Innovation or Imitation:
Some Economic Performance and Social Welfare Policy Perspectives

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ABSTRACT

This paper develops a mathematical model of innovation in technology with two main characteristics. First, it discusses the endogenously made decision on not only how much to innovate, but also, how much to imitate. Second, it demonstrates that the decision to innovate or imitate are not mutually exclusive and a firm can innovate and imitate simultaneously. A mathematical model is presented, and the authors explain the barriers to innovation development and diffusion. The model is further used to investigate the effectiveness of two technology innovation and imitation policies. It is shown that an intellectual property right (IPR) policy will better function if the price of innovation is set to a level lower than the cost of innovation. The concept "superfluous innovation" (innovations whose costs are higher than their benefits) is also proposed and developed through investigating the policy of levying subsidies on innovation.

Keywords: *Appropriability, Game Theory, Imitation, Innovation, Intellectual Property Rights, Public Goods, Social Welfare*

INTRODUCTION

The tradeoff between innovation development and innovation diffusion has been widely studied in the technology change and industry performance literature. This tradeoff arises from the fact that what we do to prevent free availability of existing innovative discoveries to all producers, although beneficial from an ex-post efficiency standpoint, will fail to provide the ex-ante incentives for further innovation (Arrow, 1962; Cohen & Levin, 1989; Cohen & Levinthal, 1990). Such a dilemma is called the appropriability problem.

In spite of its long history, the problem of how firms decide on innovation-related issues is still of much interest and importance. In its simplest form, the appropriability problem is concerned about a firm deciding on whether or not to innovate - or how much to innovate - based on the extent to which the innovation is appropriable (Arrow, 1962; Quirmbach, 1986; Ireland & Stoneman, 1986; Levin, 1988; Saracho, 1996; Sakakibara, 2002).

A newly emerging theme, mostly seen in Boldrin and Levin's (2009a, 2009b, 2009c,

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2009d) recent works is divisibility according to which, the knowledge embodied in goods or people is not costlessly available. Therefore, if one firm is to imitate another, it should devote some time, money and energy into buying some copies of the goods in which the knowledge is embodied (Boldrin & Levine, 2008, 2009a). In other words, there is no free and unpriced "spillover." Therefore, the matter of interest, here, is not only the innovator deciding how much to innovate due to the degree of appropriability, but also, how the imitator decides on how much to imitate due to the degree of divisibility (which we will refer to as imitability). Boldrin and Levin (2009b, 2009c, 2009d) have studied the appropriability and divisibility decisions and their effect on market size and structure.

In this paper, we study the interdependency between innovation and imitation and show that a firm can be an innovator and an imitator at the same time. While the two-fold role of a firm has been addressed sporadically in the field literature (such as Spence, 1984), none of these studies have considered the interdependency between innovation and imitation. Not all industries can be partitioned into innovators (i.e. north) and adopters (i.e. south) as argued by Helpman (1993) and Akiyama and Furukawa (2009). This gap in the current literature might have led to some misdefinitions of the problem. For instance, it is always postulated that a firm has less incentive for investing on easily imitable innovations only because it may then be imitated by others (Arrow, 1962; Quirmbach, 1986; Ireland & Stoneman, 1986; Levin, 1988; Saracho, 1996; Sakakibara, 2002; Spence, 1984).

In this paper we construct a model to address the question of how much to imitate in the context of the two-fold role of a firm (i.e. innovator and imitator) in a strictly competitive game setting. We will investigate how firms decide on how much to innovate and imitate and how their decisions affect social welfare under different conditions of imitability. We will also investigate the effects of two widely-noted policies: first, the intellectual property right (IPR) and second, the policy of treating innovation as a public good. We argue that under different conditions of imitability, these policies may have different effects on the outcome of the complex decision structure and hence on social welfare.

The remainder of the paper is organized as follows. In the next section, we provide the main assumptions of the model and then we present the mathematical model. In the following section, we provide the results obtained from solving the mathematical model. We also explain the insights gained from the solution results and compare them to the current appropriability literature. We then investigate the subsidy and IPR policies and examine their effect on the proposed model. The last section is devoted to conclusions and future research directions.

ASSUMPTIONS OF THE MODEL

For the sake of simplicity, we assume that there are two firms producing the same product at the same price in the market. We also assume equal market share but different production costs for the two firms. Since price and market share are assumed to be equal, the firm with lower production cost will make more profits. The market is also assumed competitive, thus, one firm's cost reduction will lessen the price and consequently the profit of the other firm. As we will see in the following sections, *appropriability* is captured in the model by linking production cost of each firm to the profit of the other firm.

Each firm can develop innovation by itself or imitate the innovation developed by the other firm. Developing or imitating one unit of innovation results in reduction in the firm's production cost but it has some costs associated with it. The effects of innovations have been considered solely on production cost, not on the quality of goods. Such an assumption is commonplace in the literature (Cole, 2001).

One unit of innovation developed by a firm and one unit of innovation imitated from the other firm will equally reduce production cost although the cost of developing one unit of innovation may differ from that of imitating it.

Therefore, the problem faced by each firm is to optimize the extent of its innovation development and imitation (i.e. to maximize its profit). In other words, the decision-making variables for each firm are the extent of innovation development and imitation and the objective is to maximize profit.

We further assume perfect information in the model which is also a common assumption in innovation diffusion models (Hylton, 2003; Goodwin et al., 2005). This assumption is realistice since each firm can predict how the other firm will decide. If one firm did not know that the other firm will imitate it, appropriability would not have evolved as a major concern in the literature on innovation diffusion and political economy.

In this model, there is no variable named "welfare" but the price of the product in the market is considered as an index of social welfare. Such an assumption is made on one hand for the sake of the simplicity; on the other hand, it accords with the common assumption of welfare economics which perceives more consumption as an index of welfare (*i.e.*, ISEW or the index of sustainable economic welfare) (Nordhaus & Tobin, 1972; Daly & Cobb, 1989). In our model, a lower price is an indicator of a higher consumption rate since the lower price, although not leading to an increase in consumption, leaves more disposable income for people.

