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Imitation versus Innovation Costs: Patent policies under common patent length*

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Abstract

This paper investigates the interaction between innovation and imitation costs for heterogeneous ideas (industries). It analyzes the effect of various patent-related policies under the common patent length across different industries. It also looks at a policy that will strengthen trade secrets such as the Soleau envelope policy. Under the common term of patent with moderate assumption about the joint distribution of costs, the model predicts the existence of imitating products which are successfully invented around the original patent.

Keywords: Costly imitation, Technology outflow, Patents, Innovation and imitation costs, Sector heterogeneity, Patent-related policy.
JEL classification: O31; O33; O34; O38; L13

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1 Introduction

The literature on optimal patent policy typically pursued the optimal length of patent. However, in the real world, the patent length is usually predetermined by law. Partially, international harmonization contributes to the determination of the fixed term length of patents across different industries. For most developed countries, the patent term is 20 years across different product categories. Some say this 20 year length in practice is too long and it is almost meaningless for certain industries which face fierce competitions. One of the reasons why 20 year length can be meaningless is that the speed at which similar products are invented around the original patent becomes faster and it is usually the case that the similar products (we call them *imitation* in this article) can be successfully launched before the original patent expires in the predetermined fixed term.

For example, in the market for LCD (Liquid Crystal Display) panel, SHARP, a Japanese company, is the original patent holder (of many technologies relating to LCD) and was a dominant manufacturer up to the fourth generation, 4G, of the panel toward the end of 20th century.[1] But the dominance did not seem to last until many relevant patents expire. Japanese manufactures had over 80% market share in production capacity in 1997, but lost its share to 13% (as oppose to Taiwanese 45% and Korean 38%) in 2006. In less than 10 years, the share held by Japanese was taken by Taiwanese and Koreans. It seems that the patent held by Japanese manufacturers did not protect them for the full length period of their patents. Taiwanese and Korean manufacturers were successful in inventing around the patents held by the Japanese. Not only SHARP lost its competition in LCD display market with East Asian imitations, but also the company is said to be on the verge of bankruptcy in 2012. (According to many magazine and newspaper articles in Japanese around November 2012.)

This article analyzes what types of patent strategies can be taken by innovators using a theoretical model in which ideas (industries or firms) are heterogeneous. Ideas differ from one another along two dimensions. One dimension is the cost of innovation, represented by $c > 0$, which is incurred by an innovator in order to make an original idea marketable (and patentable). Another is the cost of imitation, represented by $k > 0$, which is incurred by rival firms in order to invent around the original patent held by an innovator. Given above two parameters, an idea (product or industry)

[1] The size of the panel is represented by generation; the 4G is 680 x 880 and 730 x 920. The 4 G was up to the 23 inch display and the 5 G made 42 and 60 inches available.

can be characterized by a vector $(k, c) \in \mathbb{R}^2_+$.

Although most previous literature on patent policies sought for an optimal length of patent,[2] this article's model takes the term length of patent to be given and examines the optimal patent decisions for idea holders in various industries. Given these choices by innovators, we consider the effects of various policies that affect the patenting decisions of each innovator (firm). One policy is to affect the inventor's decision between patenting and trade secrecy. (Later we will analyze the Soleau Envelope policy as an example.) Another policy is to affect the sizes of each component of a vector (k, c). Some policies can affect both innovation and imitation costs. Some other policies can affect only one of them. There are policies that can affect (k, c) in the long run and other policies that can affect it in the short run.

When we consider the innovator's decision to patent or to keep the innovation secret, we can refer to the system of "Enveloppes Soleau" (the Soleau Envelope) in France and Belgium. The Soleau Envelope system (within a first-to-file patent system) is a way for innovators to keep its "trade secret" as secret and yet to be protected its legal right to use the technology as a first inventor by creating a way to register the trade secret in an official manner like a la Soleau envelope. When an innovator create some idea and he wants to keep it secret for some reason (maybe he thought the idea can be easily invented around if the crucial process is revealed in its patent publication, or maybe there are still rooms for some improvement before applying to the patent system, etc.), he put all the necessary information (description, blueprints, explanation of the processes, etc.) into an sealed envelope (the Soleau Envelope) and register at the Patent office (not as a patent but as a trade secret). The Soleau Envelope system allows the original innovator to use this dated and sealed envelope (the Soleau Envelope) as an evidence to prove that he is the first inventor on this innovation and ask for the prior-use exclusion from patent-infringement when someone else later sued him for an infringement of the relevant patent.[3] Usually most society with first-to-file patent system protects trade secret in the prior-use exclusion clause when the trade secret is proven to be invented earlier than the patent holder, but the prior-use is, in reality, hardly used because the burden of proof is too severe without a system like the Soleau Envelope. This is the first article to analyze the Soleau Envelope system using formal economic modeling.

Policies that can affect (the joint distribution of) a vector (k, c) are nu-

[2] For example, please see Nordhaus (1969, 1972), Denicolo (1996, 1999), Gallini (1992), Gilbert and Shapiro (1990), Scotchmer (2004), Scotchmer and Green (1990), and so on.

[3] In a short paper written in Japanese, Masuda (2008) described the Soleau Envelope system succinctly.

merous. Because both components are the costs of research and development (R&D), education in science and technology affects the joint distribution (maybe in the long run). Any policies that affect R&D expenditure of firms (or public funds) also changes the joint distribution.

Because k is the cost to invent around the pre-existing innovation, it is affected by the degree of breadth of the original patent. The fundamental definition of breadth of patent is how different another product must be in order not to infringe the original patent. According to Scotchmer (2004), its definition can be framed in two ways: (1) product space ... how substitutable these goods are; (2) technology space ... how costly it is to find a noninfringing substitute for the product market. This article primarily focuses on the definition in terms of (2) technology space. What policies might affect the breadth of patent? The government can set a general standard for patent infringement. In this case, the policy can affect the distribution of k alone. The court decision for a particular product (case) can determine the breadth of patent for each case separately. In this case, the policy affects a particular location (and size) of k.

In most cases, we take patent term length as given, but we can also look at the effects of policy which changes the term length itself. However, this article does not pursue the optimal length of patent. To be able to calculate the optimal length of patent, we need to know the exact joint distribution of (k, c) which we do not specify in this article. Also, the reason we conduct most of our analyses taking patent length as given is that we would like to analyze the effects of various policies within the framework which is close to the reality.

The remaining part of the article is organized as follows: the next section develops the basic model of costly imitation. Section 3 extends the basic model by introducing multiple ideas (industries) with heterogeneous imitation and innovation costs. Section 4 discusses effects of various policies. The final section summarizes the results and suggests some possible extensions.

