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The Utility Standard and the Patentability of Intermediate Technology

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Abstract

We explore the consequences of the utility requirement on speed of innovation, welfare and public policy. A weak utility requirement means that an intermediate technology with no immediate application or commercial value is patentable. Using a model of two stage innovation with free entry and trade secrecy, we identify cases when patentability is beneficial to society. Although a firm may undertake basic research protected by trade secrecy, patentability is still desirable when spillover is high and innovation costs are high. However, patentability becomes less desirable as basic research costs decrease. We also show that high value of final technology by itself does not favor non-patentability and identify condition when it does.

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1 Introduction

Utility, together with novelty and the inventive step (or non-obviousness), constitutes the three basic requirements for patentability. It requires that the invention can bring about a specific technical effect. When research is directly guided by "real-world" necessities, it is easy to establish the utility of inventions. However, when it is driven by scientific discovery, it may be an "intermediate technology", the real world utility of which can be determined only after further research. For instance, the immediate application of a gene sequence or a new chemical entity may not be clear without substantial further research. The utility requirement may reject patentability of such an intermediate technology. A weak utility requirement implies that the intermediate technology is patentable.

Despite the increasing importance of the utility standard in science-driven innovations, there are no substantive economic analysis of the standard.[1] The purpose of this paper is to present a framework and analyze the welfare implications of the utility standard.

The economic rationale of the utility standard can be best clarified in the context of cumulative innovation. Although similar in structure, our formulation differs from previous cumulative innovation analysis in several ways. Past studies have focused on the patentability of the follow-up invention and the infringement possibility of such an invention on the prior invention (Scotchmer and Green (1995) and Denicolo (2000)). That is, the first stage invention was assumed to be patentable and has a stand alone value. In our analysis, the first stage innovation is an intermediate technology and further research is necessary to realize its potential value. The issue for us is the patentability of the first stage invention while assuming patentability of the second stage invention. By definition of intermediate technology, the second stage invention always infringes on the first stage invention.

Secondly we incorporate both trade secrecy and spillover. With intermediate technology, involuntary disclosure is unlikely because the technology by itself cannot constitute a marketable final product. It may remain within confines of a building or limited number of people. Thus trade secret protection is viable as an alternative to patent protection. However trade secrecy offers no protection if competitors obtain the technology independently or if there is unintentional spillover. And spillovers often occur through academic publications and contacts

[1] There have been some legal analysis of this issue, notably Grady and Alexander (1992), Merges (1997), and Heller and Eisenberg (1998).

among researchers, both of which are significant in science-driven innovations.[2]

Because of free entry in both first stage basic research and second stage development, the rent obtained from the commercialization of the completed technology is dissipated, irrespective of the patentability of an intermediate research. In the patentability case, it will be dissipated more in the first stage (larger first stage expenditures and more entries in first stage competition). We show that preventing dissipation of rent in the second stage through a patent is welfare improving even if trade secrecy enables research, particularly if spillover is very likely, or basic research is very expensive.

Our results also suggest that reducing development costs (second stage cost) can be another way of increasing basic research (first stage) investment. Those intermediate technologies that require very high investment in the development stage for commercialization will also benefit from patents.

The relative advantage of patentability declines as basic research costs become smaller. When the marginal cost becomes very small, we show that patentability reduces welfare. This is because when cost of basic research is low, it is more effective to promote development by eliminating market power. Thus relaxing the utility requirement for intermediate technologies that are mere "ideas" is not socially desirable.

We also show that high final technology by itself does not determine desirability of weak utility requirement, despite the fact that alternative to patents is trade secrecy. Patentability of basic research improves welfare if basic research costs are relatively large compared to development costs and interest rate is sufficiently high. This is because the monopolist investment is higher when the interest rate is high. Thus welfare loss from patentability (market power) is smaller when the interest rate is high.

In the remainder of this section, we present a brief background and issues regarding the utility requirement and review three papers we feel our work is most closely related. We also clarify the difference between the utility and the novelty standards. The main analysis based on a two-stage patent race is in Section 2 followed by a section on welfare. We conclude with Section 4 with policy implications of our results. We also discuss how our results relate to investment by innovators specialized in research and to licensing.

[2]We do not consider disclosure or spillover of technology by the patenting process itself as in Scotchmer and Green (1995) or Aoki and Spiegel (2001). Although a very important aspect of the patent system, this has not been the focus of debate regarding the utility standard.

Utility and description requirements

Section 101 of the U.S. Patent Law defines the utility requirement by the following statement "Whoever invents any new and useful process, machine, manufacture, improvement thereof, or composition of matter ... may obtain a patent therefore ..."[3] The recent guidelines of the USPTO interprets that Section 101 requires that "an invention must be supported by a specific, substantial and credible utility ..." According to the guideline, utility specific to the subject matter, instead of general utility, has to be claimed. Utilities that require or constitute carrying out further research to identify or reasonably confirm a "real world" context of use are not substantial utilities. In addition, an assertion is credible unless the logic underlying the assertion is seriously flawed, or the facts upon which the assertion is based are inconsistent with the logic underlying the assertion. The utility requirement is also implicit in Section 112, which requires written descriptions of the invention and of the manner and process of making and using it without undue experimentation."