MATHEMATICAL MODEL

The mathematical notations and definitions presented in Appendix A are used to derive the models presented in this section. The price of the product is obtained from Eq. (1):

$$\text{Price} = P_0 + \frac{Cu_1 + Cu_2}{2} \qquad (1)$$

where *Price* is the market price of the product and Cu_1 and Cu_2 are the total costs of producing one unit of the product for firm 1 and firm 2, respectively. The relationship between the price and Cu is based upon the assumption of a competitive market and therefore a reduction in the total cost results in a reduction in the market price. P_0 is a constant indicating the average profit per unit. Although the price could have been formulated as in a Cournot duopoly, we did not do so for two reasons: simplicity and the assumption of strict competition. First, our main objective in this study is to investigate how firms' decisions on innovation and imitation interplay in a competitive environment. Focusing on the form of the competition will only add to the complexity of the model and divert us from the main objective of this study. Second, the competition represented by Eq. (1) is strict because the sum of the firms' profits is equal to the constant P_0. Cournot setup could not be used here because of the assumption of strict competition. Although we are not going to use the theorems related to strictly competitive games, we do use its logic when providing explanations for the results.

We find each firm's profit by multiplying its profit per unit times the number of units sold (Q):

$$\Pr ofit_1 = \left(\text{Price} - Cu_1\right) \times Q = \left(P_0 + \frac{Cu_2 - Cu_1}{2}\right) \times Q \qquad (2)$$

where Q is equal for both firms and Eq. 2 can be used similarly to find the profit for firm 1. In addition, the appropriability is captured by these equations since Cu_1 is not the sole determinant of Profit_1. Cu_2 also plays a role in determining the profit for firm 1- the less Cu_2, the less Profit_1. This is the reason why firm 1 decides on less innovation when its innovation is imitated.

The total costs for each firm consists of two components: direct or variable costs and indirect or fixed costs. The direct costs of producing a product can be represented by:

$$Cu_{\text{Direct}} = C_0 \times \left(\frac{m}{i_d + i_i}\right) \qquad (3)$$

where C_0 and m are coefficients for regulating the dimension of the equation. The dimension of C_0 is the same as that of Cu_{Direct} (the unit of money over the unit of product) and dimension of m is the same as that of i_d and i_i (the units of innovations and imitations, respectively). $i_{d,1}$ represents the units of innovations developed in firm 1 and $i_{d,2}$ represents the units of innovations developed in firm 2. Similarly, $i_{i,1}$ and $i_{i,2}$ are the units of innovation imitated by firm 1 and firm 2, respectively. Therefore, firm 1 imitates from firm 2 and vice versa. As we mentioned earlier, the effect of one unit of innovation on the production cost has nothing to do with whether the product is developed within the firm or it is imitated. This fact is also captured by Eq. (3).

The second component of the firm's total cost is indirect production expenses including costs of developing and imitating innovations:

$$Cu_{\text{Indirect}} = \frac{\int_0^{i_d} C_d d_x + \int_0^{i_i} C_i d_x}{nQ} \tag{4}$$

where C_i is the marginal cost of imitating one unit of innovation and C_d is the marginal cost of developing one unit of innovation. As we will see later, the C_i's are formulated subject to the following constraints: $i_{i_1} \leq i_{d_2}$ and $i_{i_2} \leq i_{d_1}$, because no firm is able to imitate more than the amount of innovation developed by the other firm. n equals the number of years during which the innovation is usable; that is, the time period during which the innovation has an effect on the total costs before becoming obsolete due to substitution. n is assumed exogenous and constant. The reason for including n in the denominator of the formula is that all of the terms in this model represent a period of one year (*i.e.* this is a static one-year model). Consequently, only one out of the n years during which the innovation affects Cu_{Direct} is considered. Therefore, it is necessary to take into consideration $1/n$ th of its associated cost. In addition, we include Q in the denominator because Cu_{Direct} is an overhead cost.

The marginal cost of imitating innovation for firm 1 is obtained by Eq. (5) in which the aforementioned constraint has been taken into account:

$$C_{i,1} = I_0 \times \frac{i_{i,1}}{i_{d,2} - i_{i,1}} \tag{5}$$

According to this equation, where $i_{i,1} = i_{d,2}$, the cost of imitating one more unit will approach infinity. Therefore, the constraint $i_{i,1} \leq i_{d,2}$ is applied to Eq. (5). A similar formula is used for the second firm's imitation cost. I_0 is a coefficient which makes the dimensions of the two sides consistent and is also an index for the imitability of the innovation. That is, the less I_0, the less expensive is the imitating innovation, making it more imitable. If I_0 is negligible or zero, the innovation is easily imitable and if I_0 is large, the innovation is non-imitable. I_0 plays a significant role in this study since the main goal of this paper is to analyze the situation in different states of imitability. I_0 is considered the independent variable in all the analyses and is the variable on the horizontal axis in all of the figures.

The marginal cost of developing innovation is assumed to be equal to the constant D_0:

$$C_{d,1} = C_{d,2} = D_0 \tag{6}$$

which means that the per-unit expense of developing innovation is D_0. If we substitute Eq. (5) and (6) into Eq. (4) and integrate the two sides of the resulting equations, C_i and C_d can be eliminated and the equation below will be obtained:

$$Cu_{\text{Indirect},1} = \frac{D_0 \times i_{d,1}}{nQ} - \frac{I_0}{nQ} \times \left[i_{i,1} + i_{d,2} \times \ln\left(\frac{i_{d,2} - i_{i,1}}{i_{d,2}} \right) \right] \quad (7)$$

The total cost of each firm equals the sum of its direct and indirect costs.

$$Cu = Cu_{\text{Direct}} + Cu_{\text{Indirect}} \quad (8)$$

We have thus far modeled the physical structure of the problem. Next, we model the firms' decisions which involve four equations; two of them are concerned with how much innovation the firm should develop, and the other two correspond to how much innovation the firm should imitate.