2 The Basic Model

Let us first introduce a basic model of innovation and imitation for an idea (industry). Later we will expand this basic model by introducing the heterogeneous cost of innovation and imitation for many different ideas (industries). But for now consider only one idea (industry). This part closely follows the model of costly imitation introduced by Gallini (1992).

2.1 Assumptions for basic model for an industry

In this section I outline the assumptions of the simple model for one idea or industry. Suppose there is one innovator. The innovator comes up with an idea for a particular good (which will form an industry) and decide whether to pay R&D (research and development) cost $c \geq 0$ to make an idea marketable (commercially viable) and possibly patentable. I assume here that all innovators will succeed in research once they invested c. If the prospect of future market is not bright, then the innovator might avoid investing in R&D. (This option may not be interesting in one idea (industry) model like the one in Gallini (1992), but it will become important when we consider policy issues with many ideas or industries.) Once the good is developed, the innovator faces an option of whether the innovation should be patented or kept secret. (This innovation cost c is not explicitly discussed in Gallini 1992.)

If this new product is patented, then the original inventor (firm) is awarded a monopoly over the innovation for T periods, after which the content of innovation is available at no cost to all firms in a competitive market. Although the patent can protect the innovator from direct copying of the innovation, rival firms can invent around the original invention and will come up with a patent-noninfringing imitation at cost $k \geq 0$. For the same industry, I assume that all potential rivals share the same imitation entry cost of k.[4] Following Gallini (1992), I assume there is a free entry into this imitation market. Because of free entry, the rival imitators will enter the market until the profits from imitation are dissipated. Suppose there are $m \geq 0$ imitators. Further assume that the original innovator and m imitators will compete simultaneously in the market in an oligopolistic manner, and each of them (including the innovator) earns gross profit per period of $\pi(m)$. Therefore, the imitations are considered perfect substitute for the original product and all production firms are considered symmetric once they engage in production.[5] At this moment I make the oligopolistic structure (demand and cost) of the model standard in the literature such as the one described in Mankiw and Whinston (1986).

The original innovator can also choose not to patent the product. In this case, the innovator keeps the innovation as trade secret and will face the risk of duplication by some other firms. Here I assume with probability $p \in (0, 1]$ that the innovation becomes available to others at no cost, in which case the original inventor earns zero return on investment; otherwise

[4] This assumption is made in favor of simplicity.

[5] These assumptions are made also in favor of simplicity.

it enjoys the monopoly status indefinitely. If p were 0, then no innovators would prefer the patent option because the option of trade secrecy strictly dominates. Therefore, we only consider the case where $p > 0$. Later, when we examine various patent policies, we should note that the application of *the Soleau Envelope* can be thought of as reducing the size of p.

The timing of the decisions is as follows: [1] a potentially marketable idea arrives in the mind of an innovator. [2] The innovator decides whether to invest in R&D by paying c or not to do research (because expected profit does not cover the cost). Only by paying c, the idea becomes marketable (and patentable). [3] The innovator (who invested ex ante) chooses whether or not to patent. [4] If the innovation is patented, then rival firms make decisions about imitation. [5] Production takes place and profits to firms accrue.

Because, in the end, this article will look at the governmental policy regarding patent system, there will be a precedent step to this whole process: [0] The government choose patent related policies in various ways: it may choose the optimal patent system by picking T, or the length of patent T is determined by international coordination such as TRIPS and it may try to affect p to some extent by introducing some policy like Soleau envelope. The government can also affect the sizes of both c and k by changing the requirement for patent filing application and by changing the judgment of patent infringement when the like products are introduced. The government can influence the joint distribution of (k, c) by education and R&D related policy change. However, I will discuss this step in later sections as we will expand the model into heterogeneous industries. For now let us take policy variables to be given.

As usual, we solve this game by backward induction. Let us start from stage [4] and [5].

2.2 Imitation decisions by rivals

We start from the timing after which the innovator has patented his or her innovation. A rival firm considers entry decision into a possible imitation market. For the imitation to be profitable, the following condition must be satisfied.

$$\pi(m) \int_0^T e^{-rt} dt = \pi(m)\beta(T) \geq k \tag{1}$$

where $r \in (0, 1)$ is a common discount rate per period and let $\beta(T)$ denote the cumulative discount factor for time length T. An imitation firm takes T, m, and k as given. T is a duration of patent protection which can be a subject of change in stage [0] where the government *could* pick an optimal patent policy. $\pi(m)$ is a gross profit for a firm (innovative and imitation firms are assumed symmetric in the production market) from marketing of the product when the number of rival firms is m. The right hand side of inequality, k, is a cost of the competing rival firms to invent around the original patent. In this section we will treat k to be given exogenously, but in the next section we will look at various sizes of k which varies from idea (industry) to idea (industry).

Let us first consider the property of the gross profit function $\pi(m)$. Because m is the number of imitating firms, it can possibly be an integer. But here we assume m to be nonnegative real number in order to avoid complications from the integer constrained analysis. (See Mankiw and Whinston 1986 for results contrasting the analyses with or without the integer constraint.) It is safely assumed the function $\pi(m)$ to be nonincreasing. If the market conduct is the one of Cournot, then the function is strictly decreasing. Here we assume that $\pi'(m) \leq 0$.[6]

Free entry assumption does not allow the inequality in (1) to be strict for $m > 0$ when we allow the non-integer m case.

Consider now the different duration of patent protection T. If T is long, then left hand side of inequality (1) will be larger given m. (Note that $\beta(\cdot)$ is strictly increasing in T.) If T is too short (shorter than a certain threshold), then it might be the case that the condition (1) will never hold for any $m \geq 0$. Such a threshold depends on the size of k and let us denote the threshold as $T_M(k)$.[7] This can be calculated as

$$T_M(k) = -\ln\left(1 - \frac{rk}{\pi(0)}\right)\frac{1}{r} \tag{2}$$

where $\pi(0)$ is a monopoly profit.

For $T < T_M(k)$, there is no imitation. For $T \geq T_M(k)$, imitation is abound and the number of rival firms satisfies

$$\pi(m)\beta(T) = k \tag{3}$$

because rivals will imitate until profits are dissipated. Because of free entry (into imitation market) assumption, rival imitators will earn just enough

[6] The assumption that profit is nonincreasing in the number of entrants is rigorously proved in Proposition 1 of Mankiw and Whinston (1986). In their proof, monotonicity is proved for net profit inclusive of entry cost. But the result holds true for gross profit used in this model.

