# The Utility Requirement and the Patentability of Intermediate Technology *

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**Abstract**

The utility requirement may invalidate the patentability of intermediate technology, which has only the value of enabling further research, even if it is novel and sufficiently inventive. We analyze the effects of such a requirement in a two-stage invention process with free entry, spillovers and trade secrecy as an alternative to patent protection. We show that when the value of the final technology (second-stage output) is low, a weak utility standard, or equivalently broad patentability of intermediate technology (first-stage output) is socially desirable when not only the first-stage innovation cost is high but also the second-stage cost is high. However, when the final technology is very valuable, patentability is desirable only if either the marginal or fixed second-stage cost is *low relative to first-stage marginal cost*. In particular, a high fixed cost for the second stage of development can enhance the first mover advantage conferred by a trade secret for a firm adopting an entry deterrence strategy, therefore reducing the case for patentability.
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# 1 Introduction

Utility constitutes one of the three basic requirements for patentability, together with novelty and the requirement that the innovation has an inventive step (or nonobviousness). The utility requirement is met when the invention can produce a specific technical effect. An invention such as a new chemical entity that requires further research to identify a "real world" use does not have substantial utilities.[1] The utility requirement would invalidate the patentability of such an intermediate technology, which has only value of enabling further research to establish utility, even if it is novel and sufficiently inventive.

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, the resulting technology may be an "intermediate technology," the real-world utility of which can be determined only after further research. For instance, the specific application of a gene sequence[2] or a new chemical entity may not be clear without substantial further research. The patentability of such technology may be especially critical for firms specializing in research, which are particularly prominent in the US biotechnology industry. Because these firms often have no internal assets to implement downstream research or product development, such as clinical testing of a pharmaceutical application, patents for intermediate research results are often essential to enable the firms to sell

[1] Section 101 of the US Patent Law stipulates the utility requirement with the following statement: "Whoever invents any new and useful process, machine, manufacture, improvement thereof, or composition of matter ... may obtain a patent therefore ...." Recent guidelines from the U.S. Patent Office (USPTO) interpret Section 101 as requiring that "an invention must be supported by a specific, substantial, and credible utility ...." In addition, the utility requirement is 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."

[2] In applying for a patent on partial genetic sequences in 1991, the National Institutes of Health (NIH) claimed that these could be used as diagnostic probes—for instance, for the identification of chromosomes—which constituted uncertain general utility. The NIH abandoned patenting in 1994 because it faced rejection by the USPTO based on utility and other requirements, as well as strong criticism in scientific and other circles. (See Aoki and Nagaoka (2002) for more on biotechnology and the utility requirement.)

the research outputs or to attract investment money for downstream invention (Gans, Hsu and Stern (2002)).

Despite the increasing importance of the utility requirement in science-driven inventions and substantial interest among legal scholars (Grady and Alexander (1992), Merges (1997), and Heller and Eisenberg (1998) to name a few), there is almost no substantive economic analysis of the utility requirement.[3] The purpose of this paper is to present an economic framework and to analyze the welfare implications of the utility requirement.

We employ a model of two-stage cumulative innovation where first-stage (R-stage) output is the intermediate technology. Intermediate technology has no value by itself. Second-stage (D-stage) innovation results in a final product that has value $v > 0$.

We extend the existing cumulative invention analysis in several ways. First, past studies on the novelty requirement and forward protection have focused on the patentability of D-stage invention and the possibility of such an invention infringing on a intermediate technology (see Scotchmer and Green (1990) and Denicolo (2000), for example). Because output of the first-stage investment is an intermediate technology, implementing the second-stage invention *always* infringes on the patent if the intermediate technology is patented.

Second, we incorporate both trade secrecy and spillovers. For intermediate technology, a firm will often consider trade secret protection because the technology is used only for further research. It is likely to remain within the confines of a building or to be known to a limited number of people within the inventing firm. Thus, trade secret protection is available even if patent protection is not. However, trade secrecy loses its protective power once competitors obtain the technology independently or if there is a spillover. Spillovers often occur

[3] Harhoff, Regibeau, and Rockett's (2001) analysis of genetically modified food is one exception.

through academic publications and contacts among researchers, both of which are significant in science-driven inventions. As we explain below, inclusion of these factors leads to some conclusions that are strikingly different from those of the existing literature on forward protection.