Firms determine the degree of their innovation imitation based on the amount of their innovation development. As mentioned before, the effect that one unit of imitated innovation has on the direct cost of production equals the effect of one unit of developed innovation. Therefore, if $C_i > C_d$, the firm can reduce its indirect costs by developing one more unit of innovation in exchange for one less unit of imitation, while keeping its direct costs unchanged. Similar conditions exist for the situation where $C_i < C_d$ [1]. As a result, the optimum decision concerning imitation is made under the assumption that $C_i = C_d$, and, hence:

$$C_{i,1} = C_{d,1} \quad (9)$$

$$C_{i,2} = C_{d,2} \quad (10)$$

and two other equations maximize the firms' profits with respect to developed innovations:

$$\frac{\partial \text{Profit}_1}{\partial i_{d,1}} = 0 \quad (11)$$

$$\frac{\partial \text{Profit}_2}{\partial i_{d,2}} = 0 \quad (12)$$

MODEL SIMULATION AND THE ANALYSIS OF THE RESULTS

In order to solve this model, we need to solve Eqs. (9-12) for four unknown quantities: $i_{d,1}$, $i_{d,2}$, $i_{i,1}$ and $i_{i,2}$. It should be noted that the perfect information assumption is used here. For example, when substituting Eq. (10) in Eq. (11), we are implicitly assuming that firm 1 is completely aware of the second firm's policy on imitation. In addition, the main objective is to study how the imitability of an innovation impacts upon the simulation results. Therefore, all the parameters are taken into consideration as constants except for I_0 which is used to sketch the figures.

We first equalize the marginal cost of innovation development to that of the innovation imitation (Eq. (9) for firm 1 and Eq. (10) for firm 2). As a result, the amount of imitation is obtained in terms of the amount of development. By solving Eq. (9) for $i_{i,1}$ the amount of imitation for firm 1 is:

$$i_{i,1} = i_{d,2} \times \frac{D_0}{D_0 + I_0} \quad (13)$$

and the amount of imitation for the firm 2 is:

$$i_{i,2} = i_{d,1} \times \frac{D_0}{D_0 + I_0} \quad (14)$$

As Eqs. (13) and (14) show, while I_0 is negligible, a major fraction of the developed innovations is imitated. When I_0 is large, the amount of imitation is minimal.

Eq. (13) and (14) show how the innovation imitated (i_i) by one firm is related to the innovation developed (i_d) by the other firm. When these equations are substituted in Eqs. (11) and (12), the i_is are eliminated and Eq. (11) and Eq. (12) are turned into a system of two equations with two unknowns. By solving this system, we obtain $i_{d,1}$ and $i_{d,2}$ as follows:

$$i_{d,1} = i_{d,2} = \frac{D_0 + I_0}{2D_0 + I_0} \times \sqrt{\frac{mC_0 I_0 nQ}{\left(D_0 + I_0\right) \times \left[D_0 + I_0 \times \left(\frac{D_0}{D_0 + I_0} + \ln \frac{I_0}{D_0 + I_0}\right)\right]}} \quad (15)$$

As expected, the amount of developed innovation for both firms is equal due to the symmetry assumption in the problem definition. As I_0 approaches infinity, i_d approaches $\sqrt{\frac{mC_0 nQ}{D_0}}$. This fact is proved in Appendix B.

The result of the model (Eq. (15)) is presented schematically in Figure 1.

$$(D_0 = 1, m = 5, C_0 = 1, nQ = 100)$$

A further analysis of the solution reveals some significant results. First and foremost, the amount of developed innovations is an increasing function of I_0. In other words, if imitation costs increase, firms will tend to develop more innovations. Second, interestingly, those willing to anticipate the effect of imitation costs on the amount of innovation imitation and development without considering the model may conclude that rising imitation costs have a positive effect on the innovation development (resulting in more innovation) and have a negative effect on the innovation imitation (resulting in less imitation). However, as the results show, this is not the case with every level of I_0. Increasing the imitation costs may also increase imitation. It is not difficult to justify this seemingly surprising result based upon the model relationships. When imitation costs rise, a smaller part of the developed innovations is imitated (*i.e.* the spillover fraction falls). Eq. (16) can be derived from Eqs. (13) and (14), introducing the spillover fraction as a decreasing function of I_0 (Figure 2).

$$\frac{i_{i,1}}{i_{d,2}} = \frac{i_{i,2}}{i_{d,1}} = \frac{D_0}{D_0 + I_0} \quad (16)$$

On the other hand, since the total amount of the developed innovation has increased, the amount of imitation might also rise in spite of the reduction in the spillover fraction. We consider price as an index of welfare due to our interest in studying the effect of imitation costs on social welfare. Figure 3, shows the price variations for different I_0 s.

As shown in this figure, the price is highest when I_0 has its lowest value. The reason is that no innovation will be developed because of the appropriability problem. Thus, there will be no imitation either (Figure 1).

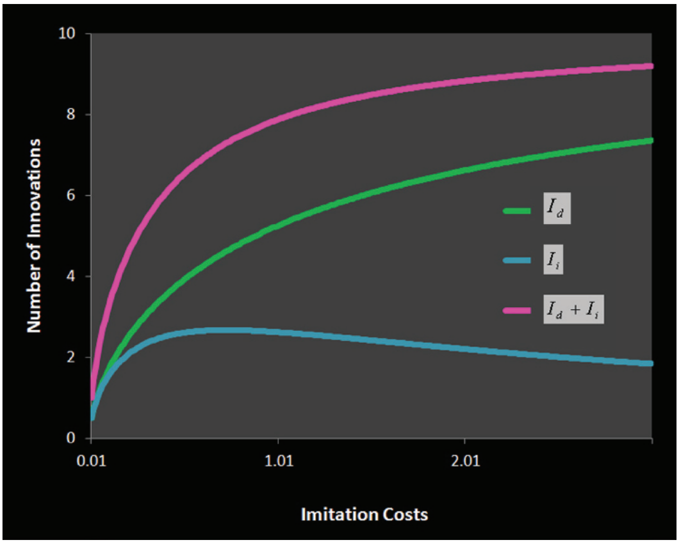
Finally, it is noted that our supposition of the existence of only two firms, weakens the importance of imitation. In a market with, for example, five firms, each firm can imitate from four other firms. When the total amount of the developed innovation is calculated, imitated innovations will gain a coefficient of 4 and developed innovations will gain a coefficient of 1.