[7] Subscript M is from iMitation or *Mane* in Japanese.

gross profit over the patent duration such that the accumulation of return covers the imitation (entry) cost k.

We now turn to one stage backward: patent decision by the original innovator, namely, stage [3].

2.3 Patent decisions by the innovator

The innovator can choose between patenting the innovation and keeping it as trade secret. After the original innovator patents the product, there can be two cases: the one without imitation and the other with m imitators.

(i) Patent and no imitation case (P) If there are no imitators (maybe because cost of imitation k is too high for rivals or T is short enough[8]), then the expected profit of the innovator from patent without imitation $E\Pi^P$ is written

$$E\Pi^P = \pi(0) \int_0^T e^{-rt} dt = \pi(0)\beta(T) \tag{4}$$

where $r \in (0, 1)$ is the same common discount rate as rivals. $\pi(0)$ represents monopoly profit during the patent life T. Note that the value of this (4) depends positively on T. (See the dotted (partially solid) line $OABC$ in Figure 1.)

(ii) Patent and imitation case (M) If there are m imitators (maybe because k is low and/or T is long), then the original innovator also earn its (per period) return $\pi(m)$ along with other rival imitators. Using (3), the expected profit for the innovator with imitation $E\Pi^M$ is written as

$$E\Pi^M = \pi(m)\beta(T) = k \tag{5}$$

which has the same value as rivals. So the return no longer depends on the patent duration T. Because of free entry assumption, the number of entering imitators m will adjust such that $\pi(m)\beta(T) = k$ holds for any T within the relevant range. (See the horizontal red line EBF in Figure 1.)

[8] According to Gallini (1992), both will be determined simultaneously in a single industry case, but two conditions can be separate in multiple industry case like the model in this paper.

(iii) No patent and trade secrecy case (S) When the innovator decides to keep the innovation as secret (trade secret option), then the expected profit from this option $E\Pi^S$ is

$$E\Pi^S = (1-p) \cdot \pi(0) \int_0^{\infty} e^{-rt} dt = (1-p)\pi(0)\beta(\infty) \tag{6}$$

because with probability p the innovation is available to anyone at no cost and the market will become competitive and the innovator makes no profit, otherwise the innovator keep its monopoly indefinitely. (See the horizontal blue line GAH in Figure 1.)

We now have to look at the relative sizes of expected profits from these three cases (i) Patent: $E\Pi^P$, (ii) iMitation: $E\Pi^M$ and (iii) trade Secret: $E\Pi^S$. These lines are drawn in Figure 1 as follows: (i) $E\Pi^P : OABC$, (ii) $E\Pi^M : EF$ and (iii) $E\Pi^S : GH$. The relative locations of these lines will determine the optimal choices by an innovator and rivals.

2.3.1 No imitation region: Patent versus Secrecy

If imitation cost is too high, i.e., $k \geq \pi(0)\beta(\infty) = \pi(0)/r$, then no rival firms enter in the imitation market for any T. (This is the case when the horizontal line EF is above the dotted line $\pi(0)\beta(\infty)$ in Figure 1.) $E\Pi^M$ is irrelevant. We only compare $E\Pi^P$ and $E\Pi^S$. Given the value of $p > 0$, we can calculate the threshold value of $T_S(p)$ above which patenting dominates trade secrecy. (In Figure 1, it is point A.) We can calculate this as

$$T_S(p) = -\frac{\ln p}{r} \tag{7}$$

which is always nonnegative because $p \leq 1$.

Lemma 1 *For a given value of $p \in (0, 1]$ and for a large size of imitation cost $k \geq \pi(0)/r$, the innovator decides to patent if $T \geq T_S(p)$, and decides to keep the innovation secret if $T < T_S(p)$.*

After patenting, imitation is impossible for $k \geq \pi(0)/r$.

2.3.2 Imitation region: Imitation versus No imitation

If $k < \pi(0)/r$, then imitation can occur depending on the size of patent length T. By comparing $E\Pi^P$ (the curve $OABC$ in Figure 1) and $E\Pi^M$ (the horizontal line EF in Figure 1), we can calculate the threshold value

$T_M(k)$ above which imitation occurs. (In Figure 1, it corresponds to an intersection point B.) We draw this value from equation (2):

$$T_M(k) = -\frac{\ln\left(1 - \frac{rk}{\pi(0)}\right)}{r} \tag{8}$$

which is always positive.

Lemma 2 *For sufficiently small size of imitation cost $k < \pi(0)/r$, the imitation occurs if $T \geq T_M(k)$, and the imitation does not occur if $T < T_M(k)$. For the values $k \geq \pi(0)/r$, no imitation occurs for any T.*

The line $OABF$ in Figure 1 illustrates the expected return for the innovator for $k < \pi(0)/r$ who decides to patent. The region OAB follows $E\Pi^P$ when $T < T_M(k)$, the region BF follows $E\Pi^M = k$ when $T \geq T_M(k)$. We still do not know if the innovator want to patent or keep it secret.

2.3.3 Imitation region: Patent versus Secrecy

One more concern is the relative size between $E\Pi^M$ and $E\Pi^S$. If $k < E\Pi^S = (1-p)\pi(0)\beta(\infty) = (1-p)\pi(0)/r$, then trade secrecy strictly dominates patents for all T.

Lemma 3 *If the size of imitation cost is small, i.e., $k < (1-p)\pi(0)/r$, then the innovator will choose trade secrecy for any T.*

Otherwise, the line $GABF$ in Figure 1 shows the expected return for the innovator when $(1-p)\pi(0)/r \leq k < \pi(0)/r$. When $k \geq (1-p)\pi(0)/r$, we know that $T_S(p) \leq T_M(k)$. We summarize this result.

Lemma 4 *If the size of imitation cost is intermediate, i.e., $k \in [(1-p)\pi(0)/r, \pi(0)/r)$, then the innovator chooses trade secrecy for low value of $T < T_S(p)$, and decides to patent the innovation if $T \geq T_S(p)$. After patenting, the innovator can maintain its monopoly for $T < T_M(k)$ and face competition from imitating rivals for $T \geq T_M(k)$.*

The expected return for the innovator is summarized as a proposition.

