An Inverted U Relationship between Competition and Innovation: A Revisit

An Inverted U Relationship between Competition and Innovation: A Revisit

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Abstract

This paper offers three possible reasons for an inverted U relationship between competition and innovation. They are based on the ideas of multidirectional innovation, cumulative innovation and rent protection activity. These explanations complement the escape competition effect identified by Aghion, Bloom, Blundell, Griffith, and Howitt (2005).

Key words: innovation, competition, R&D
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1 Introduction

R&D-based models of endogenous technical progress, pioneered by Aghion and Howitt (1992), Grossman and Helpman (1991) and Romer (1990), rest on a premise that technical progress is driven by entrepreneurs who seek future monopoly profits. Because of this property, those models predict a positive relationship between profits and the rate of technical progress. It is analogous to the prediction that competition which lowers profits discourages innovation.

Although this prediction may sound intuitive, it is not supported by data. Especially, Aghion, Bloom, Blundell, Griffith, and Howitt (2005) show an inverted U relationship between competition and innovation, using data of 311 firms in the period of 1973-1994.[1] To account for the inverted U relationship, Aghion, Bloom, Blundell, Griffith, and Howitt (2005) propose a quality-ladder model where duopoly firms compete in the product market as well as in R&D to create blueprints for higher-quality products.[2] They demonstrate that intensified competition generates two opposing effects. First, lower profits obviously reduce R&D incentives. But, the second effect is that firms invest more intensively in R&D in order to escape from competition in the product market. This "escape competition" effect dominates the first R&D-discouraging effect when monopoly power is relatively high. The opposite holds when the product market is relatively more competitive. The end result is an inverted U relationship between competition and innovation.

This paper offers three additional reasons for the inverted U relationship. In the first model, we stress that high-tech goods are typically made of different components, each of which is improved independently or subject to quality of other components. For example, a computer consists of Central Processing Unit (CPU), memory, monitors, hard disk and optical drives, etc. A processing speed of CPU dramatically increased in the past years, and larger-size

[1]Other pieces of evidence include the following. (i) The collapse of socialist economies is often attributed to the lack of competition. (ii) It is often argued that productivity growth is enhanced by trade liberalization, tax reduction and deregulation, all of which tend to promote competition. (iii) Geroski (1995) shows that there exists a strong negative correlationship between innovation and market concentration and a strong positive correlationship between market entry and innovation. (iv) According to Galdón-Sánchez and Schmitz (2001), the collapse of world steel production in the early 1980's led to significant productivity gains by iron-ore mines due to intensified competition. (v) Holmes and Schmitz (2001) argue that monopoly was pervasive in the U.S. water transportation in the 19th and 20th centuries, but subsequently prices fell and fewer inefficient technologies were used due to competition of railroads. (vi) Nickell (1996) demonstrates that TFP growth has a strong correlation with the number of firms. (vii) Blundell, Griffith, and Van Reenen (1999) show that competition in the product market promotes innovation, controlling unobserved firm specific heterogeneity.

[2]See Aghion and Howitt (1992) for discussion of the quality-ladder model of growth.

monitors are now available at lower prices than before. An important aspect of this observation is that profits in one component industry are likely to be affected by innovation in other industries. An example is a PC component called motherboards, which are often specific to CPU. Innovation of CPU renders motherboards obsolete, reducing profits of motherboards producers. Another example is PCs and computer softwares (e.g., MS Windows). Improvement of softwares increases the usefulness of PCs, increasing profits for PC manufacturers. These examples illustrate two opposite cases in terms of changes in profits due to innovation in "other" industry.

To distinguish these two cases, the following two concepts are defined. If profits in an industry are increased by innovation in a different industry and vice versa, those two industries are said to be "R&D Incentive Complements." Two industries are "R&D Incentive Substitutes" if innovation in an industry reduces profits in a different industry and vice versa.[3] To capture this observation, we construct a model of multidirectional innovation where quality of products is improved in two directions through two different R&D activities. We will demonstrate that competition in one industry promotes R&D in the other industry in the case of R&D Incentive Substitutes.