Figure 4 demonstrates the widely mentioned inverted U-shaped relationship between the amount of imitability of an innovation and social welfare (O'Donoghue & Zweimuller, 2004; Furukawa, 2007). Although the importance of imitation in reality might be more than what our model shows, analyzing a situation in which there are numerous firms is beyond the scope of this paper.

EXAMINING THE POLICIES ON THE MODEL

In this section, we study two policies that a government can consider towards innovation imitation between firms. We also show the effects of these policies on social welfare. We do not compare the performance of these policies

Figure 1. The number of units of developed, imitated and total innovation in accordance with I_0



and identify priorities. We intend to show *how* different policies function and provide some insights into this inherently complex problem rather than defining outputs for decision making as suggested by Lyneis (1999). While analyzing each policy, two points should be considered: First, how the policy is modeled and entered into the model equations. That is, how manipulating that policy changes the model parameters and equations. Second, how these changes in the equations affect the solution results.

Establishing an IPR for Innovation Policy

One of the prevalent policies for preventing innovation from free imitation is an IPR for innovation policy (Gallini & Scotchmer, 2001). The IPR for innovation policy can resolve the appropriability problem by making the innovation available to other firms in the market in exchange for a pre-determined amount of money to the innovation developer firm. This policy changes two parts of the model. First, imitation cost will increase as much as the price of buying the innovation:

$$C_{i,1} = I_0 \times \frac{i_{i,1}}{i_{d,2} - i_{i,1}} + P_i \quad (17)$$

where P_i is the price of buying one unit of innovation. By substituting Eq. (17) in Eq. (9) and solving for $i_{i,1}$, the amount of imitated innovation will be obtained:

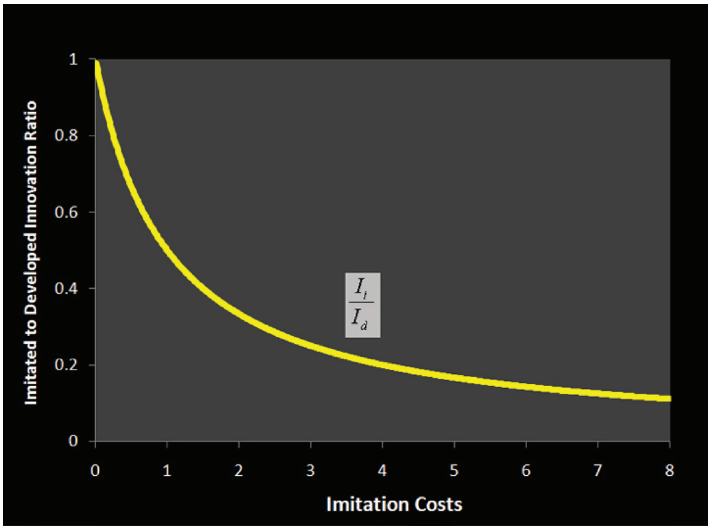
$$i_{i,1} = i_{d,2} \times \frac{(D_0 - P_i)}{(D_0 - P_i) + I_0} \quad (18)$$

Second, by implementing this policy, the first firm's indirect costs will go down according to the equation below (there is a similar change for the second firm):

$$Cu_{\text{Indirect},1} = \frac{\int_0^{i_{d,1}} D_0 d_x + \int_0^{i_{i,1}} C_{i,1} d_x - \int_0^{i_{i,2}} P_i d_x}{Q} \quad (19)$$

The amount for developed innovation can be obtained by solving this set of equations with the method described earlier:

Figure 2. The ratio of the imitated to developed innovation in accordance with I_0



$$i_{d,1} = i_{d,2} = \frac{(D_0 - P_i) + I_0}{2(D_0 - P_i) + I_0} \times \sqrt{\frac{mC_0 I_0 nQ}{\left[\left(D_0 - P_i\right) + I_0\right] \times \left\{ D_0 + I_0 \times \left[\frac{\left(D_0 - P_i\right)}{\left(D_0 - P_i\right) + I_0} + \ln \frac{I_0}{\left(D_0 - P_i\right) + I_0} \right] - \frac{2P_i\left(D_0 - P_i\right)}{\left(D_0 - P_i\right) + I_0} \right\}}} \quad (20)$$

Figures 5, 6 and 7 show the changes in the amount of developed innovation, innovated imitation and product price in terms of I_0 for both the pre-implementation and post-implementation cases.

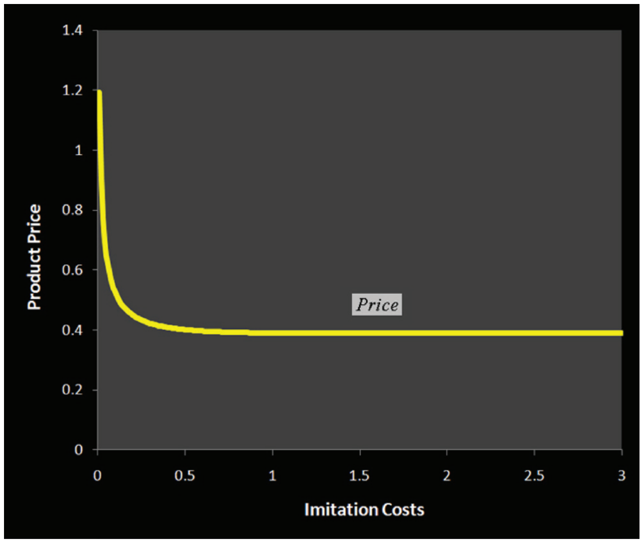
As shown in Figure 5, the implementation of the IPR policy stimulates more innovations. Two main reasons can be suggested to understand this phenomenon. First, this policy causes firms to develop more innovations when they know for sure that their innovations will not be imitated easily. Second, the innovator firm knows that if another firm wants to imitate its innovation, it must pay for it. In other words, the production cost of the innovator firm will decrease and the production cost of the imitator firm will increase (which is good for the innovator firm due to the strictly competitive nature of the game). Therefore, the innovator firm can generate some revenues in exchange for their innovation.