Proposition 1 *(i) When the imitation cost takes a lower value, i.e., $0 \leq k < (1-p)\pi(0)/r$, the innovator always keeps the innovation secret and earns*

$$E\Pi^S = (1-p)\pi(0)/r$$

for all duration of patent T.
(ii) When the imitation cost takes an intermediate value, i.e., $(1-p)\pi(0)/r \leq k < \pi(0)/r$, the innovator changes his behavior based on the duration of patent and earns

$$\begin{cases} E\Pi^S = (1-p)\pi(0)/r & \textit{for} \quad 0 \leq T < T_S(p) \\ E\Pi^P = \pi(0)\beta(T) & \textit{for} \quad T_S(p) \leq T < T_M(k) \\ E\Pi^M = k & \textit{for} \quad T_M(k) \leq T \end{cases}.$$

(iii) When the imitation cost takes a higher value, i.e., $\pi(0)/r \leq k$, there is no imitation from rivals, and the innovator earns

$$\begin{cases} E\Pi^S = (1-p)\pi(0)/r & \textit{for} \quad 0 \leq T < T_S(p) \\ E\Pi^P = \pi(0)\beta(T) & \textit{for} \quad T_S(p) \leq T \end{cases}.$$

The proposition shows the expected return for the innovator for different values of T and k.

Proof. This proposition summarizes the results in all lemmas 1-4 above. ■

For small size of imitation cost, the innovator keeps the invention secret and earns the expected return from secrecy. For large size of imitation cost, the innovator may choose to patent the innovation for large patent duration.

For intermediate size of imitation cost, the return for the innovator looks like Figure 1: $GABF$. There are 3 regions. For small duration, the innovator chooses trade secrecy (GA). For intermediate duration, the innovator chooses patenting and keeps its monopoly position (AB). For large duration, the innovator's patent will be imitated by rival firms and earns fixed return which is the same as the size of the imitation cost (BF). These choices in space of k and T can be summarized in Figure 2.

3 Extension

The question pursued by Gallini (1992) is the following: "Given a particular size of k, what is the optimal length of patent T?" This article asks a different set of questions. Given T, what are the optimal strategies for heterogeneous innovators when there are costly imitations? Given optimal decisions by heterogeneous inventor firms, what are the effects of different patent-related policies? In order to pursue these, we vary imitation cost k which was treated fixed in Gallini (1992). So we assume that k differ across different industries.

Also, this article explicitly introduces the cost of innovation $c \geq 0$. This will add one more step in the strategy space for an innovator: whether to conduct R&D or not in the first place. Also, it is natural to assume the innovation cost can also vary especially when we assume imitation costs vary as well. So let us also assume that c differs across different industries.

Thus an innovator's idea may differ in both innovation and imitation costs. We can now think that many ideas can be jointly distributed over a two-dimension space $\mathbb{R}_+^2 \equiv [0, \infty) \times [0, \infty)$. An idea can be represented by a vector (k, c). Under the current policy configuration, the idea (k, c) can be developed by paying innovation cost c and can be expected to face the competition by imitators whose imitation entry cost is k.[9] In the following analysis, we will search for optimal strategy for a particular idea innovator within this two dimension space.

But first, let us summarize the relationship between heterogeneous k with various size of patent term T.

3.1 Heterogeneous imitation cost and patent term

When we vary both k and T, the decisions taken by an innovators with an idea which can take different values of imitation cost k are shown in Figure 2. Figure 2 is basically mapping out the results of Proposition 1 in a two-dimension space of k and T.

3.1.1 When vary both k and T

In Figure 2, the curve $Oa(p)b$ comes from the imitation threshold equation (8) that shows the combination of k and T above which the imitation occur. The shaded region where the union of sets $k < (1-p)\pi(0)/r = k_S(p)$ and $T < T_S(p)$ will define represents the innovator's preference on trade secrecy. Note that the value of $T_S(p)$ is given by (7). For the combination (k, T) which is within $\{k \geq k_S(p)\} \cap \{T \geq T_S(p)\}$ region represents where the ideas are patented. The region above and left of the curve $a(p)b$ represents where

[9] In this paper, I follow the analysis by Gallini (1992) and assume that the value of imitation cost k is fixed for a particular idea (k, c). However, we can also think that the value of ex post k can differ depending on the choice made by the original innovator. For example, the value of k can take different values if we compare two cases: (1) the inventor patents the idea and (2) the inventor keeps the idea secret. The imitation cost k can be smaller in the first case of patent because some technological information must be made public after patenting. This point was made by Professor Masahisa Fujita and I thank him for teaching me a possible extention to this modeling.

we observe imitations and the region below and right of the curve represents the patented monopoly without imitations.

3.1.2 Soleau envelope policy in Figure 2

Note that the position of point $a(p)$ changes if the value of $p \in (0, 1]$ changes. The location of a point moves along the curve Ob up or down. For a large value of p it will move down left. For a small value of p it will move up right.

We do not posit that the government can freely change p, because the fundamental location of p is determined by many factors that the government cannot control. However, we assume that the governmental policy can affect p in a small scale. The policy cannot make it jump, but can move a little from the original location. (The essence is similar to the intervention policy in floating foreign exchange market.)

A policy like Soleau envelope can be expressed as $\alpha = 1 - \varepsilon$ where $\varepsilon > 0$ is a very small number. A policy can affect p such that p becomes $\alpha p < p$.

Definition 1 *Given $\varepsilon > 0$ being a very small number, a Soleau envelope policy is defined as $\alpha = 1 - \varepsilon$ where the probability p becomes αp.*

In Figure 2, the Soleau envelope policy changes the location of $a(p)$ to $a(\alpha p)$ which is up right. The change will induce the region of trade secret to be larger and the region of patenting to be smaller.

3.2 Research decision by the innovator

Although the model in previous section closely follows Gallini (1992), it seems that she assumed away about the cost of research $c \geq 0$ before the patenting decision. But I choose not to follow Gallini about this presumption. This subsection's analysis is not in Gallini and it is completely done over again by the author.

Now we go back one step further: [2] The innovator decides whether to invest in R&D (to make the product commercially viable) by paying research cost $c \geq 0$ or not. For now we take c to be given, but eventually, we will vary this cost as well.

Here, the innovator must compare the expected returns from various cases (given in Proposition 1) with the cost of research c. If expected return is higher than c, then the innovator will conduct R&D. Otherwise, the innovator will not invest in research.

We now consider two dimension diagrams with imitation cost k in horizontal axis and innovation cost c in vertical axis. We can vary both costs.

See Figure 3 and 4. A point (k, c) in these diagrams represents an idea or an industry.

Here we want to take the patent term T as fixed rather than a choice variable. There are several reasons why we do this. First, from an individual innovators point of view, the patent term is given exogenously. In order to consider optimal decisions by individual innovators, it is natural to assume T as given. Second, we now want to focus on the analysis in the two dimension between imitation and innovation costs rather than k and T or c and T. We can only do this if we take T to be given. Third, while seeking optimal T for a country (with heterogeneous ideas) can be an interesting exercise itself, it will complicate our analysis. We need to specify a particular joint distribution of (k, c) and a specific oligopoly structure in case of imitation in order to be able to calculate the social welfare. This is out of the scope of this article. (I will do this in a different article.) Therefore, in the following analysis, we take patent term as given.