The second model emphasizes an cumulative aspect of technical progress.[4] Most innovations are built upon past innovations. For example, modern steam turbine technology, which is indispensable for coal and nuclear electricity generation, develops from industrial steam engines designed by Thomas Savery in 1698. Since then, thermal efficiency dramatically increased after a series of inventions, including the Watt steam engine. Importantly, because of the cumulative nature of innovation, profits earned by future innovators are affected by past innovations. This introduces intertemporal interdependence of R&D incentives between past and future innovators. To capture this, we construct a model where one-step quality improvement of products requires two different innovations by different innovators, and establish an inverted U relationship between competition and innovation.

In the third model, we recognize that firms conduct not only R&D but also other activities to improve appropriability of research successes. An example is investment in trade secrecy and "patent blocking" where firms obtain secondary patents to protect their major inventions by increasing the R&D cost

[3]Another possibility is that innovation in industry 1 reduces profits in industry 2, but innovation in industry 2 increases profits in industry 1. We do not consider such mixed case to avoid taxonomic analysis.

[4]For example, see Scotchmer (1991) for general discussion of cumulative innovation.

of rival firms. Another example is patent litigation on patent infringement which may deter the introduction of new or similar products. These activities, which Dinopoulos and Syropoulos (2006) term *rent protection activity*, tend to decelerate technical progress, and naturally, respond to profit incentives. We will demonstrate that an inverted U relationship between competition and innovation arises when firms engage in rent protection activity as well as R&D.

Following Aghion, Bloom, Blundell, Griffith, and Howitt (2005), all models are developed in a partial equilibrium framework, taking profits as given. Those three models are developed in the following sections.

2 Multidirectional Innovation

Final output Y is produced with two types of intermediate goods x_1 and x_2 according to[5]

$$Y = AF(x_1, x_2) \tag{1}$$

$$A = \gamma^{m_1}\gamma^{m_2}, \quad \gamma > 1, \quad m_i = 0, 1, 2, ..., \quad i = 1, 2 \tag{2}$$

where γ^{m_i} is quality of inputs i and m_i is the number of innovations.

For simplicity, intermediate goods are assumed to be constant. When innovation occurs in industry i, an innovator earns flow profits π_i^b.[6] Given the quality-ladder framework, products become obsolete if innovation occurs in the same industry. On the other hand, if R&D is successful in the other industry, we assume that profits change to π_i^a.[7] This creates interdependence between firms in different industries. If $\pi_i^b > \pi_i^a$, innovation in the other industry reduces profits, implying R&D Incentive Substitutes. On the other hand, the case of $\pi_i^b < \pi_i^a$ means R&D Incentive Complements. There is no interdependence between two industries for $\pi_i^b = \pi_i^a$. To simplify presentation of our argument, we focus on two cases: (i) $\pi_i^b > 0 = \pi_i^a$, and (ii) $\pi_i^b = 0 < \pi_i^a$.[8]

[5] There are some studies which allow two types of innovation in the form of variety expansion and quality improvement. Early contributions include Li (2000) and Young (1998). See Jones (2005) for further references.

[6] Superscript b of π_i^b stands for profits *B*efore innovation in the other industry.

[7] Superscript a of π_i^a stands for profits *A*fter innovation in the other industry.

[8] Generalization of assuming $\pi_i^b > \pi_i^a > 0$ and $0 < \pi_i^b < \pi_i^a$ does not generate further insights on the issues we are interested in.

2.1 R&D Incentive Substitutes: $\pi_i^b > 0 = \pi_i^a$

Let n_i denote the number of R&D workers employed. Assume that innovation occurs with a Poisson rate of n_i^α, $1 > \alpha > 0$. Then, using V_i to denote the value of innovation in industry i, R&D firm maximizes $V_i n_i^\alpha - n_i$ (wage is normalized), giving the first-order condition:

$$V_i = \frac{n_i^{1-\alpha}}{\alpha}, \quad i = 1, 2. \tag{3}$$

The value of innovation V_i is defined by

$$rV_i = \pi_i^b - \left(n_i^\alpha + n_j^\alpha\right) V_i, \quad i \neq j, \quad i = 1, 2 \tag{4}$$

