Competition, Patent Protection, and Innovation in an Endogenous Market Structure

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Abstract

This study revisits the relationship between competition and innovation by incorporating an endogenous market structure (EMS) in a dynamic general equilibrium model. We consider a free-entry model that the leader engages in Cournot competition with both non-innovative and innovative followers in each industry. A competition-enhancing policy, which reduces entry cost, can stimulate the entry of innovative followers when the entry cost is high. However, when the entry cost is sufficiently low, the entry of non-innovative followers crowds out innovative followers from the market. As a result, there is a non-monotonic relationship (inverted-V shape) between competition and innovation. Furthermore, we show that, while strengthening patent protection positively affects innovation when competition is sufficiently intense, the effect may be negative under milder competition. This suggests that a competition policy could complement a patent policy.

JEL-Classification: O30, O40.

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1 Introduction

Over the years, many researchers have attempted to explore how intensifying product market competition (PMC) affects innovation. Based on an idea of Schumpeter (1950) that monopolistic profit is the most powerful engine driving technological progress, many Schumpeterian growth models show that competition discourages firms from innovation because post-innovation profit shrinks under harsh PMC (also known as the "Schumpeterian effect").

However, the results of empirical analyses are mixed and do not necessarily show such clear trade-off between competition and innovation. Aghion et al. (2005), the most influential study in the field, show an inverted-U relationship between competition and innovation using data for the United Kingdom. Hashmi (2013) demonstrates a negative relationship between PMC and innovation in the United States and suggests that the relationship may differ across countries. On the other hand, using the same data, Corera and Ornaghi (2014) indicate that PMC positively impacts innovation when control variables are changed. More recently, Blazsek and Escribano (2016) also suggest that PMC enhances innovation in the United States. Thus, the relationship between PMC and innovation remains a hot controversial issue.[1]

Many theoretical studies have examined the relationship between PMC and innovation assuming a fixed number of firms in the product market. Using an oligopolistic model, Aghion et al. (1997, 2001, 2005) show that strong PMC may enhance economic growth since it stimulates the neck-and-neck firms' incentive to innovate ("escape competition effect") and this outweighs the Schumpeterian effect. However, needless to say, the interrelationship between the number of firms and status of PMC is intrinsic to investigate the competition–innovation relationship more precisely. In fact, Etro (2007) points out that the escape competition effect completely disappears under the assumption of free entry. In this case, the non-monotonicity between PMC and innovation also vanishes. Hence, it is necessary to consider this issue in a more general framework, which is an endogenous market structure (EMS), where the number of firms in the product market is endogenously determined.[2]

A contribution of the present study is to revive the non-monotonic relationship between competition and innovation in Aghion et al. (2005); nevertheless we develops a dynamic equilibrium (DGE) model with EMS. Although our model does not have an escape competition effect because of free entry as Etro (2007) argues, the non-monotonicity arises from another mechanism.

In this paper, we modify the quality-ladder model in Grossman and Helpman (1991,

[1]For a comprehensive survey of empirical studies, see Cohen (2010).
[2]See Etro (2007, 2009) for EMS models.

Ch.4) by assuming Cournot competition within each product market and allowing for followers' entry to the markets. Unlike other studies that consider R&D activities by potential firms as the key driver of growth, we consider a situation in which only active firms in the product markets engage in R&D as in Aghion et al. (2005). This is inspired by some empirical findings that existing firms' quality improvement, rather than creative destruction by the entrant, is a major source of growth.[3] Furthermore, in our model, firms can enter each product market as innovative or non-innovative followers without infringing the leader's patent. Innovative followers conduct R&D activities and the successful one becomes the new leader in the market. A competition-enhancing policy, which reduces entry cost, stimulates the entry of innovative followers when the level of PMC is low.[4] However, when PMC is sufficiently tough, the policy hinders innovation since non-innovative followers crowd-out innovative followers from the market. As a result, a competition-enhancing policy has a non-monotonic effect on innovation.

Using EMS models, some studies have recently analyzed the relationship between PMC and innovation. Denicolò and Zanchettin (2010) extend a quality-ladder growth model in which the total number of asymmetric incumbents is endogenously determined. In their model, several efficient incumbents can remain in the market, even if further innovation occurs, since their model assumes that patent length is infinite and firms do not engage in Bertrand competition. Then, strong PMC excludes inefficient incumbents from the market and increases the market share of an efficient incumbent. They also demonstrate that intense PMC may stimulate the incentive to innovate through this market selection process. Bento (2014) incorporates the uncertainty of quality-improvement size in a Schumpeterian growth model, wherein the incumbent's markup is endogenously determined. In his model, a fortunate potential firm that draws the best quality among all firm becomes the monopolist. When an innovator's market entry cost is low, the number of firms that draws the lottery increases. The increase in the number of firms decreases the probability that one firm wins (this discourages each firm's research by the Schumpeterian effect), but increases the winner's quality level and innovation value (he labels this as the "Hayekian effect"). He further shows that these opposite effects generate an inverted-U relationship between PMC and research per firm.

It is worthwhile to note the differences between the present study and existing literature. Although Bento (2014) also obtain an inverted-U relationship between PMC and

[3]See Bartelsman and Doms (2000) and Garcia-Macia et al. (2016). In particular, Garcia-Macia et al. (2016) report that 87.2% of TFP growth for 2003-2013 in the United States can be attributed to existing firms' innovation.