Traditionally, utility requirement has been an issue in the chemical industry. In this industry, research may yield synthesized compounds for which no particular use is known. A 1966 U.S. Supreme Court ruling ("Brenner ruling") supports the denial of the patent for such compounds if it fails to disclose any utility, even though it is closely related to another compound which is useful. [4] However this ruling is considered to represent the "high-water mark" of utility doctrine (Merges (1997)). The recent ruling in re Brana in 1995 seems to be based on logic conflicting the the previous Supreme Court Ruling. It established that utility for pharmaceutical products can be established by animal testing which is short of an pharmaceutical product for humans. [5]

[3] The law of nature, physical phenomena, and abstract ideas are not regarded to be patentable subject matter.

[4] "Until the process claim has been reduced to production of a particular product shown to be useful, the metes and bounds of that monopoly are not capable of precise delineation. It may engross a vast, unknown, and perhaps unknowable area. Such a patent may confer power to block off whole areas of scientific development, without compensating benefit to the public. The basic quid pro quo contemplated by the Constitution and the Congress for granting a patent monopoly is the benefit derived by the public from an invention with substantial utility.But a patent is not a hunting license. It is not a reward for the search, but compensation for its successful conclusion." Brenner v. Manson, 383 U. S. 519, 148 U.S.P.Q. (BNA) 689 (1966)

[5] "FDA approval, however, is not a prerequisite for finding a compound useful within the meaning of patent laws. Usefulness in patent law, and in particular in the context of pharmaceutical inventions, necessarily includes the expectation of further research and development. The stage at which an invention in this field becomes useful is well before it is ready to be administered to humans. Were we to require Phase II testing in order to prove utility, the associated costs would prevent many companies from obtaining patent protection on promising

More recently, utility and enablement requirement has become a big issue in biotechnology where innovation are driven by scientific progress. Recent scientific advances have resulted in intermediate technology such as identification of gene sequences. This is critical for but only useful by making further research possible. In applying for a patent on partial genetic sequences (expressed sequences tags or EST) by NIH (Dr. Craig Venter) in 1991, NIH claimed that these can be used as diagnostic probes, identification of chromosomes, etc, which are uncertain generic utilities. NIH gave up patenting in 1994, when they faced a rejection by USPTO based on utility and other requirements, as well as strong criticism from scientific and the other circles. (See Aoki and Nagaoka (2002) for more on biotechnology and the utility standard.)

The patentability of research results is especially critical for firms specialized in research, which are very important players in the U.S. biotechnology industry. Since these firms do not have internal assets to implement downstream research such as clinical testing, patents for intermediate research results are essential for them to sell the research outputs or to attract investment money for engaging in downstream research. The head of the leading U.S. biotechnology venture firm states the following: "Some argue that the invention is not complete until the precise biological activity of an individual gene is identified; indeed, there is some indication that the Patent Office intends to apply the new guidelines in this way. This argument ignores the real world utility, described above, associated with the isolation, sequencing and identification of genes and their classification into categories whose general functions are known. If this standard were to apply, then only those companies that adhered to the inefficient, vertically-integrated pharmaceutical industry model would be entitled to patents. This approach would be at odds with the evolution of the pharmaceutical industry, with its attendant efficiencies."(Testimony of Randal Scott, president and chief scientific officer of Incyte Genomics Inc., before the U.S. House Judiciary Subcommittee on Courts and Intellectual Property, July 13, 2000) We discuss the application of our analysis to such an "outside" innovator in Section 4.

The utility standard can also become an issue with concept patents. That is, the patenting of a general product or business ideas that use new technology. The idea is easy to come up, so that it has little role in advancing knowledge, but which has to be used widely in applying new technology. Such concept

new inventions, thereby eliminating the incentive to pursue, through research and development, potential cures in many crucial areas such as the treatment of cancer." In re Brana 51 F. 3d 1560, 34 U. S. P. Q. 2d 1436 (Fed. Cir. 1995) patent would discourage R&D for discovering application technologies for using new technology, since it enables the patentee to collect royalty, but does not aid R&D at all in terms of knowledge. Such invention may be rejected based on a non-obviousness requirement, but can also be rejected based on the absence of specific utility.

Existing literature

In this section we review three papers that we believe our work is most closely related. Grossman and Shapiro (1987) analyze whether firms support patentability of intermediate technology in the framework of a two-stage race among duopolists, in which the completion of the first stage research is necessary for commencing the second stage research but the first stage research has no commercial value. Based on simulations, they suggest that intermediate patent may be beneficial to the firms ex-post (i. e. after the first stage research), but not ex-ante, since it intensifies competition. They assume that an intermediate patent requires the competing firm to drop out of the second stage research race, so that the second stage research is monopolized. They do not consider the possibility of trade secret protection and their focus is strictly firm's incentive.

Scotchmer and Green (1990) analyzes novelty standard with respect to the interim innovation also in a duopoly framework. The focus of their analysis is the role of the patent in facilitating disclosure, which accelerates research in their model. They take into account the possibility that a firm chooses trade secret protection for intermediate technology even if it is patentable. They find that a weak novelty requirement promotes disclosure while it does not undermine ex-ante profit significantly, and that the first-to-file regime encourages disclosure more than the first-to-invent regime (see Aoki and Nagaoka (2002) Appendix for how these findings can be carried over to the case of utility standard). It is important to note that utility standard is different from novelty standard in the following two aspects. First, in the novelty case the intermediate technology can have a direct commercial value and can compete with the final innovation, as assumed by Green and Scotchmer (1990), while it does not in the utility case. Second, in the case of the novelty standard, the second innovation may not infringe the first patented intermediate innovation, as assumed by Green and Scotchmer, even if patented. In the utility standard case, the secondary innovation infringes the patented first innovation since the first innovation provides input to the research in the second stage research. Furthermore, they do not consider variable levels of R&D investment nor number of firms.