where r is the interest rate. The first term on the right-hand side is profits, and the second term represents capital loss due to product obsolescence. The following conditions can be derived from (3) and (4):

$$\frac{n_1^{1-\alpha}}{\alpha} = \frac{\pi_1^b}{r + n_1^\alpha + n_2^\alpha}, \tag{5}$$

$$\frac{n_2^{1-\alpha}}{\alpha} = \frac{\pi_2^b}{r + n_1^\alpha + n_2^\alpha}. \tag{6}$$

These two equations determine equilibrium values of n_1 and n_2, which are drawn in Figure 1.

Now suppose that π_1^b falls, holding π_2^b, which captures intensified competition in industry 1. In Figure 1, the (5) curve shifts leftward, reducing n_1, but increasing n_2. Intuitively, intensified competition in industry 1 lowers R&D incentives in the industry, leading to a fall in n_1. On the other hand, a reduction of n_1 delays obsolescence of intermediate goods 2, increasing the average time period when profits π_2^b are earned. This increases R&D incentives in industry 2, increasing n_2.

Next, consider a fall in π_2^b. In Figure 1, the (6) shifts down with a decrease in n_2 and an increase in n_1. An intuitive reason for this result is essentially the same as before. Intensified competition in an industry spills over to the other industry. In summary,

Result 1 (R&D Incentive Substitutes)**.** *As competition intensifies in an industry, R&D incentives fall in the industry, but increase in the other industry.*

Conversely, an increase in monopoly power in an industry promotes R&D in the industry, but discourages R&D in the other industry.

2.2 R&D Incentive Complements: $\pi_i^b = 0 < \pi_i^a$

Equation (3) that determines the number of R&D workers is still valid in this case. A major difference lies in the value of innovation V_i, which is defined by

$$rV_i = -n_i^{\alpha} V_i + n_j^{\alpha} (v_i - V_i), \tag{7}$$

$$rv_i = \pi_i^a - n_i^{\alpha} v_i, \quad i \neq j, \quad i = 1, 2. \tag{8}$$

The first term on the right-hand side of (7) is capital loss due to innovation in the same industry, and the second term represents capital gain from V_i to v_i, made possible by innovation in the other industry. v_i is determined in (8).[9]

Using (3), (7) and (8), one obtains

$$\frac{n_1^{1-\alpha}}{\alpha} = \frac{n_2^{\alpha}}{(r + n_1^{\alpha} - n_2^{\alpha})(r + n_1^{\alpha})} \pi_1^a, \tag{9}$$

$$\frac{n_2^{1-\alpha}}{\alpha} = \frac{n_1^{\alpha}}{(r + n_1^{\alpha} - n_2^{\alpha})(r + n_2^{\alpha})} \pi_2^a. \tag{10}$$

Figure 2 depicts these two equations.

First, suppose that competition intensifies in industry 1. As π_1^a falls, the (9) curve pivots anticlockwise, and both n_1 and n_2 decrease. Intuitively, a fall of π_1^a reduces R&D incentives in industry 1, reducing R&D workers employed. This delays the time at which firm in industry 2 starts earning profits. This decreases the value of innovation in the industry with a lower n_2.

The result of a smaller π_2^a is basically the same as before, reducing the number of R&D workers in both industries. In summary,

Result 2 (R&D Incentive Complements)**.** *As competition intensifies in an industry, R&D incentives fall in both industries.*

Conversely, an increase in monopoly power in either industry promotes R&D in both industries.

2.3 An Inverted U Relationship

Using properties of the Poisson distribution, the average rate of technical progress (or the average growth rate of A in (2)) can be shown to be [10]

$$g \equiv \frac{\dot{A}}{A} = (n_1 + n_2) \ln \gamma. \tag{11}$$

[9] π_i^a is assumed to be independent of further innovations in the other industry.

[10] See Aghion and Howitt (1992) for example.