[4]In terms of this, our model considers a type of competition policy that prohibits conduct by a large firm that unreasonably maintaining monopoly power. While we consider a competition policy against monopolization, Aghion et al. (2005) analyze a type of competition policy against cartels by existing firms. Thus, strictly speaking, our study and Aghion et al. (2005) investigate different types of competition policy.

innovation, he did not explicitly examine the issue in a general equilibrium model because of the model's complexity.[5] Our DGE model has an advantage in the point. Furthermore, in the model of Bento (2014), each industry consists of a monopolist because of Bertrand competition and potential firms conduct all research. In contrast, our Cournot competition model under free entry in the product market allows imitators to enter and a part of these producing firms engage in R&D activities. So, the mechanism that generates the non-monotonic relationship in our model and that in Bento (2014) are different. As a parameter for PMC level, Aghion et al. (2005) use an exogenous degree of collusion in neck-and-neck industries in which duopolistic firms have the same level of technology. However, such a proxy for PMC not only lacks a micro-foundation but also captures a somewhat industry-specific competition policy because it has no impact on PMC in industries comprising firms with differing technology levels. Denicolò and Zanchettin (2010) use a parameter of conjectural variations as a measure of competition level, which has been criticized by many theorists. Unlike these studies, we use entry cost as a parameter for PMC degree, which allows us to easily highlight the policy implications.[6]

Furthermore, our model shows that strengthening patent protection does not always enhance innovation. We find that the pro-patent policy always has a positive effect on innovation when PMC is sufficiently intense. This result suggests a complementarity between a competition policy and patent policy, which is consistent with the empirical findings in Aghion et al. (2015). There are many works have been investigated the relationship between intellectual property rights and innovation.[7] In particular, Chu et al. (2016) study the effect of strengthening patent protection on economic growth in a model with EMS. They develop a hybrid model of variety expansion and quality improvement, where the introduction of a new variety is considered as a market entry and the number of firms (varieties) is endogenously determined. Their model shows that strict patent protection enhances growth in the short run but hinders it in the long run because it expands the number of entrants and decreases the market share per firm.[8] By contrast, we find that strong patent protection may have a positive effect even in the long run. Furthermore, our

[5]Also, in the context of industrial organization, many studies have dealt with the relationship between competition and innovation using partial equilibrium models. For example, Boone (2001) shows a non-monotonic relationship between competition intensity and R&D incentive.

[6]In addition to these recent studies, Van de Klundert and Smulders (1997) investigate the effect of competition on economic growth using an endogenous growth model with EMS. They use the distinction between Cournot and Bertrand competition to denote competition intensity and show that tougher PMC always yields a higher innovation rate.

[7]See, for example, Cysne and Turchick (2012), Furukawa (2007), Futagami and Iwaisako (2007), Horii and Iwaisako (2007), and Suzuki (2015). In particular, Suzuki (2015) extends a quality-ladder model in which the monopolist's markup size is endogenously determined as in this study.

[8]This trade-off between the number of firms (varieties of differentiated goods) and innovation is a common feature in models where the introduction of a new variety is considered as a market entry. See also Van de Klundert and Smulders (1997), Peretto (1999), and Minniti (2009).

study considers a competition-patent policy mix by examining the comparative statics of patent protection under several PMC levels.

The remainder of this paper is structured as follows. Section 2 describes the model and Section 3 solves the equilibrium. Section 4 discusses the effects of competition-enhancing and patent policies on innovation and welfare. Section 5 concludes.

2 The model

This section develops a DGE model with EMS. The model is based on quality-ladder type endogenous growth model in Grossman and Helpman (1991, Ch.4).

2.1 Households

We consider an economy consisting of L identical and infinitely lived households. Each household supplies a unit of labor inelastically and earns wage w in every period. Their intertemporal utility function is as follows:

$$U_t = \int_0^\infty \exp(-\rho t) \ln C_t dt, \tag{1}$$

where ρ is the subjective discount rate and C_t is an index of consumption at time t. In the economy, there is a continuum of industries indexed by $i \in [0, 1]$. The households consume final goods across all industries. The period utility is,

$$\ln C_t = \int_0^1 \ln \left(\sum_{k=0}^{\tilde{k}(i)} \lambda^k X_{kt}(i) \right) di, \tag{2}$$

where $X_{kt}(i)$ is the consumption of the good whose quality is k in industry i at time t. The quality of each good is represented as an integer k power of $\lambda > 1$, which means that the quality of the new good is λ times higher than that of the previous one. In industry i, there are $\tilde{k}(i)$ types of goods and the quality of the latest good is $\lambda^{\tilde{k}(i)}$. We can show that, in equilibrium, households buy only the highest quality good in each industry.

Under the logarithmic utility function, households spend their budget equally across the industries. Therefore, the demand of a good in the industry i is $X_{\tilde{k}}(i) = E/p_{\tilde{k}}(i)$, where E is expenditure and $p_{\tilde{k}}$ is the price of the good whose quality is $\tilde{k}(i)$.

In this setting, the ideal price index associated with the consumption index C is

$$P = \exp \left[\int_0^1 \ln \left(\frac{p_{\tilde{k}}(i)}{\lambda^{\tilde{k}(i)}} \right) \right] di. \tag{3}$$

Given the aggregate price index, households spend to maximize their intertemporal utility. From the maximization result, household's optimal time path for spending is represented by $\dot{E}/E = r - \rho$. Using aggregate expenditure as the *numéraire*, we get $E = 1$ and $r = \rho$. Hereinafter, we omit i from the notations if there is no risk of misunderstanding.

2.2 Industries

Consider an industry that consists of a leader and N followers.[9] All of them engage in Cournot competition, where their unit production costs are asymmetric. While the leader can produce a good using one unit of labor, followers must devote $\lambda\chi > 1$ units of labor to produce a unit of the same quality good. We assume that patent protection is imperfect and followers can partially imitate the leader's good without infringing the patent. Parameter $\chi \in (1/\lambda, 1)$ indicates the degree of patent breadth.[10] As we derived, the inverse demand function for goods in an industry is $p = 1/X$. In the market equilibrium, X equals the aggregate output in the industry. Given the inverse demand function and wage rate of one unit of labor, w, producer j maximizes her own profit, $\pi(j)$. Accordingly, the profit maximization problem is

$$\max_{x(j)} \pi(j) = \frac{1}{X} \cdot x(j) - c(j) \cdot w \cdot x(j), \tag{4}$$

where $x(j)$ is output level and $c(j)$ is production cost.[11] By solving this, we obtain the output of producer j as follows:

$$\begin{aligned} \frac{\partial \pi(j)}{\partial x(j)} = 0 \quad &\Leftrightarrow \quad \frac{1}{X} - \frac{x(j)}{X^2} - c(j) \cdot w = 0 \\ &\Leftrightarrow \quad x(j) = X - c(j) \cdot w \cdot X^2. \end{aligned} \tag{5}$$

We denote x_L and x_F as the output of the leader and followers in the industry. Assume that all followers are symmetric. Then, the aggregate output in the industry is written as $X = x_L + N \cdot x_F$. By using this and (5), we can derive the industry's aggregate output in

[9] In this subsection, we consider that the number of firms in the industry is an integer. But we will consider that N is a mass and neglect the integer constraint on the number of firms from the next subsection.