Given T, we consider optimal strategies for an innovator whose location is represented by a vector (k, c) in two dimension space $\mathbb{R}^2_+$.

When the imitation cost is small: $0 \leq k < k_S(p) \equiv (1-p)\pi(0)/r$ For all T, the innovator will keep the innovation secret and earns $E\Pi^S = (1-p)\pi(0)/r$. Therefore, when $c > (1-p)\pi(0)/r$, the innovator will not conduct R&D. He or she will invest in research for the region $(1-p)\pi(0)/r \leq c$.

When the imitation cost is larger: $k_S(p) \leq k$ The profit for the innovator varies with the size of T.

When T is smaller than $T_S(p)$, then the innovator will always keep the innovation secret and earns $E\Pi^S = (1-p)\pi(0)/r$. Therefore, when $c > (1-p)\pi(0)/r$, the innovator will not conduct R&D. He or she will invest in research for the region $(1-p)\pi(0)/r \leq c$. This logic applies to any size of $k \geq (1-p)\pi(0)/r$ including $k \geq \pi(0)/r$. This is drawn in Figure 3 where imitation cost is in the horizontal axis and innovation cost is in the vertical axis.

When T is larger than $T_S(p)$ and k takes some intermediate values: $(1-p)\pi(0)/r = k_S(p) \leq k < \pi(0)/r$, the expected profit for an innovator is either the maximized patented monopoly $E\Pi^P$ or the fixed profits with imitation $E\Pi^M$ depending on the value of k and T.

In particular, if k is given, then we can look at the following 2 cases: (1) when T is smaller than $T_M(k)$, we see $E\Pi^P$ whose value depends on T and (2) when T is larger than $T_M(k)$, we see $E\Pi^M$.

When there are multiple industries with different sizes of c and k, we would rather take T to be given. In this case, we take inverse function $k = k(T) = \beta(T)\pi(0)$ from $T = T_M(k)$ and let $k(T)$ be the threshold value of k below which imitation occurs and above which imitation does not occur given the value of T.

Given T, for k which is within the range of $k_S(p) \leq k < k(T)$, the condition for investing in R&D is

$$\begin{cases} \text{invest in R\&D} & \text{if} \quad k \geq c \\ \text{No investment} & \text{if} \quad k < c \end{cases}$$

and the division line is 45 degree line in Figure 4. From Figure 2 and Proposition 1, given T, the ideas with $k_S(p) \leq k < k(T)$ will face imitation once the innovators patent the ideas. Therefore, expected profit is given by k which should be compared with innovation cost c.

Given T, for k which is within the range of $k(T) \leq k$, the condition for investing in R&D is

$$\begin{cases} \text{invest in R\&D} & \text{if} \quad k(T) \geq c \\ \text{No investment} & \text{if} \quad k(T) < c \end{cases}$$

and the horizontal line at $c = k(T)$ is the division line in Figure 4. We know from Figure 2 and Proposition 1, given T, the ideas with $k(T) \leq k$ will keep monopoly once the innovators patent the ideas.

When we summarize these results, we can state the following theorems.

Theorem 1 *When the patent length is small, i.e.,* $0 \leq T < T_S(p)$*, then only the size of innovation determines the decision by individual ideas. The size of imitation cost does not matter. The decision by an individual idea* (k, c) *is now*

$$\begin{cases} \textit{invest in R\&D and keep it secret} & \textit{if} \quad k_S(p) > c \\ \textit{no R\&D investment is made} & \textit{if} \quad k_S(p) \leq c \end{cases}$$

for any values of imitation cost $k \geq 0$*.* $k_S(p) \equiv (1-p)\pi(0)/r$*. There is no patenting nor imitation by followers.*

This theorem is drawn in Figure 3.

Another theorem is more relevant to the real world where patenting is prevalent.

Theorem 2 *When the patent length is larger, i.e., $T_S(p) < T$ holds, then the decisions by individual ideas can be separated in 4 groups: (Group 1) invest in R&D and keep the idea trade secret, (Group 2) invest in R&D and patent the idea but it is imitated by followers, (Group 3) invest in R&D and patent the idea which will not be imitated by followers, and (Group 4) No R&D investment is made. The decision by an individual idea (k, c) to choose its group is now written as follows:*

$$\begin{cases} \text{Group 1} & \text{if} \quad (k,c) \in \{k < k_S(p)\} \cap \{c < k_S(p)\} \\ \text{Group 2} & \text{if} \quad (k,c) \in \{k_S(p) \leq k < k(T)\} \cap \{k \geq c\} \\ \text{Group 3} & \text{if} \quad (k,c) \in \{k \geq k(T)\} \cap \{c \leq k(T)\} \\ \text{Group 4} & \text{if} \quad (k,c) \in \{c \geq k_S(p)\} \cap \{k < c\} \cup \{c > k(T)\} \end{cases}$$

where $k_S(p) = (1-p)\pi(0)/r$ and $k(T) = \beta(T)\pi(0)$.

The results from theorem 2 are drawn in Figure 4.

Within the framework of Theorem 2, the following result about the existence of imitation can be stated.

Proposition 2 *When there is positive density in idea space $\mathbb{R}^2_+$ within the region:*

$$(k, c) \in \{k_S(p) \leq k < k(T)\} \cap \{k \geq c\},$$

there exist equilibrium with imitation.

Proof. It is obvious from Theorem 2. ■

The result here contrasts sharply with the one in Gallini (1992) where there is no imitation in the optimal patent length equilibrium. In Gallini (1992), she looks at only one idea with a certain value of imitation cost k, and her analysis shows that the optimal patent life is short enough to discourage imitation for a particular industry. Here in this article, we assume many industries with varying imitation costs and we also assume fixed patent life for all industries. In this case, we observe equilibrium with positive imitations provided that there are positive density of ideas in the relevant regions.

Because in the real world we observe existence of imitation or invented-around products, it is natural to assume that actual patent length is long enough so that Figure 4 is more relevant for policy analysis than Figure 3. So in the following analysis, let us assume that the predetermined length of patent $\overline{T}$ is in the range:

$$T_S(p) \leq \overline{T} < \infty.$$

So in the next section, we will base our arguments on Figure 4 (and the results in Theorem 2).