In the case of R&D Incentive Substitutes, fiercer competition in an industry changes n_1 and n_2 in the opposite directions. Therefore, we obtain an inverted U relationship between competition and innovation, as Figure 3 (a solid curve) shows.

In the case of R&D Incentive Complements, n_1 and n_2 alter in the same direction with lower profits in an industry. This means that competition and innovation have a monotonic (negative) relationship.

3 Cumulative Innovation

This section considers the model of cumulative innovation where one quality step-up of high-tech goods requires two successive innovations through different R&D activities. Such technological complementarity leads to the result that two types of R&D are R&D Incentive Substitutes.

3.1 The Model

Final output Y is produced according to the production function (1), but with A being redefined as

$$A = \min\{\gamma^{m_1}, \gamma^{m_2}\}, \quad \gamma > 1, \quad m_i = 0, 1, 2, ..., \quad i = 1, 2. \tag{12}$$

We assume $m_1 = m_2 = 0$ at $t = 0$. As before, we assume that quantity of intermediate goods is constant.

(12) is different from (2) in that γ^{m_1} and γ^{m_2} are "perfect complements" (or technological complements). Innovation is assumed to take place in the sequence of x_1 and x_2 to raise quality by a factor γ, and this sequence continues in the long run. To explain this assumption, consider Figure 4 or 5 where t_i, $i = 1, 2$ indicates times when innovation occurs in industry i. For a time period (t_1, t_2), R&D is active in industry 2, but not in industry 1. Similarly, firms conduct R&D in industry 1 only for a time period (t_2, t_1).

Regarding R&D technology, assume that if n_i workers are used in industry i, innovation arrives with a Poison rate of n_i. Using V_i to denote the value of innovation in industry i, the following condition should hold

$$V_i = 1, \qquad i = 1, 2, \tag{13}$$

due to free entry in R&D (wage is normalized).[11]

Next we derive the value of innovation industry 2. As Figure 4 shows, firms that succeed in R&D earn profits π_2 from t_2 to the next t_2 due to product obsolescence. Therefore,

$$rV_2 = \pi_2 + n_1 (v_2 - V_2), \tag{14}$$

$$rv_2 = \pi_2 - n_2 v_2. \tag{15}$$

where v_2 is the present expected value of profits between t_1 and t_2. On the right-hand side of (14) are profits and changes in the value of innovation due to innovation in industry 1. (15) defines v_2, and the second term on its right-hand side captures the risk of product obsolescence. Using those two equations and (13), the following condition can be derived:

$$1 = \frac{r + n_1 + n_2}{(r + n_1)(r + n_2)} \pi_2. \tag{16}$$

This condition determines n_2, given n_1.

Turning to industry 1, suppose that the $(m+1)$th innovation occurs at t_1 in Figure 5. Successful firms do not earn profits, since complementary innovation in industry 2 has not occurred yet. Firms will earn profits from t_2 to the next t_2. Now, it should be clear that the value of innovation V_1 is defined by the following recursive equations:

$$rV_1 = n_2 (v_1 - V_1), \tag{17}$$

$$rv_1 = \pi_1 + n_1 (z_1 - v_1), \tag{18}$$

$$rz_1 = \pi_1 - n_2 z_1. \tag{19}$$

An interpretation of these equations is essentially the same as that of (14) and (15). A key difference is that there is a capital gain term only on the right-hand side of (17), since no profit is earned during the first (t_1, t_2) period. Using (13), (17), (18) and (19), one can derive

$$1 = \frac{n_2 (r + n_1 + n_2)}{(r + n_1)(r + n_2)^2} \pi_1, \tag{20}$$

which determines n_1, given n_2.

[11] Innovation could be assumed to arrive with a Poisson rate n_i^α, $1 \geq \alpha > 0$. This generalization, however, does not generate any further insights, and hence, we focus on the simplest case of $\alpha = 1$.

3.2 Effects of Competition

To solve the model, derive the following equation from (16) and (20).

$$n_2 = \frac{r}{\frac{\pi_1}{\pi_2} - 1}. \tag{21}$$

$\pi_1 > \pi_2$ is required for an interior solution. Figure 6 depicts (16) and (21).