Denicolo (2000) analyzes the optimal degree of forward patent protection of the first innovation in the framework of a two-stage patent race. In his model, the patentability of the first stage innovation is assumed and he analyzes the economic effects of the patentability of the secondary innovation and its potential infringement of the first innovation, or the degree of forward protection. He shows that strong forward protection becomes less attractive as the relative profitability of the first innovation increases and the relative difficulty of obtaining it decreases. Although we use and extend his analytical framework, we address a different issue. We analyze the economic consequences of the patentability of the first innovation by comparing the case where the first innovation is patentable under the weak standard of utility and the case where it is not patentable due to the strong standard of utility so that it can only be protected by trade secret. Although the first case is equivalent either to UI (the secondary innovation is unpatentable and infringing) or PI (the secondary innovation is patentable and infringing) in the Denicolo analysis, he has not analyzed the case where first innovation is protected only by trade secret. In addition, we incorporate fixed cost of research in the analysis, since duplicative aspects or economy of scale may be important especially in the development stage of innovation.

2 The Model

We assume free entry into both the first basic research stage (R stage) and the second development stage (D stage) innovation competition unless it is constrained by patent protection or trade secrecy. Unlike Denicolo, we assume that it is possible for a firm to resort to trade secrecy to protect the intermediate technology. This is a viable option because the technology cannot not be commercialized by itself for general public consumption. Thus patenting is a choice.

However the shortcoming of trade secret protection for a firm is that it does not prevent rivals from using the same technology if it was obtained independently. Thus a firm using trade secret protection faces potential competition in the second stage. (In fact with Poisson discovery process, another firm will succeed the R stage with probability one.) This is one of the essential difference between trade secrecy and patent protection. Since we assume that research expenditure in each stage is completely sunk once commenced, there is no reason for a firm in R stage to drop out of competition when another firm has completed the R stage unless it believes that it cannot profitably enter D stage research competition. Thus the natural framework is for the firm that completes the R stage to behave as an incumbent facing potential competition in the D stage. The firm should invest so as to best exploit its first mover advantage in D stage competition.

We assume that an intermediate technology is either a type that spills over completely or a type that does not. We denote by γ the probability that the technology is the type that spills over. This probability is common knowledge. Once the R stage is completed, i.e., a firm obtains the intermediate technology successfully, the firm knows immediately which type the technology is. If the technology is the spillover type, spillover occurs immediately unless it is protected by a patent.[6] In this case D stage will be competitive with free entry. If the technology is the no spillover type (which is the case with probability $1-\gamma$), then trade secrecy will be effective unless technology is obtained independently.

Specifically, firm i chooses research intensity x_{it} for cost c_t for R&D at stage t, where $t = R$ or $t = D$. Discovery in each stage follows a Poisson process. We assume there is a fixed cost f_t to participate in stage t. If the intermediate technology is patentable, then the patentee will be the sole developer of the final technology.[7] Because it is an intermediate technology, there is no value to the result of the R stage innovation.[8] The value of the final technology is v.

We consider two cases, when the intermediate technology is patentable and when it is not. If it is patentable, whoever succeeds the R stage has a choice of patenting. The regime when the intermediate technology is not patentable is the same as the no patenting decision when the technology is patentable. Only the D stage differ according to patentability.

2.1 D Stage investment

We will first analyze the D stage investment behavior under the two regimes. We characterize the equilibrium investments, the patenting choice and the cor-

[6]Successful completion is observed by all firms and thus other firms will also know immediately which type the technology is.

[7]Because of the Poisson discovery process, there is no advantage to licensing and having many firms engage in R&D. Of course a firm may be forced to license if it does not possess resources to engage in D stage. This case is discussed in Section conclusion. Even in this case, the particular innovation technology implies there should only be one licensee.

[8]This is equivalent to Denicolo's UI or PI with $v_1 = 0$.

responding profits.[9]

The intermediate technology is Patentable

We characterize the equilibrium investment when the firm has a patent on the intermediate technology (P). There is no spillover because patent protection is perfect. It will be shown later that a firm always prefers to patent the intermediate technology if this is legally possible.

When firm has the patented technology, it is able to invest as a research monopolist. It chooses x to maximize,

$$\int_0^\infty exp^{-(x+r)\tau} xv d\tau - c_D x - f_D = \frac{xv}{x+r} - c_D x - f_D.$$

The monopoly investment, x_m, is

$$x_m = \sqrt{\frac{rv}{c_D}} - r,$$

and the monopoly profit is,

$$\pi_m = \left(\sqrt{v} - \sqrt{c_D r}\right)^2 - f_D. \quad (1)$$

We assume that this is always positive,

$$(\sqrt{v} - \sqrt{c_D r})^2 > f_D. \quad (2)$$

The equilibrium D stage profit when the intermediate technology is patented is, $\pi_D^P = \pi_m$ and the corresponding investment is $X_D^P = x_m$.