We use a model of two-stage innovation employed by Denicolo (1999, 2000), but we have made two major changes to his framework to reflect the conditions explained above. Because Denicolo's model focuses on the patentability of the second-stage invention, he assumes the first-stage invention is always protected and profitable (he assumes zero fixed cost of research). As a result, a higher second-stage cost always makes *weaker* protection of the first-stage invention more desirable. We show that *stronger* protection of the first-stage invention or its patentability can be desirable when the second-stage cost is very high, to create an incentive to undertake first-stage invention (Proposition 1). In addition we introduce the possibility of protecting the first-stage invention by means of trade secrecy. Although trade secrecy does not give the first inventor the ability to exclude others who invent independently, it does bestow on him the position of first-stage winner, i.e., Stackelberg leadership, in the second stage because R&D costs are sunk. (In the next section we discuss how the first inventor can obtain such leadership.) We show that the fixed and sunk cost is indeed crucial for appropriation of the first-stage invention with trade secrecy: higher second-stage fixed cost can make trade secret protection more effective and the patentability of the first invention less desirable (Lemma 3, Proposition 3).

Scotchmer and Green (1990) also considered trade secrecy an alternative to patents in their analysis of another patentability requirement, the novelty requirement, focusing on information disclosure. The novelty requirement is similar to the utility requirement in that both pertain to the patentability of a first-stage invention, but the relationship to the second-stage invention differs in the following sense. When novelty is the issue for the first invention, there is no harm in assuming, as Scotchmer and Green do, that the second-stage invention does not infringe. However, such assumptions do not make sense when the first invention is an intermediate technology. Reflecting the independence of the first and second inventions, they assume that the first invention has a value even without further research, which is not possible when it is an intermediate technology. (See the Appendix in Aoki and Nagaoka (2002) for a more complete explanation of findings by Scotchmer and Green that can be extended to the case of the utility requirement).

Grossman and Shapiro (1987) analyzed the patentability of an intermediate technology that must be discovered before stage two and has only the value of potential research. Because they assume that the loser of the first stage always drops out of the race, there is no trade-off between competition and ease of appropriation in stage two. Their interest is the profitability of the firm, not patent policy from a welfare point of view. Finally, Matutes, Regibeau, and Rocket (1996) characterized the optimal patent policy in a two-stage invention process, where the first-stage invention has only the value of potential research. They explored the trade-off between disclosure and protection of first-stage research, whereas we focus on the trade-off between first- and second-stage inventions, following Chang (1995), O'Donoghue, Scotchmer, and Thisse (1998), O'Donoghue (1999), Denicolo and Zanchettin (2002), and others. (See Scotchmer (2004) for an overview of sequential invention).

We introduce the model in the following section and characterize the equilibrium investments when the utility requirement is weak (first-stage invention is patentable) and strong (it is *not* patentable). We compare welfare with the two regimes in Section 3. Section 4 presents concluding remarks.

## 2 The Model

There is free entry into both the first-stage basic research (R-stage) and the second-stage development (D-stage), unless it is constrained by patent protection or trade secrecy. When a firm succeeds in R-stage innovation, it can always choose to resort to trade secrecy to protect the intermediate technology unless it is of the spillover type (see the discussion below).

We assume that a firm's success becomes known to all firms immediately. If a firm resorts to patent protection, this is not really an assumption because patents are published. When the firm applies trade secrecy, then our assumption means that the successful firm always announces its discovery without disclosing its specific content. Announcement is credible because the announcement is accompanied by the implementation of the second-stage investment, which is also verifiable and becomes sunk.[4] In addition, the firm has an incentive to announce the discovery because it can deter a follower's second-stage investment. Because trade secret protection does not prevent rivals from using the same technology if it is obtained independently, a firm protected by trade secrecy faces potential competition in the second stage. (In fact, with a Poisson discovery process, another firm will succeed in the R-stage with probability 1.)

All firms are ex ante symmetric, but the R-stage winner with trade secret protection has the advantage of Stackelberg leadership in the D-stage and invests as an incumbent anticipating entry. Because we assume that research expenditure in each stage is completely sunk once research is commenced, there is no reason for a firm in the R-stage to drop out of competition even when another firm has completed the R-stage, unless it believes that it cannot profitably enter the D-stage development competition.