Suppose that competition intensifies in industry 1. A lower π_1 shifts up the (21) line, leaving the (16) curve intact. It is clear that n_1 falls. This result is the same as in the existing R&D-based models. However, the figure shows that a decrease in π_1 increases n_2. That is, fiercer competition in industry 1 promotes innovation in industry 2. Intuitively, a decrease in π_1 reduces R&D incentives in industry 1 with a lower n_1. But, a lower n_1 means a longer time period required for innovation to occur in industry 1, which in turn implies that the time period (t_2, t_1) in Figure 4 (or Figure 5) gets longer. In other words, firms in industry 2 can earn profits for a longer period than before due to intensified competition in industry 1. As a result, firms find it more profitable to do R&D in industry 2 with a higher n_2. Furthermore, using (16) and (21) it is easy to establish that intensified competition in industry 2 promotes R&D in industry 1.

These results are equivalent to Result 1. This section demonstrates that cumulative innovation makes two R&D activities R&D Incentive Substitutes.

3.3 An Inverted U Relationship

To derive the average rate of technical progress, note that $1/n_i$ is the average time period required for a single innovation to occur in industry i. Therefore, it takes $1/n_1 + 1/n_2$ on average for the quality index (2) to increase from γ^m to γ^{m+1}, and its inverse gives the number of innovations during a unit interval. This means that the average rate of technical progress is

$$g = \frac{n_1 n_2}{n_1 + n_2} \ln \gamma. \tag{22}$$

Now consider the effect of competition on technical progress. When competition intensifies in an industry, n_1 and n_2 change in the opposite directions. Therefore, a relationship between competition and innovation takes an inverted U shape, as shown in Figure 3 (a solid curve).

4 Innovation and Rent Protection Activity

This section considers the model where entrant firms conduct R&D and incumbent firms engage in rent protection activity. Rent protection activity is shown to be one of the reasons for an inverted U relationship between competition and innovation.

4.1 The Model

The production function of final output Y is

$$Y = \gamma^m F(x), \quad \gamma > 1, \quad m = 0, 1, 2, ... \tag{23}$$

where x is intermediate goods. As in the previous models, innovation increases the quality level of the goods and x is assumed to be constant.

A Poisson rate of innovation is

$$I = \delta(k) n, \quad \delta' < 0 < \delta'', \quad \delta(0) > 0 \tag{24}$$

where n is the number of workers that entrant firms employ in R&D. k denotes the number of workers that an incumbent firm uses for rent protection activity. As k increases, obsolescence of the incumbent's product is delayed in time, which allows the firm to earn profits for a longer time period.

The value of innovation is defined by the following equation:

$$rV = \pi - k - \delta(k) nV. \tag{25}$$

$\pi - k$ on the right-hand side is profits net of costs of rent protection activity, and the last term is capital loss due to innovation by a new entrant firm. An incumbent firm chooses k so as to maximize V. The first order condition is

$$1 = -\delta'(k) nV. \tag{26}$$

On the other hand, given total R&D cost being n (wage is normalized) for new entrants, the following equation holds

$$V\delta(k) = 1 \tag{27}$$

due to free entry.[12]

[12]Footnote 11 applies here.

4.2 Effects of Competition

Combining (26) and (27) gives

$$I = -\frac{\delta(k)^2}{\delta'(k)}, \tag{28}$$

which determines k, given I. It is easy to see that I and k are negatively related. Intuitively, a higher I shortens the time period during which an incumbent firm earns profits, and this reduces incentives for rent protection activity.

Next, using (24) and (25), one can derive the following equation:

$$I = (\pi - k)\,\delta(k) - r. \tag{29}$$

This condition determines I, given k, showing a negative relationship between those variables. Intuitively, a higher k makes it more difficult for innovation to occur, which in turn reduces R&D incentives with a lower number of R&D workers.

(28) and (29) are depicted in Figure 5. Although multiple equilibria are a possibility, we focus on a unique equilibrium for simplicity.