The intermediate technology is Not Patentable

When the intermediate technology is not patentable (N), there are two subgames after completion of the R stage, depending on the type of technology: one with spillover (probability γ) and one without (probability $1 - \gamma$). If there is spillover, the firm must compete with new entrants in the D stage on equal footing. If there is no spillover, the firm can invest to exploit first mover advantage.

[9]D stage constitutes a subgame of the two stage game. The equilibrium we characterize is part of a subgame perfect Nash equilibrium strategy.

We start with the case with spillover. There are n firms (the number determined in equilibrium) in D stage competition. Firm i's profit when its investment is x_i is,

$$\pi_i = \int_0^\infty exp^{-(\sum_{j=1}^n x_j + r)\tau} x_i v d\tau - c_D x_i - f_D = \frac{x_i v}{\sum_{j=1}^n x_j + r} - c_D x_i - f_D. \quad (3)$$

First order condition for profit maximization is,[10]

$$\frac{\partial \pi_i}{\partial x_i} = v \frac{\sum_{j \neq i} x_j + r}{(x_i + \sum_{j \neq i} x_j + r)^2} - c_D = 0. \quad (4)$$

There will be an incentive to invest a positive amount when this marginal profit is positive at $x_i = 0$ which is the case by virtue of assumption (2).

In symmetric equilibrium with free entry, profit given by (3) should equal 0 and $x_j = x$ for all j. Equations (3) and (4) become

$$\frac{xv}{nx + r} - c_D x - f_D = 0, \quad (5)$$

$$\frac{(n-1)x + r}{(nx + r)^2} v - c_D = 0. \quad (6)$$

The two equations characterize the equilibrium investment and number of firms.

The equilibrium investment is

$$x_0 = \frac{\sqrt{f_D v} - f_D}{c_D}.$$

Ignoring the integer problem, we have the equilibrium number of firms engaged in D stage investment,

$$n_0 = \sqrt{\frac{v}{f_D}} - \frac{c_D r}{\sqrt{f_D v} - f_D}.$$

Number of firms is decreasing in both fixed and marginal costs. Investment by each firm is also decreasing in marginal cost but will be increasing in fixed cost if fixed cost is sufficiently small relative to value of technology,

$$\frac{dx_0}{df_D} = \frac{\sqrt{v} - 2\sqrt{f_D}}{c} \gtreqless 0 \quad \sqrt{v} \gtreqless 2\sqrt{f_D}. \quad (7)$$

[10] All summation hereafter will be for $i = 1, \ldots, n$ unless noted $j \neq i$ which is for $j = 1, \ldots, i-1, i+1, \ldots n$.

When fixed cost increases, the direct effect is the reduction of both number of firms and investment by each firm (equation(5)). However fewer firms will increase investment (equation (6)). The first effect is dominant when the fixed cost is large and second effect dominates when fixed cost is small. The total investment with spillover is however always decreasing in both costs.

$$X_0 = n_0 x_0 = \frac{v - \sqrt{v f_D}}{c_D} - r.$$

The equilibrium profit when there is spillover is zero, i.e., $\pi_S = 0$.

If there is no spillover, the firm acts as an incumbent in D stage anticipating entry. It invests to such an extent that even an entrant expecting no further entries cannot make money. That is, we assume that entry deterrence is more profitable than entry accommodation.[11] The firm chooses x to deter entry. An entrant's profit when it invests x_e is,

$$\pi_e = \int_0^\infty exp^{-(x_e+x+r)\tau} x v d\tau - c_D x - f_D = \frac{x_e v}{x_e + x + r} - c_D x_e - f_D. \tag{8}$$

The entrant will invest to maximize this profit, given incumbent's investment x. That is, x_e satisfies the first order condition,

$$\frac{\partial \pi_e}{\partial x_e} = v\frac{x + r}{(x_e + x + r)^2} - c_D = 0.$$

The incumbent will choose x so that profit π_e will be zero even when the entrant is profit maximizing. The entry deterrent output, x_b is,

$$x_b = \frac{(\sqrt{v} - \sqrt{f_D})^2}{c_D} - r.$$

$x_b > x_m$ for

$$\frac{(\sqrt{v} - \sqrt{f_D})^2}{\sqrt{v}} > \sqrt{r c_D}. \tag{9}$$

This condition requires that the fixed cost not be too large and is also a sufficient condition for $\pi_m \geq 0$. If this condition does not hold, then entry will be blocked with monopoly investment. Note that $x_b \to X_0$ as $f_D \to 0$: entry deterrence is

[11] While we assume the optimality of entry deterrence strategy in the following analysis, the conclusions of the analysis (all propositions) apply exactly in the case of the entry accommodation strategy, as long as the level of the D stage aggregate investment in the case of entry accommodation strategy X_a, which is equal to the sum of the investment of an incumbent and those of entrants, is between that of entry deterrence and that of competition (i.e $x_b < X_a < X_0$).

impossible if there is no fixed cost.

The equilibrium profit with entry deterrence will be,

$$\begin{aligned}\pi_b &= v - (\sqrt{v} - \sqrt{f_D})^2 - c_D r \left(\frac{v}{(\sqrt{v} - \sqrt{f_D})^2} - 1 \right) - f_D \\ &= 2\sqrt{f_D}(\sqrt{v} - \sqrt{f_D}) - c_D r \left(\frac{v}{(\sqrt{v} - \sqrt{f_D})^2} - 1 \right). \end{aligned} \tag{10}$$

The entry deterrence profit is decreasing in c_D. It is also decreasing in the fixed cost, f_D, when it is large but increasing in fixed cost when f_D is small. While larger f_D means it is possible to deter entry with smaller deviation from the monopoly profit, it also directly reduces profit (including the monopoly profit). The positive effect dominates only when f_D is small.