4 Effects of Various Policy Changes

We now look at various patent-related policies. We start with the Soleau envelope policy which makes the option of trade secret more attractive by affecting the probability of other inventors finding out the secret. Then we briefly discuss what will happen to Figure 4 diagram when we can change the size of patent length T. Finally, we review various long-run and short-run policies that can affect the joint distribution of innovation and imitation costs. We will also note that some policies can have global effects and other policies can influence locally.

4.1 Soleau Envelope Policy

The Soleau envelope policy changes the location of $x(p)$ to $x(\alpha p)$ in Figure 4. The policy change broadens the region of trade secret. For example, the point A was previously in the No R&D region, but it is now in the Trade Secret region. So the points like A are the innovations that are previously not realized but now invested (in R&D) and kept as secret. Therefore, the Soleau envelope policy can be said to increase the stock of new innovation.

Another point B was previously in the Patent & Imitation region, but it is now in the Trade Secret region. So the points like B are the innovations that are previously patented (and imitated) but now kept as secret. Therefore, the Soleau envelope policy decreased the stock of patented knowledge (which should increase basic knowledge) and reduced the imitation which is considered wasteful by Gallini (1992). Within the framework of this model, patenting itself will not create a new innovation, but it does in the real world with dynamic process. Therefore, we can conclude the following.

In an economy with many innovations (larger mass in joint distribution) with cost structure (k, c) which is close to point A, then the Soleau envelope policy will improve the social welfare. In an economy with many innovations (larger mass in joint distribution) with cost structure (k, c) which is close to point B, then the Soleau envelope policy will not change the stock of innovation as a whole, but will reduce the stock of patented knowledge available to the society. If the stock of patented knowledge has the dynamic effect (which is outside of this model), then it might be the case that the Soleau envelope policy may have some negative impacts for innovations relating to the points near point B.

Whether the social welfare goes up or down depends upon the shape of joint distribution in (k, c) space.

4.2 Change in Patent Length

Despite that we assumed the fixed term for most of our analyses, the patent length T can (in theory) be changed as well. If T is changed, then the location of a point $y(T)$ in Figure 4 will move. For larger T, then the location of $y(T)$ will move upward and rightward along the 45 degree line. It will broaden the area of Patent & Imitation. To some extent, previously No R&D region will become Patent & No Imitation region, but some No Imitation region will be changed to Imitation region. So raising T involves some trade-offs. It will increase the number of new innovation, but imitation also increases and socially imitation cost k is considered wasteful. (Gallini 1992)

In order to calculate the optimal length of patens, we need to know the exact shape of joint distribution in (k, c). In this article, we will not assume any specific distribution. Therefore, we will not discuss optimal length of patents in this article.

4.3 Shifts in the joint distribution of (k, c)

Various policies can affect the shape of the joint distribution of (k, c). There are policies that shifts the distribution in the short-run and policies that shifts it in the long-run. There are policies that affects the overall joint distribution and policies that affects only a part of the industries (locally) within the joint distribution. We will look at those effects from various policies that affect the joint distribution in (k, c) space.

4.3.1 Long-run shift policy

Education in science and technology can affect both costs of imitation and innovation. Therefore, increasing education can reduce both costs and shift the joint distribution leftward and downward. Similarly to education, the governmental support for basic research has similar long-run effects.

4.3.2 Short-run shift policy

The governmental support for applied research has similar effect as education or basic research support, but may have a shorter-run effects.

The enforcement policy change can affect the joint distribution in the short run. For example, making the patent application easy by reducing the paper work or allowing the online application can reduce the size of c and shifts joint distribution downward. According to Jaffe and Lerner (2004), the

1982 strengthening of the Court of Appeals for the Federal Circuit (CAFC) encouraged patent applications in the United States.

Any policy that makes imitation easier can affect the joint distribution as well. For example, if the Patent office allows the patent applications available online (not only the patented innovation but also applied innovation) then it makes easier for anyone to come up with imitation and it will shift the joint distribution leftward by reducing the size of k.

4.3.3 Overall affecting policy

Some policies can affect the overall global joint distribution rather than locally. Education policy and the enforcement policy that affects all the innovation will affect the joint distribution overall. Examples given in the above long-run and short-run policies are such policies.

4.3.4 Partly affecting policy

Other policies can affect ideas only locally. For example, some enforcement policies can be determined in court decisions which may depend on product-by-product and case-by-case. In such a case, the policy decision can affect only a subset of innovation, rather than overall. In this case, the policy affects only part of the innovation locally rather than shifting the overall joint distribution.

5 Conclusion

This article extends the model of costly imitation by Gallini (1992) by introducing multiple industry with heterogeneous imitation cost. The existence of imitation confers the breadth of patent system in technology space. It is natural to think that the breadth of patent varies from industry to industry. When we map the relationship between cost of imitation and patent length, we can conclude the following results: (1) for shorter length of patent and smaller cost of imitation, innovators will choose not to patent and keep the innovation secret. (2) for longer length of patent and larger cost of imitation, innovators will choose to patent the idea. (3) Among the ideas which are patented, whether the rivals imitate or not depends on the relative relationship between patent length and imitation cost, in particular, when the imitation cost is smaller (or patent length is longer) than the corresponding imitation threshold line in Figure 2, there will be imitation in the equilibrium.

The article also introduces the cost of innovation. The interaction between these two costs creates interesting mapping of strategy for a particular firm (innovator) with a particular combination of costs of innovation and imitation. In order to show the optimal strategy in a mapping between two costs, we presumed that the patent length is fixed and exogenously given. When the patent length is smaller than a particular threshold for trade secrecy, then there will be no equilibrium patenting (this is the case described in Figure 3). So we posit that the likely size of patent length is long enough so that the relevant mapping is represented by Figure 4. In this setup, the smallest group of imitation cost chooses trade secrecy, the intermediate group will patent the innovations but imitated by rivals, and the largest group can maintain patent monopoly.

Given the mapping of Figure 4, we can posit that the potential ideas can be jointly distributed over two dimension space with imitation and innovation costs. We then look at effects of several patent-related policies. The Soleau envelope policy will expand the region of trade secrecy. This will increase total innovations researched, but some patented ideas may become trade secrecy in response to the policy change. Trade-off will depend on the joint distribution and the dynamic impact of patented knowledge to successive innovations following the patented knowledge (which is outside of this article's model). The increase in patent length (from finite length) will expand the region of ideas which will be patented, which is positive. However, it will also increase the region with imitation and this effect is negative. Trade-off depends on the joint distribution again. There are other various policies that can affect the joint distribution of imitation and innovation costs. Some of them are long-run policies and others are short-run policies. Some affects overall distribution and others affects only locally.