[10] Patent breadth is the extent to which patent holders can legally prevent imitators from copying their patented technologies. In our model, patent breadth is the broadest when $\chi = 1$ and narrowest when $\chi = 1/\lambda$. The same specification of patent breadth was applied in Iwaisako et al. (2011).

[11] Note that $c(j) = 1$ when producer-j is the leader and $c(j) = \lambda\chi$ when she is a follower.

the Cournot equilibrium as follows:

$$\begin{aligned} X &= X - wX^2 + N \cdot \left(X - \lambda\chi w X^2\right) \\ \Leftrightarrow X &= \left(\frac{N}{1+\lambda\chi N}\right)\frac{1}{w}. \end{aligned} \tag{6}$$

Then, the price in the Cournot equilibrium is

$$p = \left(\frac{1+N\lambda\chi}{N}\right) w. \tag{7}$$

By using (5), we can find that the ratio between x_L and x_F is equal to that of the markup $p - c(j) \cdot w$. Then, we have

$$\begin{aligned} \frac{x_L}{x_F} &= \frac{p-w}{p-\lambda\chi w} = 1 + (\lambda\chi - 1)N \\ \Leftrightarrow x_L &= [1 + (\lambda\chi - 1)N] x_F(i). \end{aligned} \tag{8}$$

Using this, we obtain the equilibrium output of each producer as follows:

$$x_F = \left[\frac{N}{(1+\lambda\chi N)^2}\right]\left(\frac{1}{w}\right), \tag{9}$$

$$x_L = \left[\frac{N}{(1+\lambda\chi N)^2}\right][1 + (\lambda\chi - 1)N]\left(\frac{1}{w}\right). \tag{10}$$

Then, the follower's and leader's profit are

$$\pi_F(N) = \left(\frac{1}{1+\lambda\chi N}\right)^2, \tag{11}$$

$$\pi_L(N) = \left(1 - \frac{N}{1+\lambda\chi N}\right)^2. \tag{12}$$

These functions are decreasing in N.

2.3 Followers: Imitators and Research Firms

Following Etro (2007), in this section, we incorporate the concept of EMS in the model.

There are two types of followers in the model. First is the non-innovative firms who only imitate a state-of-the-art good. We label this type of followers as "imitators" in a narrow sense. Second is the type of firms that not only produces an imitated good but also conducts R&D activities. We label them as "research firms." We assume that all R&D activities are conducted by research firms; therefore, there is no potential researcher in the model.[12]

The success of R&D activities follows a Poisson process. By employing a worker, a research firm can draw a lottery that may succeed to create a high-quality good with a small probability of a. In the model, there is no decision regarding the amount of R&D investment by research firms. Therefore, the total number of research firms is equal to that of workers employed by research firms.[13] Let R denote the total number of research firms in an industry. Then, the probability of an innovation occurring in the industry at the interval of dt is $(Ra)dt$. In addition, we denote M as the total number of imitators in the industry. In this case, $N = M + R$ holds.

We assume that all N followers must pay a cost of $e > 0$ in each period. Since this cost can prevent potential firms from entering the industry, in our model, we consider it an entry cost.In a narrow sense, entry cost is a fixed cost that all entrants must pay when they enter the market. However, in reality, entrants often regularly pay several other costs (e.g., advertisement and patent license fee) which also serve as an effective entry cost in a broad sense. [14] This assumption simplifies the analyses of comparative statistics. The leader does not pay this cost because entry cost is a barrier that protects incumbent.

Then, the free-entry condition for imitators is,

$$\pi_F(N) \leq e \;\text{ equality holds when }\; M > 0. \tag{13}$$

Similarly, the free-entry condition for research firm is,

$$\pi_F(N) + aV_t - w \leq e \;\text{ equality holds when }\; R > 0, \tag{14}$$

where V_t is the value of innovation.[15] In the equilibrium, M and R are determined by these conditions.

[12] In most R&D-based growth models, only potential firms engage in R&D activities, while incumbents do not because of the Arrow's replacement effect. By contrast, in our model, R&D activities can be performed for only producing firms. This assumption can be justified when the research productivity of existing firms is lower that of potential ones because manufacturing experience gives the producer essential clues about further innovations.

[13] Marsiglio and Tolotti (2015) also assume that research choice is binary. Alternatively, we can interpret research firms as non-production workers who set up their enterprise and engage in R&D activities. Horii and Iwaisako (2007) also considered a similar R&D process specification. Note that free-entry condition (14) also holds in this interpretation because wage is an opportunity cost.

[14] Alternatively, we can consider that all entrants borrow some money when they enter and constantly repay or all followers' projects are completed instantaneously.

[15] Note that the firm value of imitators V^M and the firm value of research firms V^R is always zero. So, we do not need to consider these evolution.

3 The Steady State

3.1 Equilibrium

In labor market equilibrium, aggregate labor demand ($x_L + N \cdot \lambda\chi x_F + R$) must be equal to labor supply L. The labor market clearing condition is

$$\left(\frac{N}{1+\lambda\chi N}\right)\left(1+\frac{N\left(\lambda\chi-1\right)}{1+\lambda\chi N}\right)\left(\frac{1}{w}\right)+R=L. \tag{15}$$

The equilibrium wage rate w is determined to satisfy this condition.

Consider the evolution of innovation value V_t. A leader earns π_L in every period, unless a certain research firm successfully innovates. The leader loses her position and must exit from the market with the probability of Ra. We assume that there is a perfectly risk-free asset market. Therefore, the following equation holds as a no-arbitrage condition in the asset market:

$$rV_t = \pi_L(N) + \dot{V}_t - RaV_t. \tag{16}$$

3.2 The Steady State

In the equilibrium, depending on the magnitude of $e > 0$, there are two possible cases. First, there is no imitator ($M = 0$, $N = R$) in the industry when e is sufficiently large. Second, imitators and research firms coexist in the same industry ($M > 0$, $N = M + R$) when e is sufficiently small. In the subsection, we solve the steady state for each case.