Summarizing, investment (x_{NS}) and profit (π_{NS}) when there is no spillover are x_b and π_b if (9) holds, and x_m and π_m if (9) does not hold. We make the following observation about relative size,

Lemma 1. *If condition (9) holds, then*

$$x_m < x_b = x_{NS} < X_0, \quad \pi_m > \pi_b = \pi_{NS}.$$

Otherwise,

$$x_m = x_{NS} < X_0, \quad \pi_m = \pi_{NS}.$$

Comparing the different levels of investments, we see that both x_b and X_0 are linear in v (maximum order is v) but x_m is order of $\sqrt{v}$. Distortion from monopoly power increases with value of the final patent, v.

The equilibrium D stage profit of the firm successful in R stage[12] when the intermediate technology is not patentable is,

$$\pi_D^N = \gamma \pi_S + (1-\gamma)\pi_{NS} = \gamma 0 + (1-\gamma)\pi_b. \tag{11}$$

π_D^N is always less than π_m for any probability of spillover γ and strictly less for $\gamma > 0$.

Lemma 2. *If condition (9) holds or there is a positive probability of spillover($\gamma > 0$), then a firm will always patent the intermediate technology if it is patentable. That is, $\pi_D^P = \pi_m > \pi_D^N$.*

[12]The other firms' profits are zero.

In our framework patent enforcement is perfect and there is no spillover related to patenting. Although trade secret protection is also perfect it offers no protection against independent innovation. This alone makes patent protection always more attractive.

2.2 R stage investment

General solution of R stage

We derive a general solution for R stage when the payoff to the winner from the D stage is π_D and loser gets nothing. Firm i's expected payoff when it invests x_i and other firms invest x_j is,

$$\pi_i = \frac{x_i \pi_D}{x_i + \sum_{j \neq i} x_j + r} - c_R x_i - f_R. \tag{12}$$

First order condition for profit maximization is,

$$\frac{\partial \pi_i}{\partial x_i} = \frac{\sum_{j \neq i} x_j + r}{(x_i + \sum_{j \neq i} x_j + r)^2} \pi_D - c_R = 0. \tag{13}$$

There will be an incentive to invest a positive amount when this marginal profit is positive at $x_i = 0$ which will hold if $\pi_D > c_R r$.

In symmetric equilibrium with free entry, (12) should equal 0 and $x_j = x$ for all j. Equations (12) and (13) become

$$\frac{x \pi_D}{nx + r} - c_R x - f_R = 0,$$
$$\frac{(n-1)x + r}{(nx + r)^2} \pi_D - c_R = 0.$$

The two equations characterize the equilibrium investment and number of firms. The equilibrium investment is

$$x_R = \frac{\sqrt{f_R \pi_D} - f_R}{c_R}.$$

In order for this to be positive (interior solution), profit from the next stage must be sufficiently large, $\pi_D > f_R$. Investment is decreasing in marginal cost and increasing in D stage profit π_D. The effect of fixed cost on investment is analogous to (7). Ignoring the integer problem, we have the equilibrium number of firms engaged in R stage investment,

$$n_R = \sqrt{\frac{\pi_D}{f_R}} - \frac{c_R r}{\sqrt{f_R \pi_D} - f_R}.$$

The number of firms is also decreasing in both costs and increasing in D stage profit π_D. The aggregate investment, X_R, is

$$X_R(\pi_D) = n_R x_R = \frac{\sqrt{\pi_D}}{c_R}\left(\sqrt{\pi_D} - \sqrt{f_R}\right) - r, \tag{14}$$

if π_D is sufficiently large and $X_R = 0$ otherwise. This is also increasing in D stage profit. It highlights together with Proposition 1 how investment is increased in one stage at the cost of reducing it in the other. The equilibrium investments when the intermediate technology is patentable, X_R^P, and when not patentable, X_R^N can be found by substituting the appropriate equilibrium profits from D stage, π_D^P and π_D^N.

Proposition 1. *Patentability of the intermediate technology increases R stage research investment but reduces D stage investment.*

From (14), we can make the following observation:

Lemma 3. *When the intermediate technology is not patentable, spillover must be sufficiently unlikely and costs (c_D,c_R, f_R) small enough for there to be investment in the intermediate technology. That is,*

$$X_R^N > 0 \quad \Leftrightarrow \quad \sqrt{(1-\gamma)\pi_b} \geq \frac{\sqrt{f_R}}{2} + \sqrt{c_R r + \frac{f_R}{4}}. \tag{15}$$

The entry deterrence profit was decreasing in f_D only when it is large. The proposition also holds for such range of f_D. Recall that D stage equilibrium profit π_D will be low when D stage costs are high. This lemma shows that if D stage costs are increased, there must be a corresponding decrease in R stage costs, or there will no investment in basic research when equation (15) holds as an equality. Not surprisingly, very high likelihood of spillover results in no R stage investment.