Meanwhile, Figure 6 bears another interesting result. The IPR policy, an anti-imitation policy, leads to more imitations. This policy not only lessens the spillover *percentage*, but it also causes more innovations to be developed. As a result, more *absolute* value of the innovations will be imitated.

Taking Figures 5 and 6 into consideration, we can see that an IPR policy is not effective for large I_0 s. In other words, for large I_0 s, innovation development, innovation imitation and product prices are the same whether or not this policy is implemented. The reason is because this policy increases imitation costs and it does not work for cases where the imitation costs are already high.

Another issue of concern is how to set P_i to better handle the IPR policy. Note that if

Figure 3. The product price for each firm in accordance with $I_0(P_0 = 0.2)$



the amount of P_i is chosen to be more than D_0, there will be no reason for the firms to imitate from each other because the marginal cost of innovation development will always be less than that of innovation imitation $(C_d < C_i)$. In other words, when P_i is large, developing an innovation is always more economical than imitating the innovation and no imitation will occur.

This important result gives us an interesting insight into adopting suitable policies for innovation prices. As shown in Figure 7 (product price versus I_0 for $P_i = D_0 / 2$), the product prices for low I_0s is less than those for infinite I_0s. In other words, lower prices are reached when P_i is set to quantities smaller than D_0. Therefore, our model proposes setting innovation selling prices smaller than innovation development costs so that this policy functions more effectively.

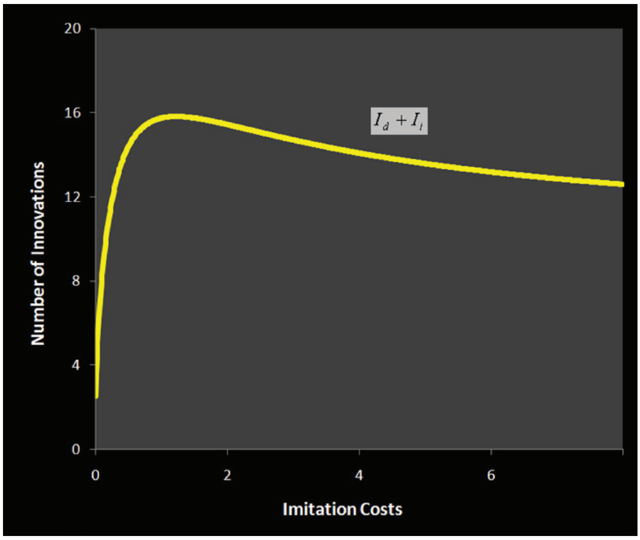
This analysis suggests the importance of making a distinction between the two purposes of the IPR policy mentioned above. The first purpose is to motivate the firms by guaranteeing a protection against imitation; and, the second purpose is to motivate them with the profit from selling their innovations. If P_i is very large, it will certainly protect firms against spillover. But, this very protection can also discourage imitation and therefore may result in a loss of earnings for the firm since its innovation is not imitated by others. Hence, a large P_i may reduce the incentives to develop innovations.

Establishing an Imitable Innovation as Public Goods (Tax-Subsidy Policy)

There are two elements in the definition of public goods. First, using public goods by someone is not an impediment for others to use it. Second, it is very costly to prevent someone from using public goods (Varian, 1992). It is obvious that public goods can't be produced by the market because of the free riding problem (Waldman, 1987).

Innovation entails the first characteristic of public goods. When an innovation is used by one firm, it does not prevent other firms from doing so. Meanwhile, if the innovation is imitable, it will also have the second characteristic. It can be

Figure 4. The total units of innovation in a market of 5 firms



stated that the appropriability problem is nothing but the free riding problem in a specific case that the innovation of the product is imitable.

Consequently, it seems that introducing a tax system for compensating firms' innovation costs could be an appropriate policy for encouraging firms to develop more innovations that are easier to imitate. Governments can collect a fraction of the total innovation costs from both firms in the form of taxes. That is, if the innovation development costs for firms 1 and 2 are $C_{D,1}$ and $C_{D,2}$, respectively, the government will levy a tax equal to $\alpha\left(C_{D,1} + C_{D,2}\right)/2$ on each firm. Then, the government can use these collected taxes to pay $\alpha C_{D,1}$ to firm 1 and $\alpha C_{D,2}$ to firm 2 $(0 < \alpha < 1)$. Accordingly, the government makes firms participate in each other's innovation development costs. This policy changes the equations as follows (similar modifications should be applied to the equations concerning Firm 2):

$$Cu_{\text{Indirect},1} = \frac{(1-\alpha)\int_0^{i_{d,1}} D_0 d_x + \alpha \int_0^{i_{d,2}} C_{d,2} d_x - \int_0^{i_{i,1}} C_{i,1} d_x}{nQ} \tag{21}$$

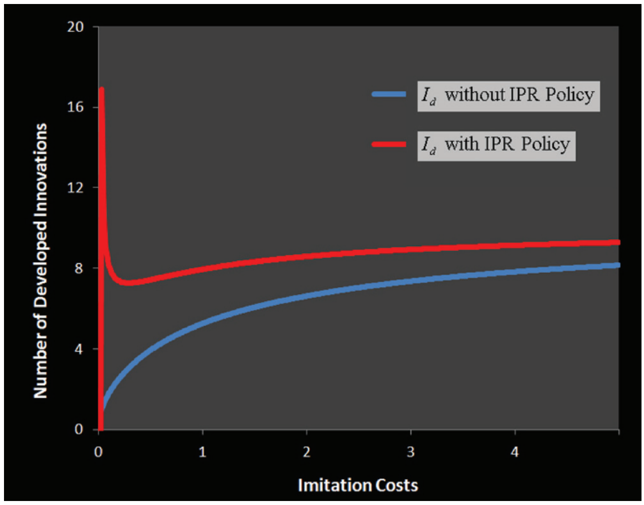
$$i_{i,1} = i_{d,2} \times \frac{D_0(1-\alpha)}{D_0(1-\alpha) + I_0} \tag{22}$$

α is a coefficient which shows what fraction of firms' innovation costs is subject to the tax-subsidy policy. In fact, α is an index of how strictly the government enforces the tax-subsidy policy. If α equals zero, it means that the government collects no taxes at all. In other words, Eqs. (21) and (22) are the same as Eqs. (4) and (13), representing the no tax condition in the model.