Case 1: No imitators ($M = 0, R > 0$)

From the no-arbitrage condition, normalization, and profit, we obtain

$$\dot{V}_t = 0 \Leftrightarrow V_t = \frac{\left[1 - R/(1+\lambda\chi R)\right]^2}{\rho + Ra}. \tag{17}$$

This is a decreasing function in R.

In this case, the free-entry condition for research firms (14) is binding but the free-entry condition for imitators (13) does not since e is sufficiently large. While imitators do not enter the market because $\pi_F < e$ holds, research firms do because they have an expectation of innovation aV. This means that research firms have a stronger incentive to enter the market than imitators. By substituting the free-entry condition for research firms

(14) with the labor market clearing condition (15), we get

$$V_t = \frac{1}{a}\left[e + \left(\frac{R}{1+\lambda\chi R}\right)\left(1+\frac{(\lambda\chi-1)R}{1+\lambda\chi R}\right)\left(\frac{1}{L-R}\right) - \left(\frac{1}{1+\lambda\chi R}\right)^2\right]. \tag{18}$$

This is an increasing function in R. These two equations reveal that the steady state is unique and unstable as in Panel (a) of Fig.1. To guarantee the existence of intersection of (17) and (18), we suppose that the entry cost is sufficiently small:

Assumption 1.

$$e < \frac{a}{\rho} + 1 \equiv e^{\max}. \tag{19}$$

Since there is only jumpable variables in the dynamics, to satisfy the transversality condition, V_t must immediately jump to its steady-state value at $t = 0$. There is no transitional dynamics in our model as in Grossman and Helpman (1991, Ch.4). Therefore, the comparative statics between different steady states are applicable.

Case 2: Coexistence ($M > 0, R > 0$)

In case 2, free-entry conditions (13)-(14) are binding since e is sufficiently small. The free-entry condition for imitators (13) determines the total number of followers N:

$$N = \frac{1}{\lambda\chi}\left(\frac{1}{\sqrt{e}} - 1\right) \equiv \bar{N}(e). \tag{20}$$

Then, by substituting equations (12) and (20) with equation (16), we have

$$\dot{V}_t = 0 \Leftrightarrow V_t = \frac{\left[1-(1-\sqrt{e})/(\lambda\chi)\right]^2}{\rho + Ra}. \tag{21}$$

This is a decreasing function in R. Using equations (13) and (14), we obtain $aV_t = w_t$. From this, (20), and labor market clearing condition (15), we can derive

$$V_t = \left(\frac{1-\sqrt{e}}{a\lambda\chi}\right)\left[1 + \left(\frac{1-\sqrt{e}}{\lambda\chi}\right)(\lambda\chi - 1)\right]\left(\frac{1}{L-R}\right). \tag{22}$$

This is an increasing function in R. Panel (b) of Fig.1 states that the steady-state in case 2 is also unique and unstable and V_t must jump to its steady-state value immediately at $t = 0$. We define $e^{\min}$ as the minimum value that case 2 happens (See Appendix). Under $e^{\min} < e < e^{\max}$, the number of research firms in the steady-state, R^*, is strictly positive.[16] We focus on this range of entry cost in the comparative statics.

[16]Because $0 < e^{\min} < 1 < e^{\max}$ always holds, the range of e is not empty.

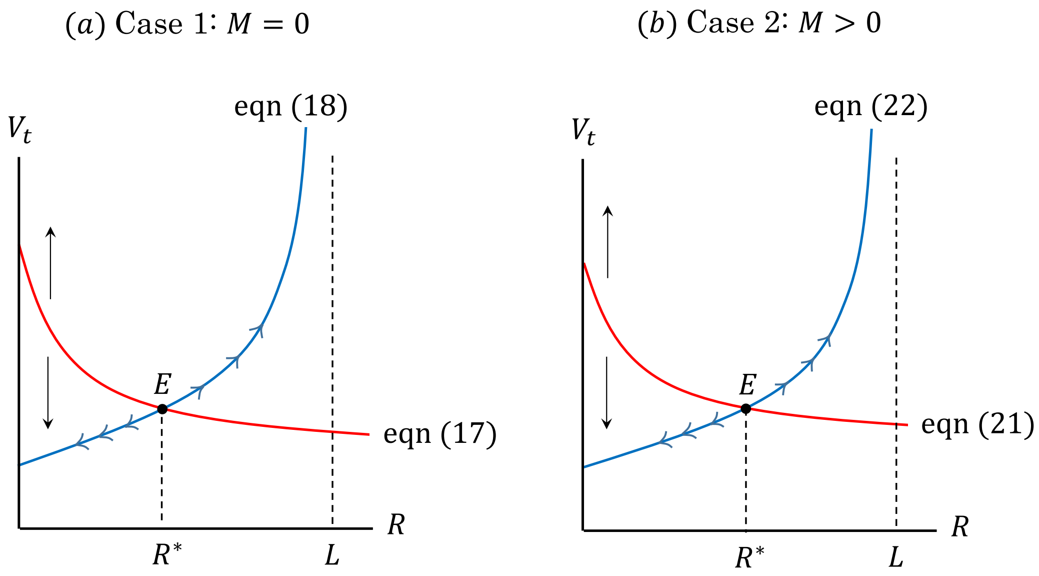

Figure 1: The steady-state.

4 Policy Effects

4.1 Competition Policy

This section investigates the impact of competition-enhancing policy on innovation, which lowers entry cost. In the model, the implication of a growth effect is same that of innovation since the economic growth rate $g^* \equiv \dot{C}/C$ is calculated as $g^* = R^* a \ln \lambda$. Therefore, we also interpret the results in the section as the growth effects of competition-enhancing policy.

Case 1: No imitators ($M = 0, R > 0$)

At first, we consider the effect of pro-competitive policy when the entry cost is sufficiently large. There is a threshold value of entry cost $\tilde{e}$ that divides the economy into two cases (See Appendix), so case 1 happens when $\tilde{e} < e < e^{\max}$.