3 Welfare

The value of technology v is the firm's private value. This does not capture the additional value to society from the innovation which we denote by s. Given aggregate investment X,

$$P(X) = \frac{X}{X+r},$$

is the "adjusted probability" of innovating (Denicolo (2000)). It discounts the value according to the delay which is distributed according to a Poisson process. The expected welfare is, denoting investments in R stage and D stage by X_R and X_D,

$$W(X_R, X_D) = P(X_R)\{P(X_D)(v+s) - c_D X_D - n_D f_D\} - c_R X_R - n_R f_R.$$

From Lemma 3, we can immediately identify a case when patentability will unambiguously improve welfare.

Proposition 2. *If there is no R stage investment without patentability and if there is with patentability, then patentability will improve welfare.*

There will be no R stage investment when condition (15) does not hold. In this case welfare is zero. Note that the condition is violated not only when R stage investment costs are high but also when D stage marginal cost is high. Given that a firm can recover investment in R stage research only from commercialization of D stage innovation, not only high cost of R stage research but also high marginal cost of D stage research tends to favor patentability of the intermediate technology. Thus if an intermediate technology required a large amount of additional work (high investment costs) for commercialization, this would be precisely the situation when making the intermediate technology patentable will improve welfare.

Noting that profit is bid down to zero in equilibrium in both stages of competition, the welfare with and without patentability of the intermediate technology are,

$$W^P = P(X_R^P)P(X_D^P)s = P(X_R(\pi_m))P(x_m)s,$$
$$W^N = P(X_R^N)\{\gamma P(X_0) + (1-\gamma)P(x_b)\}s = P(X_R((1-\gamma)\pi_b))\{\gamma P(X_0) + (1-\gamma)P(x_b)\}s.$$

Superscripts N and P denote when intermediate is "not patentable" and "patentable".

An iso-welfare curve in (X_R, X_D) space is depicted in Figure 1. Convexity can be derived as in Denicolo (2000). The figure demonstrates the trade-off of making intermediate technology patentable. Patentability increases X_R and reduces X_D (Proposition 1). In the figure, this means patentability will change investments in the direction of the arrows.

We first characterize situations when patentability is welfare improving.

Proposition 3. *Patentability of intermediate technology improves social welfare when the basic research cost c_R is very high. That is, there is always a level of cost, c_R^{ϕ}, such that,*

$$W^P > W^N,$$

for all $c_R \geq c_R^{\phi}$

Proof. We first show that the reduction of welfare due to decline in D stage investment caused by the monopolization of that stage research is bounded from below. Let us define k as satisfying $v = rc_D(1+k)^2$, which provides a measure of profitability of the final patent relative to the marginal cost of development. From characterizations of X_0 and x_b, we have,

$$X_0, x_b \leq \frac{v}{c_D} - r = r(1+k)^2 - r = (k^2 + 2k)r.$$

From characterization of x_m, we also have,

$$x_m = r(1+k) - r = rk.$$

Thus we have,

$$\frac{X_R^P}{X_R^N} \geq \frac{rk}{(k^2+2k)r} = \frac{1}{k+2}.$$

From Lemma 1, assuming condition (9) holds, we have

$$X_0, x_b > x_m.$$

It follows that,[13]

$$\frac{X_D^N + r}{X_D^P + r} > 1.$$

This implies

$$\frac{P(X_D^P)}{P(X_D^N)} > \frac{1}{(k+2)}. \qquad (16)$$

[13]Recall D stage investment with no patenting (or not patent) was X_0 with spillover and x_b without. X_D^N is defined by

$$P(X_D^N) = \gamma P(X_0) + (1-\gamma)P(x_b).$$

From monotonicity of the function $P(\cdot)$, $x_b < X_D^N < X_0$.

Using (14) we have

$$\frac{P(X_R^P)}{P(X_R^N)} = \frac{X_R^P}{X_R^N} \times \frac{r + X_R^N}{r + X_R^P}$$

$$= \frac{\sqrt{\pi_D^P}(\sqrt{\pi_D^P} - \sqrt{f_R}) - c_R r}{\sqrt{\pi_D^N}(\sqrt{\pi_D^N} - \sqrt{f_R}) - c_R r} \times \frac{\sqrt{\pi_D^N}(\sqrt{\pi_D^N} - \sqrt{f_R})}{\sqrt{\pi_D^P}(\sqrt{\pi_D^P} - \sqrt{f_R})}. \qquad (17)$$

The expression is 1 when $c_R r = 0$, increasing in $c_R r$ in the range $c_R r < \sqrt{\pi_D^N}(\sqrt{\pi_D^N} - \sqrt{f_R})$, and approaches infinity as $c_R r \to \sqrt{\pi_D^N}(\sqrt{\pi_D^N} - \sqrt{f_R})$. Since $\pi_D^N = (1-\gamma)\pi_b$ is independent of c_R, we can find a c_R^ϕ such that for all $c_R \geq c_R^\phi$,

$$\frac{P(X_R^P)}{P(X_R^N)} > (k+2).$$

Then using (16), we have for all $c_R \geq c_R^\phi$,

$$\frac{W^P}{W^N} = \frac{P(X_R^P)}{P(X_R^N)} \frac{P(X_D^P)}{P(X_D^N)} > 1.$$

□

The expression (14) implies that $c_R r$ being close to π_D^N means R stage investment X_R is small. In Figure 1 it would be a point such as T, a point at which the change in investments from patentability improves welfare.