The amount of developed innovation can be obtained by solving this set of equations with the method described earlier:

$$i_{d,1} = i_{d,2} = \frac{D_0(1-\alpha) + I_0}{2D_0(1-\alpha) + I_0} \times \sqrt{\frac{mC_0 I_0 nQ}{\left[D_0(1-\alpha) + I_0\right] \times \left\{ \begin{array}{l} D_0(1-\alpha) + I_0 \times \\ \left[\begin{array}{l} \dfrac{D_0(1-\alpha)}{D_0(1-\alpha) + I_0} + \\ \ln \dfrac{I_0}{D_0(1-\alpha) + I_0} \end{array} \right] \end{array} \right\}}} \tag{23}$$

Figure 5. The total units of developed innovation (with and without IPR policy $(\frac{P_i}{D_0} = 0.5)$*)*

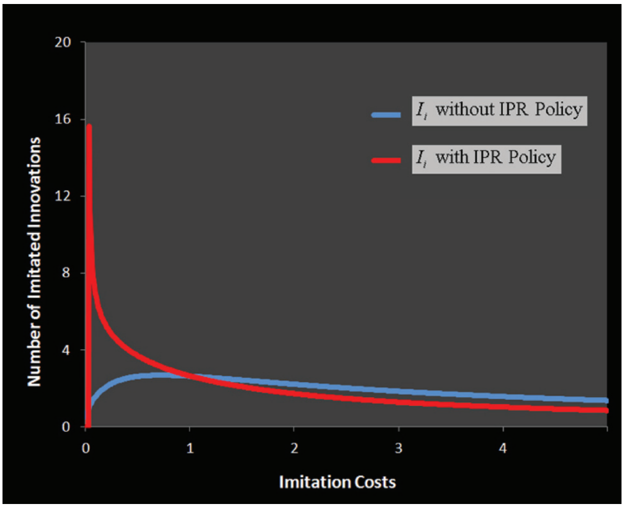


Figures 8 and 9 show the amount of developed and imitated innovations versus I_0 (Figure 8 schematically represents Eq. (23)). Product prices are also shown versus I_0 in Figure 10 (in order to study welfare).

As shown in Figure 8, implementing a tax-subsidy policy stimulates firms to develop more innovations for all quantities of I_0 because firm 1 knows that firm 2 will bear a part of firm 1's innovation costs (a similar story for firm 2). The benefits to the firm are twofold. First, this could result in a reduction of the firm's innovation development costs and ultimately a reduction in the total costs. Second, it will lead to an increase in the rival firm's costs which is beneficial for the innovating firm due to the strictly competitive nature of the game.

As shown in from Figure 10, the tax-subsidy policy decreases the total production cost for relatively low I_0 s. This might be due to the fact that innovation development occurs less when I_0 is low and this policy induces firms to develop more innovations. Figure 10 also shows that when I_0 is large, the tax-subsidy policy not only does not reduce the total production cost, but rather increases it. When analyzing this apparently strange result, it should be taken into consideration that more innovations do not necessarily lead to a higher level of welfare. More innovations lead to more welfare only when the benefits of innovation changes exceed its associated costs. As we already mentioned, while this policy is implemented, a percentage of each firm's innovation development costs will be imposed on the other firm. Therefore, firm 1 starts to develop innovations in a large scale because it pays less for its innovation development in comparison with the situation in which there is a no tax-subsidy policy. That is, with a tax- subsidy policy, firm 1 imposes a part of its innovation development costs on firm 2 by means of the tax collected from both of them. Firm 2 acts exactly in the same way and a portion of firm 2's innovation development costs will be imposed on firm 1. In other words, although both firms pay less for developing the innovations, they inadvertently suffer from each other's costs, so they will develop "*superfluous innovations*" (innovations whose costs are higher than their benefits) which can lead to higher total costs and hence higher prices.[2]

Figure 6. The total units of imitated innovation (with and without IPR policy ($\frac{P_i}{D_0} = 0.5$))



In summary, the tax-subsidy policy is only appropriate for the conditions in which the innovation is imitable, that is, it has low imitation cost (*i.e.* low I_0). In other conditions, this policy leads to *superfluous innovations* and increases production costs.

This result further validates our model since we have already stated that any innovation can be considered as public goods where I_0 is low. Therefore, when I_0 is high, innovation cannot be considered as public goods, implying that the free riding problem will not occur. Each firm tends to develop as many innovations as it needs while tax-subsidy policy results in more developing innovations than are needed.

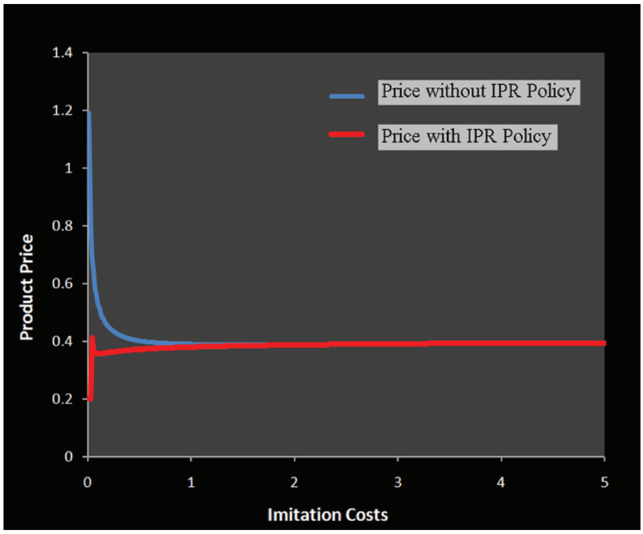
Note that one of the model's assumptions was that market demand is inelastic, that is, the sales quantity (Q) is fixed and is not affected by the price. Such an assumption is not necessarily true for all kind of markets since demand is generally elastic in realistic circumstances. When demand is elastic, the tax-subsidy policy will not create as much negative effect as our model shows. If an increase in innovation development leads to higher prices (having superfluous innovation), higher prices will lead to less demand and less Q, and less Q leads to less profit for the firms. In the real world, firms make decisions on the basis of their profits, so a decrease in profits will guide them to give up developing innovations in a way that is unprofitable.