This policy shifts curve of equation (18) downward, as in Panel (a) of Fig.2, and raises R^* along the curve of equation (17). This means that the competition-enhancing policy has a positive effect on innovation. The intuition is simple: since research firms have to pay entry cost, a smaller entry cost allows many research firms to enter the market. In this case, the reduction of entry cost can attract the research firms.

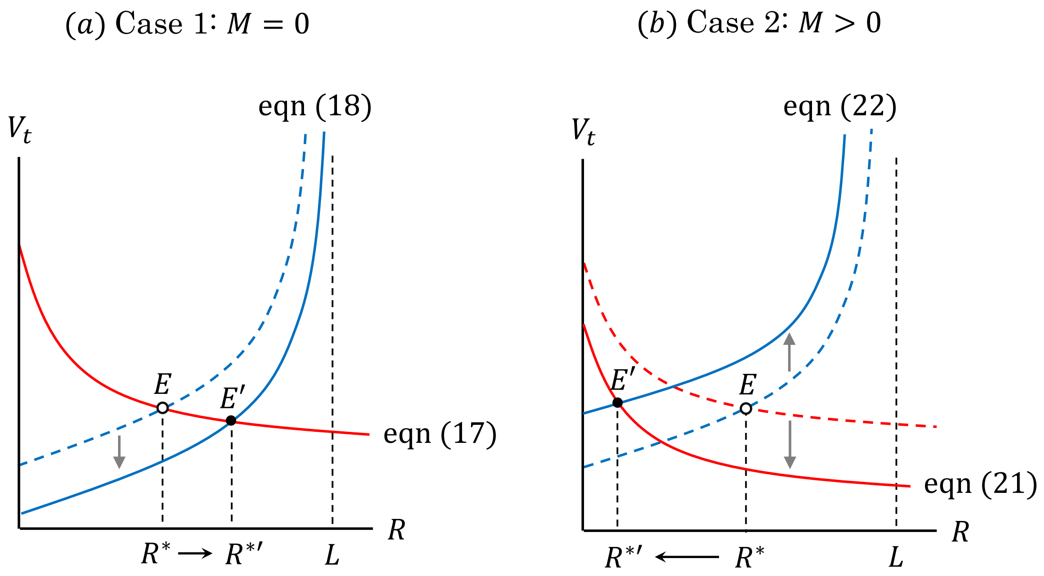

Figure 2: The competition-enhancing policy ($e \downarrow$).

Case 2: Coexistence ($M > 0, R > 0$)

However, in case 2 ($e^{\min} < e < \tilde{e}$), the competition-enhancing policy has a negative effect on innovation caused by two mechanisms.

First, the policy raises the equilibrium wage, which is the cost of R&D activities. According equation (20), the decreasing e increases the total number of followers, $\bar{N}(e)$ and this increases the labor demand in production. This shifts the curve of equation (22) upward.

Second, stronger competition reduces the expected innovation value. In case 2, entry cost e disappears under the free-entry condition of research firms since $\pi_F(N) = e$ holds. This implies that the decision of entry for research firms just depends on the expected innovation value (which declines in M^*) and wage (which increases in M^*). As a result, the policy shifts the curve of equation (21) downward.

Both shifts work to decrease R^* as in Panel (b) of Fig. 2. In sum, in case 2, the competition-enhancing policy invites more imitators and the imitators crowd-out research firms. In other words, the research firms' incentive to enter becomes weaker than that of imitators. This is opposite to that in case 1.

Note that the proxies of PMC often used in empirical studies (e.g., average Lerner's index, Herfindahl-Hirschman Index) have a monotonic relationship with the entry cost in our model since the total number of followers is strictly decreasing in $e \in (e^{\min}, e^{\max})$. Therefore, we can state that a decrease in e is a competition-enhancing policy in the

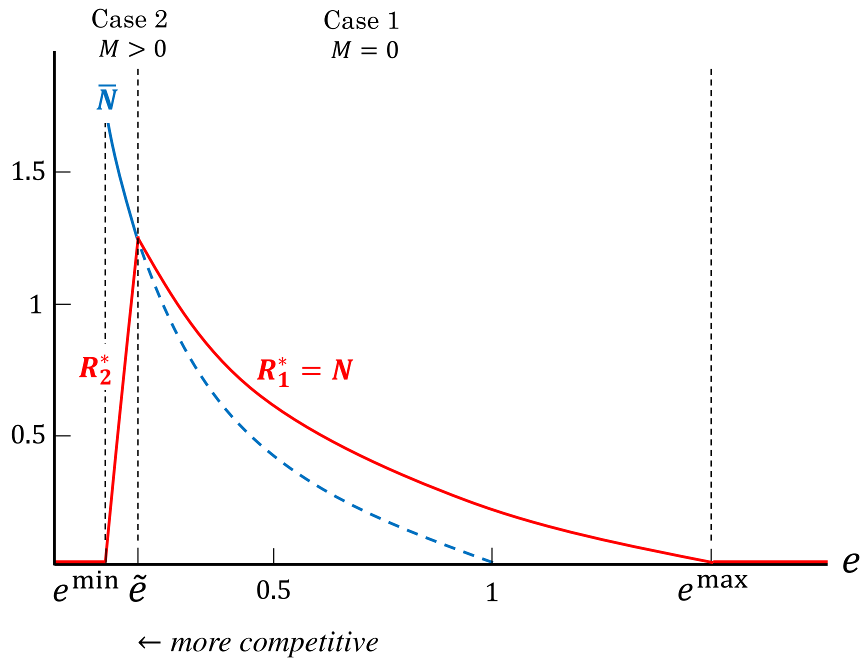

Figure 3: The number of research firms in case $h = 1, 2$ (R_h^*) and entry cost (e). The numerical example is calculated by setting $L = 10$, $\lambda = 1.2$, $\chi = 0.85$, $\rho = 0.02$, and $a = 0.01$. Under these parameters, $e^{\min} \simeq 0.12$, $\tilde{e} = 0.2$, and $e^{\max} = 1.5$. All parameter assumptions are satisfied. Note that this inverted-V result can be analytically shown.

model.