Although Gallini (1992) pursued optimal length of patent given the size of the imitation cost, this article looks at optimal decisions of individual firms (innovators) given the length of patent. Within this setup, the article discussed the effects of Soleau envelope policy where the government can raise the profitability of trade secret option. The article suggests what kind of industry benefit from this type of policy.

This article does not seek optimal length of patent. The optimal length depends on two things: (1) the nature of joint distribution of imitation and innovation costs, and (2) the nature of oligopolistic structure; both of which are not specified in this article's model. To calculate welfare using specific assumptions about those two points can be one possible extension in the future research.

I also ruled out the possibility of licensing the ideas to third parties. I did so because I wanted focus on the interaction between innovation and imitation costs without complicating analyses. However, introducing possible licensing option for an innovator is another path to extend the analysis presented in this article.

One other possible extension of the current article's model is to introduce foreign imitators. What happens to the social welfare of the country if imitations occur from foreign entrants? Imitation costs are known to be socially waste (according to Gallini 1992), and if some, if not all, social wasteful costs could be born by foreign firms, then the calculation of social welfare will change for sure. At this stage, I must confess that I am unable to come up with a way to incorporate foreign imitations without complicating the analyses further. This path must also be left for the future.

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Figure 1

Expected Profit for the Innovator

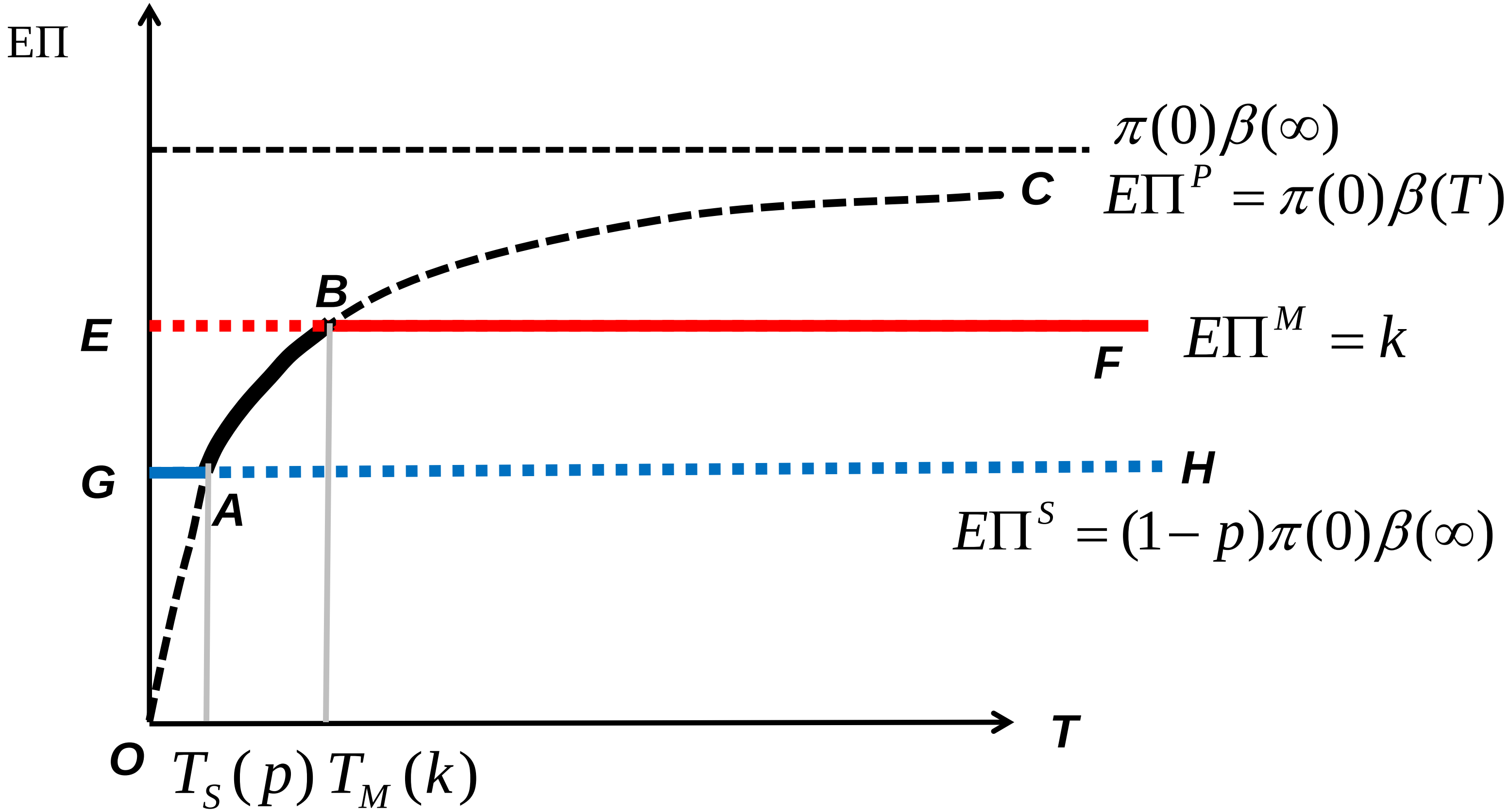

Figure 2

Imitation, Monopoly and Trade Secrecy

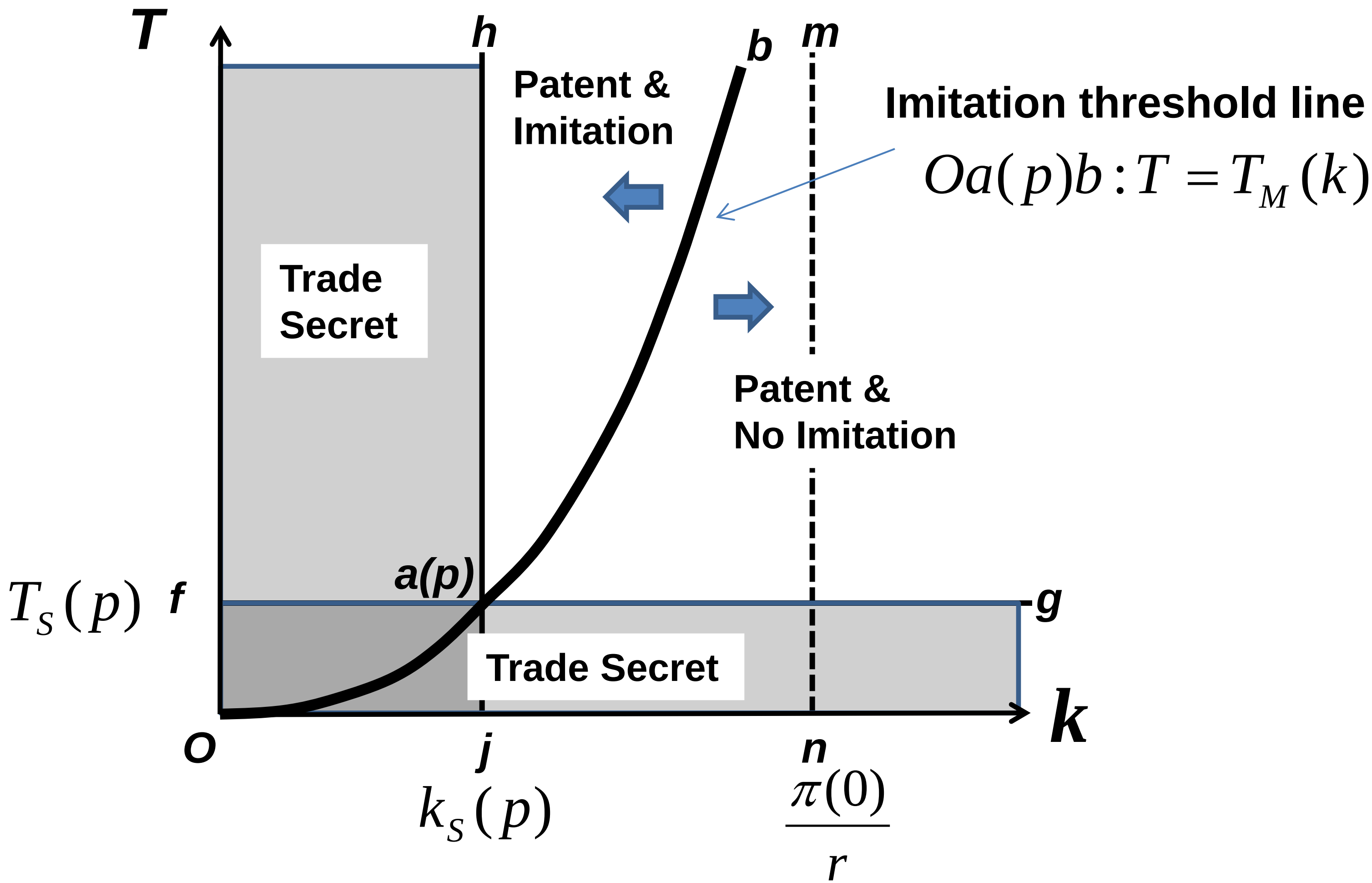

Figure 3

Innovation and Imitation costs
When T is small, i.e., $0 \leq T < T_S(p)$

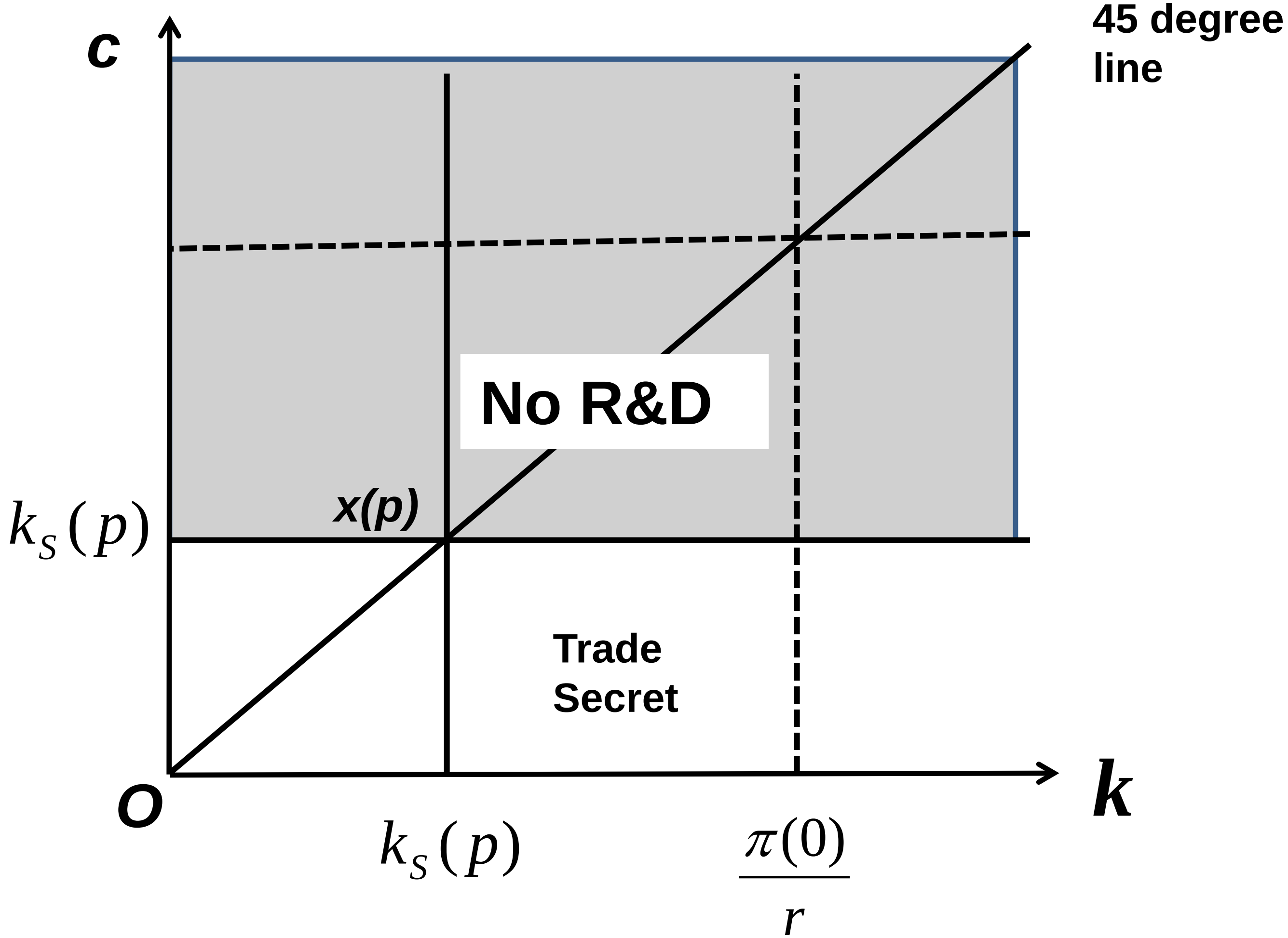

Figure 4

Innovation and Imitation costs $T_S(p) \leq T < \infty$