[4]Of course there is a possibility that the firm uses investment to signal success or failure (Aoki and Reitman (1992)). It is possible to justify our assumption even if R-stage outcome is private information as long as investments are observable. Successful firm investment to signal success is a separating equilibrium behavior.

We assume that an intermediate technology is a type that spills over either completely or not at all. We use $\gamma$ to denote the probability that it is the type that spills over. This probability is common knowledge. Once the R-stage is completed, i.e., once a firm obtains the intermediate technology successfully, the firm knows immediately which type it is. If the technology is the spillover type, spillover occurs immediately, unless the technology is protected by a patent.[5] If spillover occurs, the D-stage will be competitive with free entry. If the technology is the nonspillover type, which is the case with probability $1 - \gamma$, then trade secrecy is effective.

Specifically, firm $i$ chooses research intensity $x_{it}$ for unit cost $c_t$ for R&D at the $t$-stage, where $t = R$ or $t = D$. Research intensity is equal to the instantaneous probability of the discovery. Therefore, we assume constant returns. Discovery in each stage follows a Poisson process. We also 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.[6] Because it is an intermediate technology, there is no direct commercial value resulting from the R-stage invention.[7] The value of the final technology is $v$.

We consider two cases, one where the intermediate technology is patentable and the other where it is not. If it is patentable, whoever succeeds in the R-stage has the choice of patenting. The regime when the intermediate technology is not patentable is the same as that for the no-patenting decision, even when the technology is patentable.

[5] Because the firm announces the discovery of technology of the nonspillover type and spillover is assumed to take place immediately after the discovery, successful completion is observed by all firms so that other firms will also immediately know the technology type.

[6] Because of the Poisson discovery process, there is no advantage in 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 the D-stage. This case is discussed in section three. Even in this case, the particular invention technology implies there should only be one licensee

[7] This is equivalent to Denicolo's $UI$ or $PI$ with $v_1 = 0$, although he does not consider either trade secrecy or fixed cost of research.

## 2.1 D-stage investment

First, we analyze the D-stage investment behavior under the two regimes. We characterize the equilibrium investments, the patenting choice, and the corresponding profits.[8]

**The intermediate technology is patentable**

First, we characterize the equilibrium investment $x$ when the firm has a patent on the intermediate technology ($P$-regime). Because we assume that patent protection is perfect, it chooses $x$ to maximize the monopoly profit:

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

Because the function is concave, the optimal investment, $x_m$ satisfies the first-order condition:

$$\frac{rv}{(x+r)^2} - c_D = 0.$$

The monopoly investment is:

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

and the monopoly profit is:

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

We assume that this is positive:[9]

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

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

[9] Later, we introduce Assumption 1, which is a sufficient condition for condition (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 ($N$-regime), there are two subgames after the completion of the R-stage, depending on the type of technology: one with spillovers (probability $\gamma$) and one without (probability $1-\gamma$). If there is spillover, the firm must compete with new entrants in the D-stage on an equal footing. If there is no spillover, the firm will be the only firm engaged in D-stage until another firm completes the R-stage on its own. The firm exploits the first-mover advantage and invests as an incumbent; i.e., a Stackelberg leader.

We start with the case when there is spillover, using the framework of Denicolo (1999). There are $n$ firms, the number determined in equilibrium, in D-stage competition. Firm $i$'s profit when its investment is $x_i$ is:

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

Marginal profit is:[10]

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

In the symmetric equilibrium with free entry, profit should be zero for all firms; i.e., $x_i = x$ for all $x$ and $\pi_i = 0$ in (3) and $\frac{\partial \pi_i}{\partial x_i} = 0$ in (4):

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

[10] Hereafter, all summation will be for $i = 1, \ldots, n$ unless noted otherwise.

Then 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 the D-stage investment:

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

The total investment with a spillover is as follows and is always decreasing in both costs:

$$X_0 = n_0 x_0 = \frac{v - \sqrt{v f_D}}{c_D} - r. \tag{5}$$

We use capital letters for aggregate investment levels. The equilibrium profit when there is a spillover is zero; i.e. $\pi_S = 0$.