It can be shown that $\frac{P(X_R^P)}{P(X_R^N)}$ is increasing in f_R (see proof of Proposition 5). Thus critical value c_R^ϕ is lower when R stage fixed cost is larger. The range of R stage marginal costs for which patentability is socially beneficial is larger (there is improvement even for lower marginal cost) when fixed cost is larger.

Now we characterize a condition when patentability reduces welfare.

Proposition 4. *Patentability of intermediate technology reduces social welfare when the basic research cost, c_R, is very low. That is, there is a c_R^* such that*

$$W^P < W^N,$$

for any $c_R \leq c_R^*$.

Proof. From Proposition 1, we have $X_D^P < X_D^N$, and thus $\frac{P(X_D^P)}{P(X_D^N)} < 1$. From (17), we have $\frac{P(X_R^P)}{P(X_R^N)} > 1$ converging to 1 as c_R approaches zero. □

Small c_R implies X_R is large, such as point S in Figure 1.

As with the previous Proposition, monotonicity of $\frac{P(X_R^P)}{P(X_R^N)}$ with respect to f_R implies that the critical value c_R^* is smaller when f_R is larger. The range of R stage marginal cost for which patentability is undesirable becomes smaller when the fixed cost is larger.

Social welfare depends on the product of the adjusted probability of D stage success and that of R stage success. As a result, when the probability R stage success is high due to lower research cost of that stage (low c_R and low f_R), it is more efficient to encourage the expansion of the D stage reward. Since patentability reduces the D stage adjusted probability, non-patentability becomes more advantageous.

We have characterized welfare for extreme values of R stage costs in the proceeding two propositions. We have the following proposition about welfare at value in between.

Proposition 5. *The ratio W^P/W^N is (i) increasing in c_R and (ii) increasing in f_R.*

Proof. In the following, $X(\theta)$ means X is a function of parameter θ which is either c_R or f_R. Then,

$$\frac{dP(X_R)}{d\theta} = \frac{dX_R}{d\theta}\frac{r}{(X_R+r)^2}.$$

Given that $\frac{dP(X_D)}{d\theta} = 0$, we have the following:

$$\frac{d\ln(W^P/W^N)}{d\theta} = \frac{dP(X_R^P)/d\theta}{X_R^P} - \frac{dP(X_R^N)/d\theta}{X_R^N}$$

Using (14),

$$\frac{dX_R}{dc_R} = -\frac{X_R+r}{c_R}.$$

Thus, we have

$$\frac{dP(X_R)}{dc_R} = -\frac{r}{c_R(X_R+r)}.$$

Since $X_R^N < X_R^P$, we have $-dP(X_R^N)/dc_R > -dP(X_R^P)/dc_R > 0$. It follows that

$$\frac{d\ln(W^P/W^N)}{dc_R} > 0.$$

Similarly,

$$\frac{dX_R}{d\sqrt{f_R}} = -\frac{X_R + r}{\sqrt{\pi_D} - \sqrt{f_R}},$$

so that

$$\frac{dP(X_R)}{d\sqrt{f_R}} = -\frac{r}{(\sqrt{\pi_D} - \sqrt{f_R})(X_R + r)}.$$

Since $X_R^N < X_R^P$ and $\pi_D^N < \pi_D^P$, we have

$$-dP(X_R^N)/d\sqrt{f_R} > -dP(X_R^P)/d\sqrt{f_R} > 0.$$

□

This proposition is analogous to Proposition 5 of Denicolo (2000). We were able to show that the ratio is actually less than 1 for c_R small and greater than 1 for c_R large. And we have already used the proposition in interpreting those propositions.

We now characterize the relationship between extent of possible spillover and the welfare effect of patentability. Using (11) and Lemma 1, the adjusted probability for R stage is, for any γ,

$$P(X_R(\pi_D^N) = P(X_R((1-\gamma)\pi_b)) < P(X_R(\pi_D^P)) = P(X_R(\pi_m)).$$

$P(X_R^N)$ is decreasing in γ. When condition (9) holds, then

$$\gamma P(X_0) + (1-\gamma)P(x_b) > P(X_D^P) = P(x_m),$$

holds for any γ. Greater spillover benefits society at the D stage but it has an adverse effect on R stage investment. Using (1), (10), and (14), we are able to identify the minimum γ above which patentability of the intermediate technology is beneficial to society.

Proposition 6. *Patentability of intermediate technology always improves social welfare when spillover is very large. That is, there is always a level γ^P such that for all $\gamma \geq \gamma^P$ the following holds,*

$$W^P > W^N.$$

Proof. There is always a $\gamma^P > 0$ such that

$$P(X_R^P)P(X_D^P) = P(X_R((1-\gamma)\pi_b))P(X_0).$$

For any $\gamma \geq \gamma^P$,

$$P(X_R((1-\gamma)\pi_b))P(X_0) > P(X_R((1-\gamma)\pi_b))\left\{\gamma P(X_0) + (1-\gamma)P(x_b)\right\}.$$

. □

Although spillover increases D stage investment, profit is dissipated by free entry. This will reduce the incentive to invest in the R stage. Note that this is independent of the size of fixed costs.

We synthesize the above propositions by the following proposition for a large v.

Proposition 7. *When the final technology is very valuable, patentability is desirable only if following condition holds:*

$$\sqrt{rc_R} > 2(1-\gamma)\sqrt{c_D f_D}.$$

That is, if the condition holds, then

$$W^P > W^N,$$

for sufficiently large v.