Fig.3 and the following proposition summarize the above discussion:

Proposition 1. *There is an inverted-V relationship between PMC and innovation. When the level of PMC is low ($\tilde{e} < e < e^{\max}$), the competition-enhancing policy ($e \downarrow$) has a positive effect on innovation. On the other hand, when PMC is sufficiently intense ($e^{\min} < e < \tilde{e}$), the competition-enhancing policy ($e \downarrow$) has a negative effect on innovation.*

Perhaps, this inverted-V result captures four stages in an industry life-cycle: introduction, growth, maturity, and decline. In the first stage, an innovative firm creates the emerging industry, and the entry cost must be extremely high ($e > e^{\max}$) because the new technology is not standardized. However, in the second stage ($\tilde{e} < e < e^{\max}$), only some ambitious firms enter the industry and engage in R&D activity even though they earn negative profit in each period. In the third stage ($e^{\min} < e < \tilde{e}$), because the technology is sufficiently standardized, many imitative firms enter the industry in order to earn profit and crowds out innovative firms. In the last stage ($0 < e < e^{\min}$), the industry is completely matured, and there is no room for innovation.

Although the non-monotonic relationship between PMC and innovation is similar to that discussed in earlier studies, the channels are starkly differ. Our model does not have the escape competition effect in the model by Aghion et al. (2005) because we assume that the number of firms is not fixed. In their model, even if the competition-enhancing policy decreases the current profit, two neck-and-neck existing firms have no choice but to increase their R&D efforts. However, in our model with free-entry, research firms are allowed to exit (truly escape) from the market as in case 2. Furthermore, the decrease in current profit distracts potential firms from entering the market. These effects are not considered in Aghion et al. (2005).

Welfare Implication

Here, we investigate whether the growth-maximizing $\tilde{e}$ also maximizes households' welfare. To do so, we calculate the welfare evaluated in the case where the economy starts at the steady state.

In the steady state, we have $\ln C_t = g^* \cdot t + \ln X$ from equation (2). By integrating the lifetime-utility function (1) with respect to time, we obtain welfare:

$$\begin{aligned} W &= \int_0^\infty \exp(-\rho t) \left[g^* \cdot t + \ln X \right] \\ &= \frac{1}{\rho} \left[\frac{R^* a \ln \lambda}{\rho} + \ln(L - R^*) \right]. \end{aligned} \tag{23}$$

By differentiating this with respect to R^*, we obtain

$$\frac{\partial W}{\partial R} > 0 \Leftrightarrow R^* < L - \frac{\rho}{a \ln \lambda}. \tag{24}$$

When this inequality holds, an increase in R^* also increases welfare. If $L - \rho/(a \ln \lambda) \leq 0$ holds, the inequality is violated since $R^* \geq 0$, and then, a rising R^* decreases welfare. From this result and Proposition 1, we have the following Proposition:

Proposition 2. *The growth-maximizing $\tilde{e}$ does not always maximize welfare and the welfare implication depends on the value of $L - \rho/(a \ln \lambda)$.*

(i) When $R^*(\tilde{e}) \leq L - \rho/(a \ln \lambda)$, the welfare and the PMC level have an inverted-V relationship, which is the same as that in Proposition 1.

(ii) When $L - \rho/(a \ln \lambda) \leq 0$, this relationship becomes V-shaped.

(iii) When $0 < L - \rho/(a \ln \lambda) < R^*(\tilde{e})$, this relationship is ambiguous.

From equation (6), we can also write welfare as follows:

$$W = \frac{1}{\rho}\left[\frac{R^* a \ln \lambda}{\rho} + \ln N - \ln(1 + \lambda\chi N) - \ln w\right]. \tag{25}$$

The competition-enhancing policy affects welfare through the following three channels: a decrease in e (i) always increases the number of followers N, (ii) always increases (decreases) innovation R in case 1 (case 2), and (iii) has a positive (ambiguous) effect on wage rate w in case 1 (case 2). We cannot analytically derive the total effect in both cases.[17] However, as in Fig. 4, we can numerically show all patterns written in the previous proposition by changing discount rate ρ. The inequality in (24) is satisfied if ρ is sufficiently small. This reflects that the first innovation-stimulating effect becomes stronger when ρ is small because the households consider dynamic gains from quality improvement more important than static distortion by imperfect competition. The large total labor supply L also works to satisfy the inequality because the market price of goods decreases because the wage rate in the labor market equilibrium decreases.

4.2 Patent Policy

Now, we explore the effect of strengthening patent protection on innovation. To do so, we consider the repercussions of a government raising χ in both cases.

First, we discuss the effects in case 2. Strengthening patent protection reduces the number of followers $\bar{N}$. Then, it shifts the curve of equation (21) in Panel (b) of Fig. 1 upward since $e < 1$, and this positively affects innovation. This shift reflects the Schumpeterian effect: strong patent protection increases the post-innovation profit π_L and innovation value. Furthermore, because labor demand in the production sector decreases and this puts downward pressure on equilibrium wage (R&D cost), the curve of equation (22) in Panel (b) of Fig. 1 moves downward. This also has a positive effect on innovation. Consequently, by the standard Schumpeterian effect and wage decreasing effect, innovation increases in case 2.

Proposition 3. *Strengthening patent protection ($\chi \uparrow$) spurs innovation ($R^* \uparrow$) when the PMC level is sufficiently high ($e^{\min} < e < \tilde{e}$).*

Note that the growth-maximizing level of PMC ($\tilde{e}$) becomes lower under stronger patent protection.[18] This suggests that strengthening patent protection and competition-enhancing

[17] In case 1, the third effect has a negative impact on welfare, whereas the first and second effect increases welfare. In case 2, the first and second effects are conflicting.

[18] To understand this, see Fig.3. Since strengthening patent protection reduces the number of followers $\bar{N}$, the curve of equation (20) shifts downward. From Proposition 3, we know that the graph of $R_2^*(e)$ in Fig.3 moves upward.

