in the product market, firms tend to overinvest in technology (part of the benefit of a firm's cost reduction comes from cannibalizing its competitors, so when their joint profit is considered, the firm's investment in R&D should be reduced).

Other industrial organization studies of R&D have focused on the interaction between market structure and research activities. Yi (1999) studied the incentive to innovate in a Cournot oligopoly and, as in this analysis, found that the incentive decreases with the number of firms. Yi used constant rather than increasing marginal cost. More importantly, Yi studied the effect of competition on innovation, while this study focused primarily on the effects of

cost, which in turn is a reduction of yesterday's cost) while this analysis does not.

⁶For studying imitation, it is natural to assume that a firm is either an innovator or an imitator, i.e., the flow of technology is one directional. For R&D spillover, although the symmetric case is the simplest possible and is used by almost all the models, that assumption is not necessary. It is easy to imagine a setting in which spillover is asymmetric so that the flow of technology is one directional. Nevertheless, the driving forces identified in those studies continue to operate, and their major conclusions are unlikely to change.

imitation.

Mookherjee and Ray (1991) studied technology diffusion with a single innovator and a competitive fringe and demonstrated that faster diffusion may speed up the adoption of innovations. In this analysis, by contrast, imitation was assumed to take place instantly, while Mookherjee and Ray assumed that diffusion takes time. If their diffusion were instant, no innovation would ever be adopted. Also, this analysis worked with quantity competition, while Mookherjee and Ray used price competition. They actually showed that the opposite conclusion is obtained if firms compete in quantity.

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