Initially, we consider an interior solution. It is easy to see that competition that reduces profits π shifts down the (29) curve in Figure 5. Consequently, k falls, but I increases. Intuitively, there are two opposing effects of competition on the Poisson rate of innovation. First, rewriting (24) as $n = -\delta(k)/\delta'(k)$, one can see that a lower π reduces n. This shows that competition reduces R&D incentives, and entrant firms decreases R&D employment. This tends to decrease I. Second, an incumbent firm also reduces workers used for rent protection activity in response to lower profits. This tends to increase I. One can easily confirm that the second effect dominates the first effect with the following result:

Result 3. *In the case of an interior equilibrium with rent protection activity, intensified competition in the product market increases the Poisson arrival rate of innovation.*

Next, suppose that profits are so low that the (29) curve is entirely located below the (28) curve in Figure 5. In this case, an equilibrium is obtained as a corner solution at a vertical intercept of the (29) curve with $k = 0$. As profits fall further, an equilibrium I falls. In the limit, we have $I = 0$ for

$\pi = 0$. This confirms that competition unambiguously lowers the Poisson rate of innovation in the absence of rent protection activity.

4.3 An Inverted U Relation

Using (23) and (24), the average rate of technical progress is given by

$$g = I \ln \gamma. \tag{30}$$

It is drawn as a dotted curve in Figure 3. When π is high, R&D and rent protection activity are both active. As profits fall with competition, the Poisson rate of innovation increases. Once the economy turns from an interior equilibrium to a corner solution, I starts falling, as profits decrease, in the absence of rent protection activity.

5 Conclusion

This paper offers three possible reasons for an inverted U relationship between competition and innovation. They are based on multidirectional innovation, cumulative innovation and rent protection activity. These explanations complement the escape competition effect identified by Aghion, Bloom, Blundell, Griffith, and Howitt (2005).

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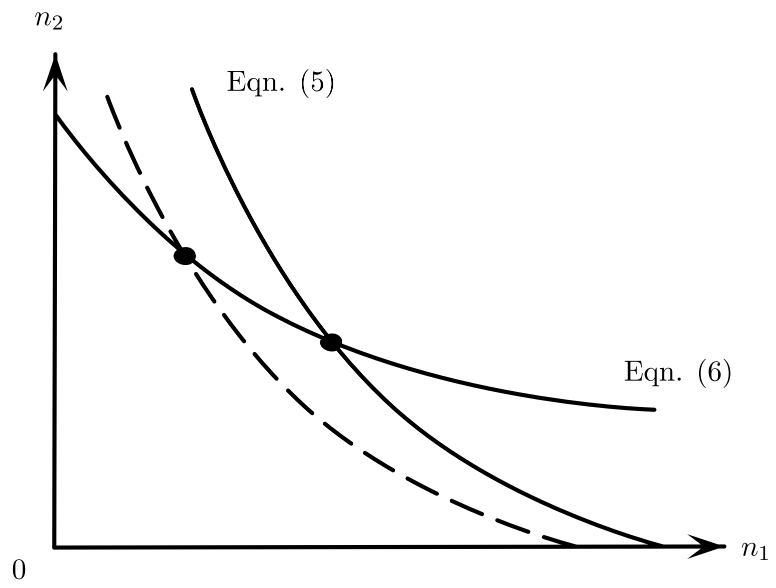

Figure 1: Multidirectional innovation and R&D Incentive Substitutes.