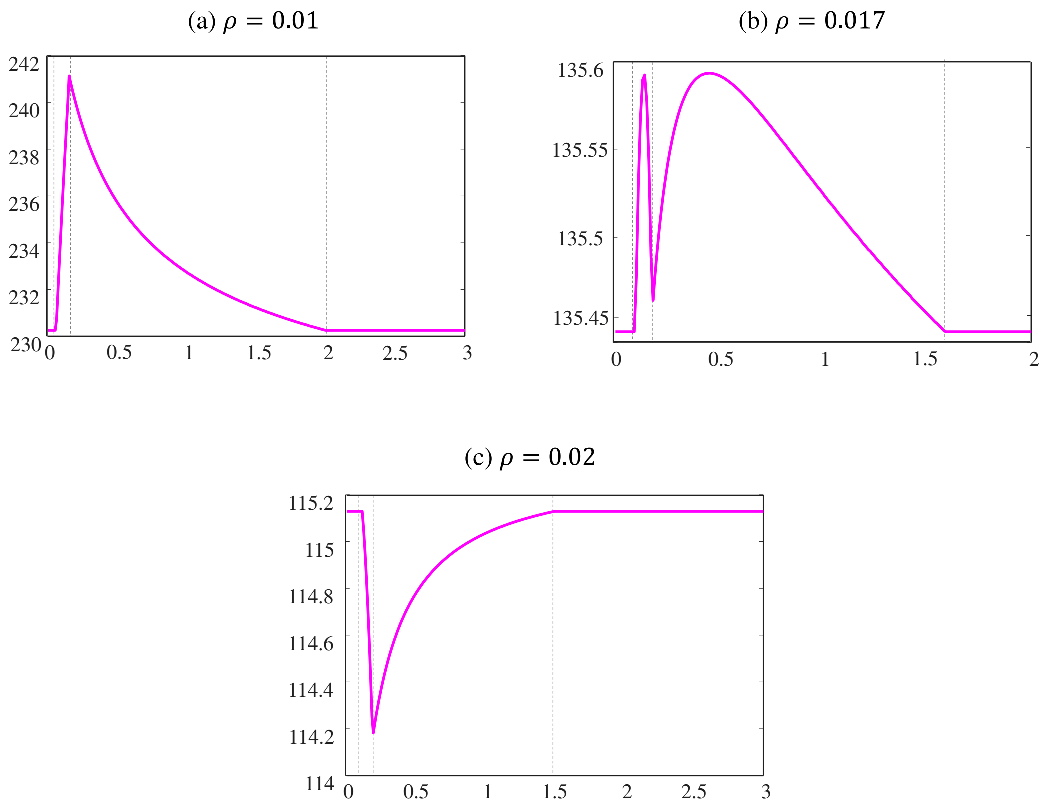

Figure 4: Welfare and entry cost under $\rho = 0.01, 0.017, 0.02$. Parameters are common to the numerical example in Fig. 3.

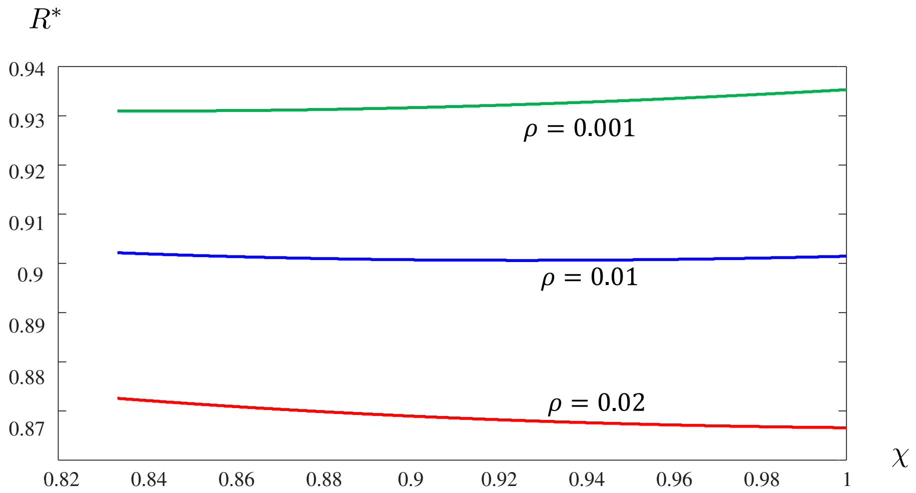

Figure 5: Comparative statics of χ. Calculated numerically by setting $L = 10, \lambda = 1.2, e = 0.5$, and $a = 0.1$. Under these parameters, we investigate the effect on innovation when $\rho = 0.02, 0.01, 0.001$. In these parameter settings, Assumption 1 is satisfied and $\tilde{e}$ is lower than $e = 0.5$.

policy may be complementary. Aghion et al. (2015) also showed the complementary relationship by using a step-by-step innovation model without free-entry as in Aghion et al. (2005). But we here show that in an EMS model, so it is also a contribution of the paper.

In case 1, the effect on innovation is complex. Strengthening patent protection has a positive impact on innovation through the Schumpeterian effect and wage decreasing effect as in case 2. However, in case 1, the policy also decreases current profit π_F and this negatively affects innovation. [19] While the curve of equation (17) in Panel (a) of Fig. 1 moves upward, the direction of the shift of equation (18) is ambiguous. However, we can anticipate that the sign of the policy effect depends on the discounted rate. If ρ is sufficiently small, the research firms may understate the decrease of current profit π_F. We numerically examine the effect of strengthening patent protection on innovation. Fig. 5 indicates that while stronger patent stimulates innovation when ρ is low, it discourages innovation when ρ is high. However, when ρ is in between, there is an ambiguous relationship.