The superfluous innovation effect, however, is not the only damaging effect of the tax-subsidy policy on the performance of the system. Another effect is that the tax-subsidy policy decreases the marginal cost of innovation development, with the marginal cost of imitation remaining unchanged. Therefore, as shown in Figure 9, we should expect the spillover fraction, and maybe even the absolute value of imitation to decrease [3] (see Eqs. 16 and 22). We should also note that this effect could not be captured with a model not endogenizing the imitation decisions (*e.g.* Spence, 1984).

CONCLUSIONS AND FUTURE RESEARCH DIRECTIONS

The model introduced in this paper explained how the appropriability problem might arise from the interactions between firms. The above-mentioned model differs from the present

Figure 7. The product price (with and without IPR policy ($P_0 = 0.2, \frac{P_i}{D_0} = 0.5$))



models in the literature in that it considers two firms which both can simultaneously develop and imitate innovation; therefore, two key points about the firms' decisions are considered simultaneously in this model. First, a firm's decision on how much innovation to develop influences its decision on how much to imitate and vice-versa. Second, a firm's decision about how much to innovate and imitate is dependent on rival firms' decision. We have already examined the effect of imitability of innovation on social welfare through a simple framework which is also close to the real world. In this analysis it was indicated that the imitability of an innovation might not only reduce the extent of creating innovation (known as appropriability) but also reduces the degree of imitating innovations.

We used the model to analyze two policies using a descriptive rather than a prescriptive approach. That is, our purpose was mainly to give insights into the problem, and not to prescribe a solution. We illustrated that IPR policy leads to more innovation development in two ways. First, it guarantees that the firm's innovations will not be easily imitated (it appropriates innovation). Secondly, it guarantees that if the firm's innovations are imitated, it will earn a profit from selling that innovation and also an equal cost will be incurred to the imitating competitor. It was also shown that the latter function is not fulfilled when the intellectual property is priced high.

The results have also shown that imitable innovation (having low I_0) can be considered as public goods. By simulating the model, we observed that in this case, tax-subsidy policy might result in more innovation development and more social welfare. Meanwhile, it was noted that this policy does not function properly in the case of non-imitable innovations (having high I_0). Meanwhile, we showed that as I_0 increases, the effect of the tax-subsidy policy gradually becomes less effective and even harmful to welfare since it causes a large amount of superfluous innovation to be developed. While the aforementioned insight is quite interesting, the main contribution of investigating the effects of a tax-subsidy policy is the proposition of "superfluous innovation".

The output of this work includes not only the insights driven from the model, but also the model itself. This model can be used as an instrument for analyzing how different factors affect the appropriability problem and its rec-

Figure 8. The total units of developed innovations (with and without tax-subsidy policy)

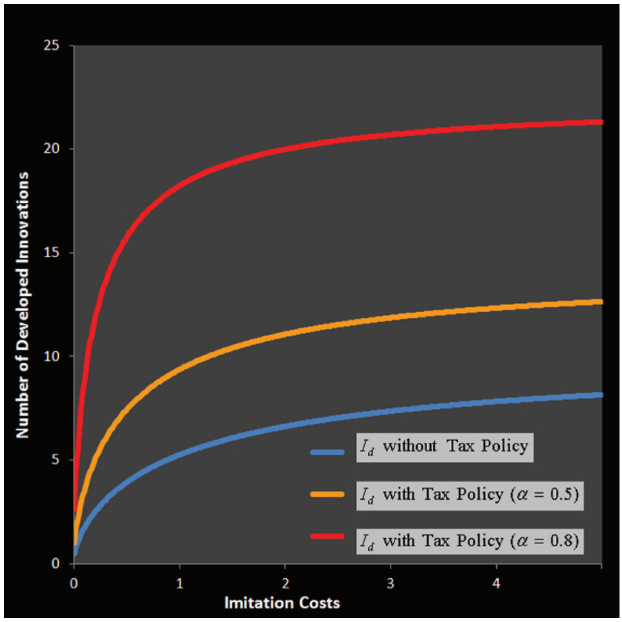


Figure 9. The total units of imitated innovations (with and without tax-subsidy policy)

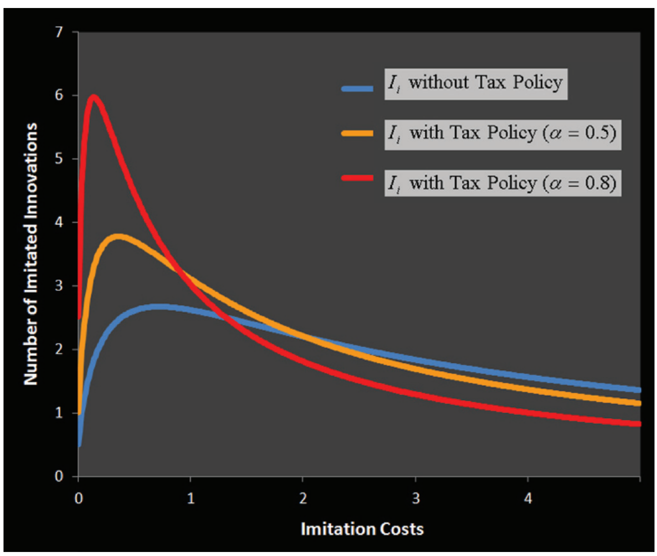
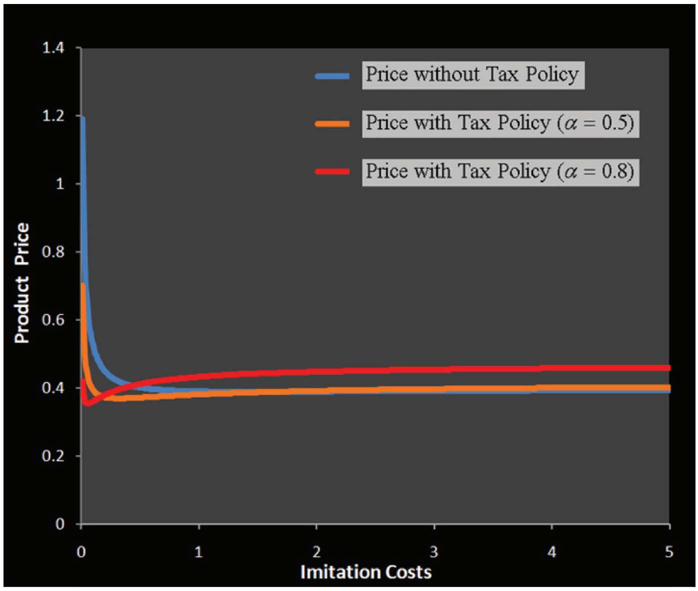