If there is no spillover, the firm is protected by trade secrecy until another firm succeeds in the R-stage independently. We assume that it invests to such an extent that not even an entrant expecting no further entries can make money. Although we focus on the entry-deterrence strategy in the following analysis, the major conclusions would apply in cases of the entry-accommodation strategy.[11] The firm will choose the entry-deterrence strategy when the fixed cost of the D-stage ($f_D$) is large (see Appendix 6). The firm chooses $x$ to deter entry. An entrant's profit when it invests $x_e$ is:

$$\pi_e = \int_0^\infty exp^{-(x_e+x+r)\tau} x v d\tau - c_D x_e - f_D = \frac{x_e v}{x_e + x + r} - c_D x_e - f_D. \tag{6}$$

The entrant will invest to maximize this profit, given the incumbent's investment

[11]See Aoki and Nagaoka (2005), available upon request.

$x$. 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 $\pi_e$ will be zero even when the entrant is profit maximizing. Note that the entrant's profit declines with $x$ ($\partial \pi_e/\partial x < 0$). The entry deterrent investment, $x_b$, is:

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

We assume throughout the analysis that the following condition holds.

**Assumption 1.** *(Monopoly investment is not entry blocking)*

$$\frac{(\sqrt{v} - \sqrt{f_D})^2}{\sqrt{v}} > \sqrt{rc_D},$$

*which is the condition for $x_b > x_m$.*

This condition requires that the fixed cost is not so large that monopoly output will block entry. Because the firms are symmetric, this upper bound on fixed cost also implies $\pi_m \geq 0$ (condition (2)), as shown in Appendix 1. We have the standard relationship, $x_b \to X_0$ as $f_D \to 0$. y7 The equilibrium profit with entry deterrence is:

$$\begin{aligned}\pi_b &= v - (\sqrt{v} - \sqrt{f_D})^2 - c_D r\left(\frac{v}{(\sqrt{v} - \sqrt{f_D})^2} - 1\right) - f_D \\ &= 2\sqrt{f_D}(\sqrt{v} - \sqrt{f_D}) - c_D r\left(\frac{v}{(\sqrt{v} - \sqrt{f_D})^2} - 1\right). \qquad (7)\end{aligned}$$

Note that $\pi_b \to 0$ as $f_D \to 0$. Summarizing, investment ($x_{NS}$) and profit ($\pi_{NS}$) when there is no spillover are $x_b$ and $\pi_b$, respectively. ($NS$ represents the nonspillover case.) The equilibrium D-stage profit of the firm successful in the R-stage,[12] when the intermediate technology is not patentable, taking into account the fact that nature determines the type of technology, is:

$$\pi_D^N = \gamma\pi_S + (1-\gamma)\pi_{NS} = (1-\gamma)\pi_b. \tag{8}$$

We make the following observation about relative size.

**Lemma 1.** *When Assumption 1 holds, then:*

$$x_m < x_b = x_{NS} < X_0, \quad \pi_D^P = \pi_m > \pi_b = \pi_{NS} > \pi_D^N > 0.$$

Based on this lemma ($\pi_D^P > \pi_D^N$), we can make the following claim.

**Corollary 1.** *A firm will always patent the intermediate technology if it is patentable.*

Even if trade secret protection is perfect, it offers no protection against independent invention. This alone always makes patent protection more attractive than trade secret protection.

## 2.2 R-stage investment

### General solution of the R-stage

We derive a general solution for the R-stage when the payoff to the winner from the D-stage is $\pi_D$ and the losers receive nothing (note that only the winner undertakes the D-stage invention). Firm $i$'s expected payoff when it invests $x_i$ and other firms invest $x_j$ is:

$$\pi_i = \frac{x_i\pi_D}{x_i + \sum_{j\neq i} x_j + r} - c_R x_i - f_R. \tag{9}$$

[12] The other firms' profits are zero.

The first-order condition for profit maximization is:

$$\frac{\partial \pi_i}{\partial x_i} = \frac{\sum_{j \neq i} x_j + r}{(x_i + \sum_{j \neq i} x_j + r)^2} \pi_D - c_R = 0. \tag{10}$$

Again, using symmetry,[13] we obtain the equilibrium investment:

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

For this to be positive (the interior solution), the profit from the next stage must be sufficiently large to cover the fixed cost; i.e., $\pi_D > f_R$.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 aggregate investment, $X_R$, is:

$$X_R(\pi_D) = n_R x_R = \frac{\sqrt{\pi_D}}{c_R} \left( \sqrt{\pi_D} - \sqrt{f_R} \right) - r. \tag{11}$$

Aggregate investment is increasing in D-stage profit and decreasing in both costs. The equilibrium investments $X_R^P$ (when the intermediate technology is patentable) and $X_R^N$ (when not patentable) can be found by substituting the appropriate equilibrium profits from the D-stage, $\pi_D^P$ and $\pi_D^N$, respectively. Equation (11) and Lemma 1 together show that an increase in investment in one stage is achieved at a cost of reduction in investment in the other stage.