We summarize the results as follows:

Numerical Result 1. *Strengthening patent protection ($\chi \uparrow$) has any of negative, ambiguous, or positive effect on innovation when the level of PMC is sufficiently low ($\tilde{e} < e < e^{\max}$).*

Our result differs from the findings in Chu et al. (2016), that is, a stricter patent pro-

[19] This effect disappears in case 2 because $\pi_F = e$ holds and then, the decision of entry for research firms depends on aV and w (equation (14)).

tection deteriorates growth in the long run. In case 2, our model shows that strengthening patent protection enhances innovation through the Schumpeterian effect. It is widely known that empirical findings on the effects of tightening IPR protection on innovation or economic growth are mixed.[20] To this effect, our ambiguous result is more consistent with the findings of these studies. What are the causes of this variance? To answer this question, let us consider the difference in entry between these models. In Chu et al. (2016), an entrant becomes the monopolist in a differentiated intermediate goods industry with her own patents. Strengthening patent protection attracts many entrants over time, and then, expanding the number of firms gradually decreases market share per firm. Because of this "dilution effect," the incumbents' cost-reducing R&D is discouraged in the long run. By contrast, in our model, all entrants (imitators and research firms) are initially followers who imitate the leader's technology and strengthening patent protection decreases their pre-innovation profit. In case 2, this policy reduces the number of imitators and accordingly, attracts many research firms. This implies that the results depend on whether researchers are damaged by strong patent protection.

We find that strengthening patent protection always enhances innovations in case 2, but discourages them in case 1. The results suggest a complementarity with a competition-enhancing policy, which is consistent with the empirical finding in Aghion et al. (2015), who also theoretically explain the complementarity in a model without free-entry. However, since their result depends on the escape competition effect, such complementarity disappears once we consider free entry, as Etro (2007) discussed. A key contribution of our model is that we are able to retain the complementarity even after incorporating EMS in the model.

5 Conclusion

This study developed an analytically tractable innovation model to evaluate the effect of a competition policy on innovation. To analyze the effect more realistically, we considered free entry in the product market and a situation in which only existing firms engage in R&D activities.

Our study makes three contributions to the literature. First, we reconciled the result of Aghion et al. (2005) and EMS proposed by Etro (2007). We found that a competition-enhancing policy has a non-monotonic effect on innovation, which is also in the model comprising a fixed number of firms by Aghion et al. (2005). Nevertheless, while Etro (2007) points out that non-monotonicity disappears once we consider a framework with EMS, we succeeded in retaining it using a DGE model with EMS. Second, we showed that

[20] For related studies and surveys, see Falvey et al. (2006), Rockett (2010), and Greenhalgh and Rogers (2010).

the innovation-maximizing PMC level does not always maximize welfare and it depends on parameters such as a discount rate. Interestingly, there is a case in which the welfare function has two extreme values with respect to entry cost. Finally, we investigated the effect of strengthening patent protection on innovation. The model demonstrates that stronger patent protection does not necessarily enhance innovation because it decreases pre-innovation profit and research firms exit the market. This effect does not exist in the model without free entry.

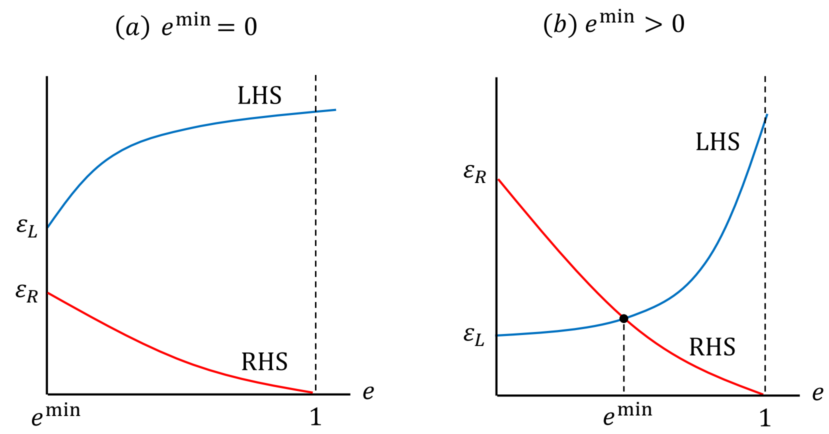

Figure 6: The determination of $e^{\min}$.

Appendix

The steady-state in case 2

We consider the existence of steady-state in case 2 given by the intersection of (21) and (22). For the existence, it is required that, at $R = 0$, the curve of (21) is upper than that of (22). The condition is

$$\frac{\left[1 - (1-\sqrt{e})/(\lambda\chi)\right]^2}{\rho} \geq \left(\frac{1-\sqrt{e}}{a\lambda\chi}\right)\left[1 + \left(\frac{1-\sqrt{e}}{\lambda\chi}\right)(\lambda\chi - 1)\right]\left(\frac{1}{L}\right). \tag{26}$$

The LHS of (26) is an increasing in e and strictly positive in the interval $0 \leq e \leq 1$, and the RHS of (26) is an decreasing in e and becomes zero at $e = 1$. Therefore, there exists a parameter region $e^{\min} \leq e \leq 1$ that satisfies the inequality in (26) where $e^{\min}$ is the minimum value. At $e = 0$, the value of LHS is $\left[1 - 1/(\lambda\chi)\right]^2/\rho \equiv \varepsilon_L$, and the value of RHS is

$$\frac{1}{a\lambda\chi L}\left[1 + \frac{1}{a}\left(1 - \frac{1}{\lambda\chi}\right)\right] \equiv \varepsilon_R. \tag{27}$$

When $\varepsilon_L \geq \varepsilon_R$ holds, we have $e^{\min} = 0$. If $\varepsilon_L < \varepsilon_R$, then $e^{\min} > 0$ uniquely exists. Fig. 6 shows these two cases.

Threshold of Entry Cost

We consider the threshold of entry cost $\tilde{e}$ that divides the economy into two cases. Such threshold can be derived by solving $\bar{N}(e) = R_2^*(e)$, where $R_h^*(e)$ is the number of research firms in the steady state in case $h = 1, 2$. Although we cannot analytically derive $\tilde{e}$, we can easily show that it uniquely exists in $(e^{\min}, 1)$. Remember that $\bar{N}(e)$ is a strictly decreasing function in e. Furthermore, we have $\bar{N} \to \infty$ when $e \to 0$ and $\bar{N} = 0$ holds when $e = 1$. On the other hand, $R_2^*(e)$ is always a finite positive value in $e \in (e^{\min}, 1)$ and a strictly increasing function in this interval. Therefore, the intersection of $\bar{N}(e)$ and $R_1^*(e)$ must be uniquely determined.

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