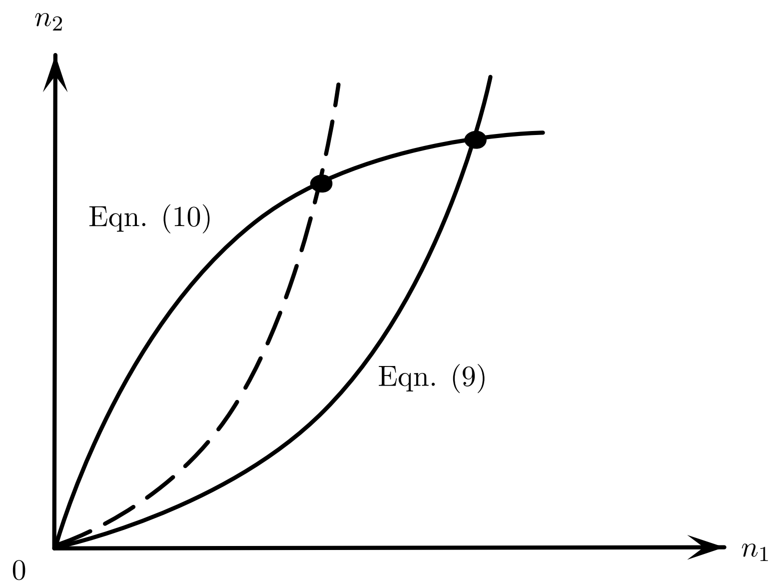

Figure 2: Multidirectional innovation and R&D Incentive Complements.

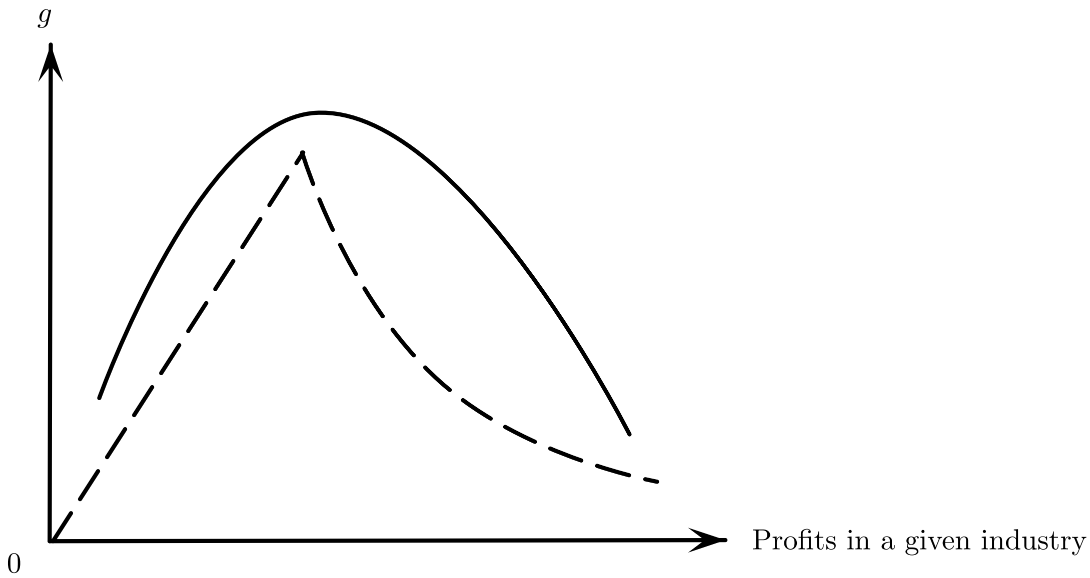

Figure 3: An inverted U relationship between competition and innovation.

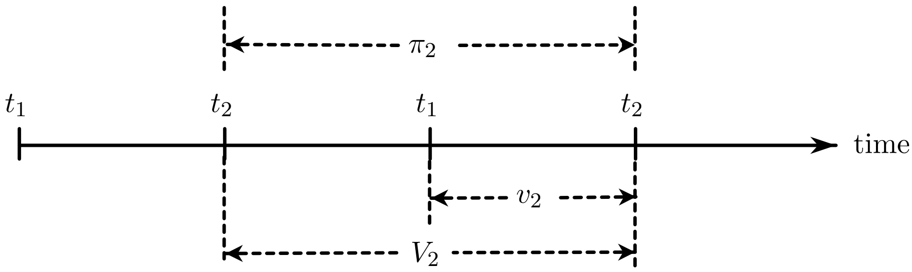

Figure 4: Profits and the value of innovation in industry 2.