[13] In a symmetric equilibrium with free entry, (9) should equal 0 and $x_j = x$ for all $j$. Equations (9) and (10) 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 the number of firms, respectively.

**Lemma 2.** *Patentability of the intermediate technology increases R-stage research investment but reduces D-stage investment.*

From (11), we can make the following observation.

**Lemma 3.** *When the intermediate technology is not patentable, there will be R-stage investment if and only if costs ($c_D$,$c_R$, $f_R$) and/or spillovers are low. That is:*

$$X_R^N > 0 \quad \Leftrightarrow \quad \sqrt{(1-\gamma)\pi_b} > \sqrt{\frac{f_R}{2}} + \sqrt{c_R r + \frac{f_R}{4}}. \tag{12}$$

# 3 Welfare

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

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

is the "adjusted probability" of innovating (Denicolo (2000)). This adjusted probability discounts the value by delay, which is distributed according to a Poisson process. Denoting the investments in the R-stage and the D-stage by $X_R$ and $X_D$, respectively, the expected welfare is:

$$\begin{aligned} W(X_R, X_D) &= P(X_R)\left\{P(X_D)(v+s) - c_D X_D - n_D f_D\right\} - c_R X_R - n_R f_R, \\ &= P(X_R)P(X_D)s + P(X_R)\pi_D - c_R X_R - n_R f_R. \end{aligned}$$

Noting that any surplus in D-stage is exhausted in equilibrium through R- stage competition, the welfare levels with and without patentability of the intermediate technology are:

$$W^P = P(X_R^P)P(X_D^P)s = P(X_R(\pi_m))P(x_m)s,$$

$$W^N = P(X_R^N)\left\{\gamma P(X_0) + (1-\gamma)P(x_b)\right\} s = P(X_R((1-\gamma)\pi_b))\left\{\gamma P(X_0) + (1-\gamma)P(x_b)\right\} s,$$

respectively. Superscripts $N$ and $P$ denote that intermediate technology is "not patentable" and "patentable", respectively. From Lemma 3, we can immediately identify a case where patentability will unambiguously improve welfare.

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

There will be no R-stage investment without patentability if condition (12) does not hold, in which case, welfare will be zero. Given that a firm can recover its R-stage investment only by commercializing D-stage inventions, the patentability of the intermediate technology tends to be favored not only by the high cost of R-stage research but also by the high marginal cost of D-stage development, when the value of final technology is not very high. Thus, if an intermediate technology requires a large amount of additional work (i.e., high investment costs) for commercialization, this would be precisely the situation where welfare is improved by making the intermediate technology patentable.

An iso-welfare curve in $(X_R, X_D)$ space is depicted in Figure 1 for $\gamma = 0$ and $X_D = x_b$. Convexity can be derived as in Denicolo (2000). The figure demonstrates the trade-off involved in making intermediate technology patentable. Patentability increases $X_R$ and reduces $X_D$ (Lemma 2). In the figure, this means patentability will change investments in the direction of the arrows. We make the following observation about extreme points $S$ and $T$. Patentability will increase welfare if it is originally at $T$ but will reduce welfare if it is originally at $S$. When R-stage investment is low to begin with, increasing it slightly is very effective in increasing welfare. Similarly, when D-stage investment is low, decreasing it slightly is detrimental. A more detailed analysis of the implications of patentability for welfare is presented in the two propositions below.

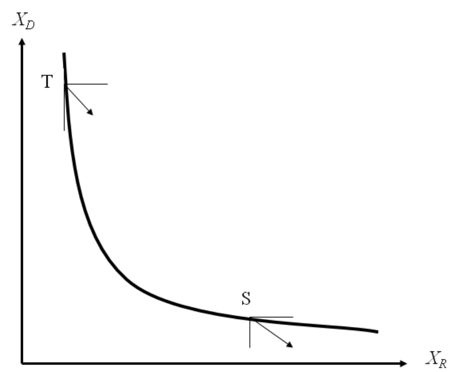


Figure 1: Iso-Welfare Curve

We begin by establishing the following relationship.