Proof. The following approximation holds for large X,[14]

$$P(X) = \frac{X}{X+r} \approx 1 - \frac{r}{X}. \quad (18)$$

For small θ_1 and θ_2, we have the following approximation,

$$\frac{1-\theta_1}{1-\theta_2} \approx 1 - \theta_1 + \theta_2. \quad (19)$$

Using (18) and (19), we have for sufficiently large X_R^N, X_D^N, X_R^P, and X_D^P,

$$\frac{W^P}{W^N} = \frac{P(X_R^P)}{P(X_R^N)} \times \frac{P(X_D^P)}{P(X_D^N)} \approx 1 + r\left(\frac{1}{X_R^N} - \frac{1}{X_R^P} + \frac{1}{X_D^N} - \frac{1}{X_D^P}\right).$$

Although all ivestment levels are increasing in v, speed of divergence differ. We

[14] Approximations are derived by ignoring all terms of order greater than $\frac{1}{X^2}$. The approximation can be arbitrarily close to the original expression by choosing X sufficiently large.

can make the following approximations for large v,

$$\frac{1}{X_R^N} \approx \frac{c_R}{2(1-\gamma)\sqrt{f_D v}}, \quad \frac{1}{X_R^P} \approx \frac{c_R}{v}, \quad \frac{1}{X_D^N} \approx \frac{c_D}{v}, \quad \frac{1}{X_D^P} \approx \frac{1}{\sqrt{\frac{rv}{c_D}}}.$$

Thus for sufficiently large v,

$$\frac{W^P}{W^N} \approx 1 + \frac{r}{\sqrt{v}} \left(\frac{c_R}{2(1-\gamma)\sqrt{f_D} - \sqrt{\frac{c_D}{r}}} \right) > 1.$$

□

The proposition shows that the high value of final technology by itself does not determine if patentability of intermediate technology is desirable or not, despite appropriation via trade secrecy. In particular, the interest rate must be sufficiently large. When interest rate is high, it is optimal for monopolist to make a large investment to achieve success early and avoid investing for longer periods. Thus high interest has the effect of reducing monopoly distortion that occur with patentability making patentability desirable. Conditions on c_R and γ are consistent with Propositions 3, 4, and 6.

4 Concluding Remarks

We can derive several policy implications from our analysis. Implication of Propositions 3 and 4 is that patentability be rejected when the intermediate technology covers a mere "idea" that is easy to acquire. Proposition 5 suggests that reduction of basic research costs, due to subsidy or tax breaks make unpatentability of intermediate technology more desirable. We showed that high value of final technology combined with high interest rate is more likely to make patentability desirable (Proposition 7). It follows that when the intermediate technology result in very valuable product, society benefits from weak utility requirement.

Because of constant returns to scale nature of innovation, having more firms engage in innovation will not increase the return from innovation. This means a patentee firm capable of doing D stage innovation itself (a vertically integrated firm) will not gain by licensing to another firm to also do D stage innovation. If the patentee is unable to do D stage innovation itself (an independent inventor or a vertically unintegrated firm), it will not gain by licensing to more than one firm. If there is to be multiple licensing, it would have to be compulsory licensing (see Aoki and Nagaoka (2002) for how it works). Such compulsory licensing can introduce D stage competition while not totally destroying D stage profit. Thus, it may provide an efficient balance between non-patentability and patentability under certain circumstances.

We have focused the analysis when intermediate technology owner is an integrated firm, able to engage in D stage innovation. If only independent innovators can engage in R stage research, patentability of intermediate technology becomes socially more desirable since such a firm has to share profit from the D stage research with the licensee under most circumstances. If the patentee appropriates all the rent, our analysis follows, including the welfare results. This would be case if there is free entry into the licensee market, or if the patentee is able to make a take or leave it offer. Any other license bargaining (sequential, Nash Bargaining) will result in the independent inventor's rent being reduced which weakens R stage incentive.

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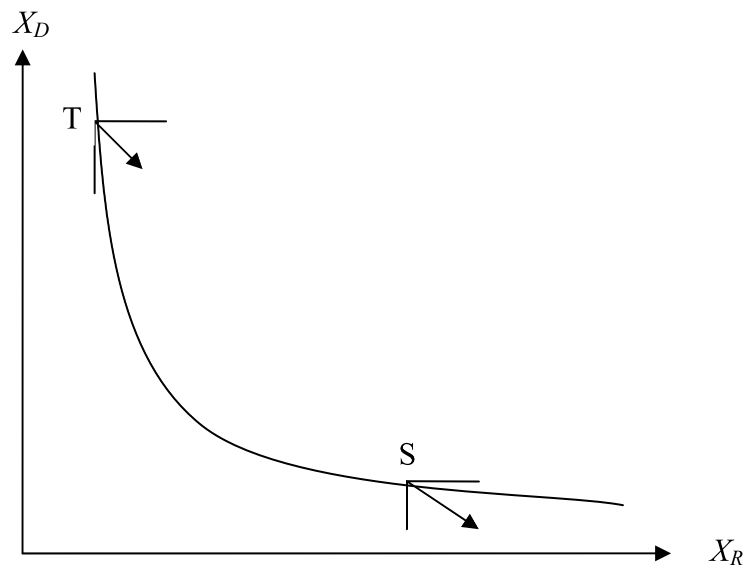

Figure 1: An Iso-welfare Curve