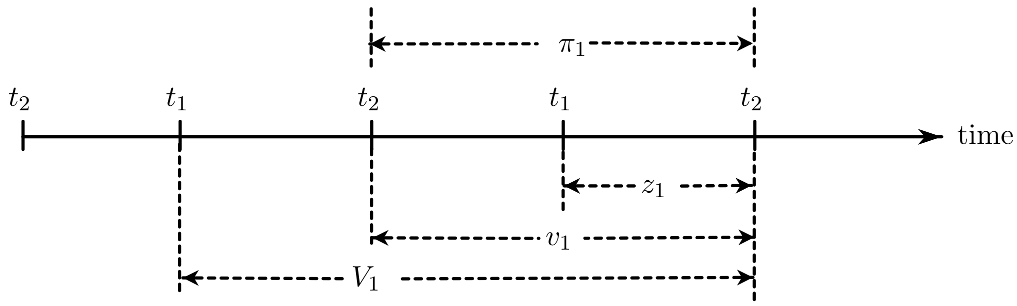

Figure 5: Profits and the value of innovation in industry 1.

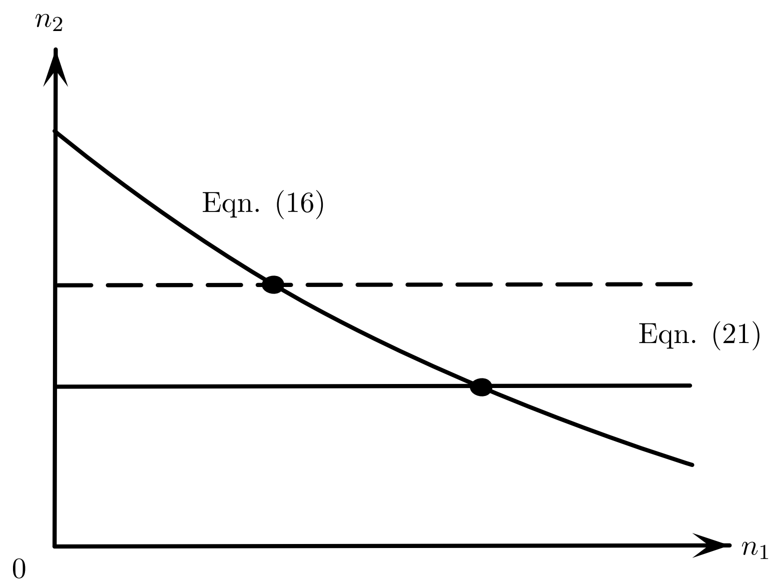

Figure 6: Cumulative innovation.

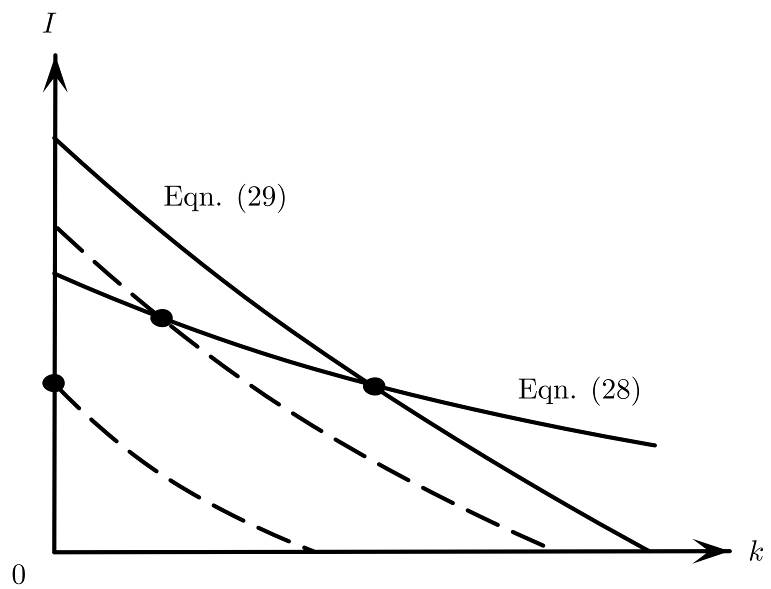

Figure 7: Rent protection activity and innovation.