**Lemma 4.** *When condition (12) holds, the ratio $W^P/W^N$ is (i) increasing in $c_R$ and (ii) increasing in $f_R$.*

The proof is in Appendix 2.

Whether this ratio ($W^P/W^N$) is greater or less than one determines whether welfare is higher or lower with patentability. First, we characterize the relationship between R&D costs and the welfare effect of patentability using Lemma 4.

**Proposition 1.** *The following statement holds under condition (12).*

*(i) Patentability of intermediate technology improves social welfare if the marginal cost of the R-stage research is very high. More generally, there is a value of $c_R^*$ such that:*

$$W^P \gtreqless W^N \Leftrightarrow c_R \gtreqless c_R^*. \tag{13}$$

*(ii) Patentability of intermediate technology improves welfare if the fixed cost of the R-stage research is very high, making R-stage research without patentability barely profitable. More generally, there is a value of $f_R^*$ such that:*

$$f_R \lesseqqgtr f_R^* \Leftrightarrow W^P \gtreqqless W^N.$$

*(iii) Similarly, patentability always improves social welfare when D-stage marginal and fixed costs are large. That is, there are values of $c_D^*$ and $f_D^*$ that satisfy condition (12), such that:*

$$c_D > c_D^*, f_D > f_D^* \quad \Rightarrow \quad W^P > W^N.$$

The proof is provided in Appendix 3.

The expression (11) implies that if $r$ is close to $\sqrt{\pi_D^N}(\sqrt{\pi_D^N} - \sqrt{f_R})/c_R$, the R-stage investment $X_R$ is very small. In Figure 1, this situation would be represented by a point such as $T$, at which the change in investments due to patentability improves welfare. On the other hand, a small $c_R$ implies that $X_R$ is large ($X_R \to \infty$ as $c_R \to 0$), as represented by a point such as $S$ in Figure 1. 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 of R-stage success is high because of the low research cost in that stage (i.e., low $c_R$), it is more efficient to encourage expansion of the D-stage reward. Because patentability reduces the D-stage adjusted probability, nonpatentability becomes more advantageous.

Monotonicity of $\frac{P(X_R^P)}{P(X_R^N)}$ with respect to $f_R$ and $c_R$ (see Lemma 4 ) implies that the critical value $c_R^*$ is decreasing in $f_R$. The range of R-stage marginal costs for which patentability is undesirable becomes smaller when the fixed cost is larger.

Now, we characterize the relationship between the extent of possible spillovers and the welfare effect of patentability. Using (8) and Lemma 1, the adjusted probability for the R-stage is, for any $\gamma$:

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

$P(X_R^N)$ is decreasing in $\gamma$ and approaches zero as $\gamma$ approaches unity. On the other hand:

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

holds for any $\gamma$. A greater spillover benefits society at the D-stage, but it has an adverse effect on R-stage investment. Using (1), (7), and (11), we are able to identify the minimum $\gamma$ above which patentability of the intermediate technology is beneficial to society.

**Proposition 2.** *Patentability of intermediate technology always improves social welfare when the spillover is very large. That is, there is always a level of $\gamma^P$ such that, for all $\gamma \geq \gamma^P$, the following holds:*

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

The proof is provided in Appendix 4.

We can synthesize as well as extend the above propositions by the following proposition (and Figure 2) when the value of the final technology $v$ is very large. When $v$ is very high, $X_D^P$ and $X_R^N$ increase with $\sqrt{v}$, whereas $X_R^P$ and $X_D^N$ increase only with $v$. Thus, whether the patentability is desirable depends only on the ratio of $X_D^P$ to $X_R^N$. Given that $X_D^P \cong \sqrt{rv/c_D}$, and $X_R^N \cong \left\{2(1-\gamma)\sqrt{f_D v}\right\}/c_R$, we have the following proposition.