Figure 10. The product price (with and without tax-subsidy policy ($P_0 = 0.2$))



ommended policies. Some of these important factors are: asymmetry in production costs or imitation costs between two firms, asymmetry of firms' sizes (which heightens the importance of economies of scale), and innovation obsolescence time, etc. For example, some factors such as cost structure or market share of the two firms can be considered as asymmetric and the results could be solved and interpreted for an asymmetric case.

Furthermore, the boundary of this model can be extended in some aspects. For example, one way might be adding uncertainty effect to the model and then studying interactions between appropriability and uncertainty by omitting the perfect information assumption. Such an omission could lead to the transformation of our static model to a dynamic structure because when firms do not know, they should learn and learning is a dynamic phenomenon. This might be the reason why Arrow (1962) has used some dynamic terms such as "pre-invention" and "post-invention".

Another interesting extension of the model is to consider innovation's obsolescence time as endogenous rather than external and exogenous since some innovations are substituted for others. The rate of the innovation development might affect its life time (*i.e.*, I_d may affect n) and ultimately impact the results and policies extracted from the model. In addition, it would be interesting to investigate the effects of possible cooperation between firms on the amount of innovation development and imitation. In order to do this, one should replace the simple strictly competitive market structure of our model with a Cournot structure - or some other standard structure which allows for the possibility of cooperation and examine the effects of collusions on innovation related issues. Finally, it would be interesting to study our model in the context of the theory of international political economy and the rapidly changing policies and economic conditions of the international community. More precisely, the interlink between economics and politics and the strategy that the state develops to ensure economic stability (Evaghorou, 2010). The systems thinking approach suggested by Kamppinen et al. (2008) could also be useful in understanding and managing the multitudes of conditions and effects that constitute economic stability.

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ENDNOTES

1 Such a formulation captures the fact that a low rate of imitation can occur not only when the imitation process is costly, but also when the innovation development is not difficult to implement.

2 Now, we can question the recommendation that all policies should be designed in such a way to encourage more innovation.

3 This effect could be greater even when the number of firms is greater than 2.

APPENDIX A.

Table A1. Mathematical notations and definitions

$C_{d,1}$	Marginal cost of developing 1 unit of innovation in firm 1
$C_{d,2}$	Marginal cost of developing 1 unit of innovation in firm 2
$C_{D,1}$	Total cost of developing innovation in firm 1
$C_{D,2}$	Total cost of developing innovation in firm 2
$C_{i,1}$	Marginal cost of imitating 1 unit of innovation in firm 1
$C_{i,2}$	Marginal cost of imitating 1 unit of innovation in firm 2
$Cu_{Direct,1}$	Direct production costs for firm 1
$Cu_{Direct,2}$	Direct production costs for firm 2
$Cu_{Indirect,1}$	Indirect production costs for firm 1
$Cu_{Indirect,2}$	Indirect production costs for firm 2
Cu_1	Total costs for firm 1
Cu_2	Total costs for firm 2
D_0	Cost of developing 1 unit of innovation
$i_{d,1}$	Total units of innovation developed by firm 1
$i_{d,2}$	Total units of innovation developed by firm 2
$i_{i,1}$	Total units of innovation imitated by firm 1
$i_{i,2}$	Total units of innovation imitated by firm 2
I_0	A parameter representing innovation imitability
n	Life time of innovation (years)
Price	Price per unit
Profit_1	Profit of firm 1
Profit_2	Profit of firm 2
P_i	Cost of buying 1 unit of innovation under IPR
P_0	Average profit per unit of the good
Q	Sales volume for each firm
α	A fraction of the firms' innovation costs which is subject to tax- subsidy policy

APPENDIX B.

We stated that as I_0 approaches infinity, i_d approaches $\sqrt{\frac{mC_0nQ}{D_0}}$. This fact is proved here.

The amount of developed innovations can be obtained through the equation below:

$$i_{d,1} = i_{d,2} = \frac{D_0 + I_0}{2D_0 + I_0} \times \sqrt{\frac{mC_0I_0nQ}{\left(D_0 + I_0\right) \times \left[D_0 + I_0 \times \left(\frac{D_0}{D_0 + I_0} + \ln \frac{I_0}{D_0 + I_0}\right)\right]}}$$

Using the following equation for the natural logarithm:

$$\ln\left(1 + x\right)_{x \to 0} \sim x - \frac{x^2}{2} + \ldots$$

We see that as I_0 (imitation cost) approaches infinity, the amount of developed innovations approaches:

$$\lim_{I_0 \to \infty} I_d = \sqrt{\frac{mC_0I_0nQ}{I_0 \times \left[D_0 - I_0 \times \frac{1}{2} \times \left(\frac{D_0}{D_0 + I_0}\right)^2\right]}} = \sqrt{\frac{mC_0nQ}{D_0}}$$