**Proposition 3.** *When the final technology (v) is very valuable, patentability is desirable if and only if the monopoly research expenditure in the D-stage under nonpatentability is larger than the aggregate competitive expenditure in the R-stage under nonpatentability. That is:*[14]

$$W^P > W^N \quad \Leftrightarrow \quad \sqrt{\frac{r}{c_D}} > 2(1-\gamma)\frac{\sqrt{f_D}}{c_R} \quad \Leftrightarrow \quad \frac{c_R}{\sqrt{c_D f_D}} > \frac{2(1-\gamma)}{\sqrt{r}}.$$

The proof is provided in Appendix 5.

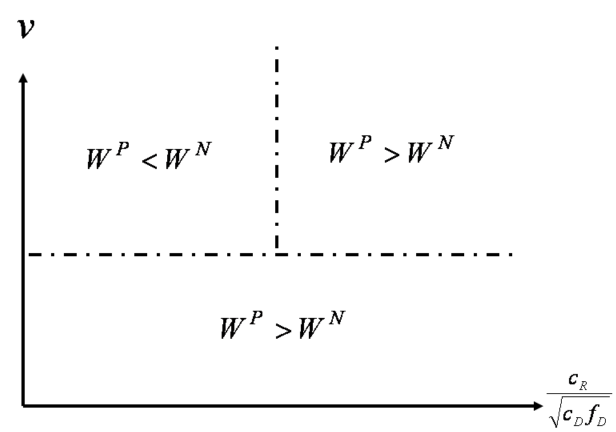

Figure 2: Summary of Propositions 1 – 3

This proposition shows that even if the technology can be protected by trade secrecy, a high value of final technology by itself does not make the patentability of intermediate technology undesirable, assuming the entry deterrence strategy. We can interpret the above inequality in the following way. When the value of the final technology is high, the desirability of patentability depends only on the ratio of $X_D^P$ to $X_R^N$, which are the levels of investment at the "bottleneck"

[14]Conditions on $\gamma$ and $c_R$ are consistent with Propositions 1 and 2. It is also consistent with the the assumption that $f_D$ is sufficiently large so that entry deterrence is better than entry accommodation. For instance, if $c_R = 2$, $\gamma = .7$, $c_D = 1$, $v = 10$, then $f_D = 0.7$ is small enough to satisfy the condition so that $\frac{c_R}{\sqrt{c_D f_D}} = 3.65$ and $\frac{2(1-\gamma)}{\sqrt{r}} = 2.68$ but large enough so that $\pi_b = 2.8$ and accommodation profit is (about) 2.15.

stages of the patentability and nonpatentability regimes, respectively, where "bottleneck" refers to the stage at which the level of investment is relatively small. When the interest rate $r$ is high or when $c_D$ is low, the investment in the D-stage is high, even when the intermediate technology is patentable and the second-stage invention is monopolized. The monopoly investment increases as $r$ increases because a high interest rate induces a monopoly firm to realize the invention quickly to avoid heavy discounting. Therefore, the patentability is desirable. On the other hand, when $f_D$ is high, the first-mover advantage from trade secret protection is large for the firm that is successful in the first stage of research. Therefore, the D-stage profit can be high with a high $f_D$ even under the nonpatentability regime.[15] This makes the investment in the R-stage high. A low $c_R$ has the same effect on R-stage investment. Both situations make the patentability of intermediate research undesirable. In summary, balancing the incentives for the two stages matters even if the final technology has a very high value.[16]

# 4 Concluding Remarks

We highlight the following two points from our findings. First, our paper has shown that the high cost of the second stage can make it desirable to provide stronger protection of first-stage research, in terms of the patentability of the intermediate technology in a two-stage R&D race model (see (iii) of Proposition 2), in contrast to the findings of Denicolo (2000). This difference arises from the fact that our paper analyzes the patentability of the intermediate technology, which has only the value of enabling further research and does not rule out a fixed cost for research.

[15]Equation (7) shows that the profit of the first firm to succeed in the R-stage increases with $f_D$ when $v$ is large, for relatively small $f_D$.

[16]Conditions on $v$ and $c_R$ are consistent with Propositions 2 and 3.

Second, our model has incorporated trade secret protection as well as spillovers, which has enabled us to clarify that the fixed and sunk cost of the second-stage research is an important determinant of the ease of appropriation of innovation in cumulative innovation. Higher fixed costs in the second-stage can increase the first-mover advantage of the firm that is successful in the first-stage research, when the costs are small relative to the value of the patent ($v$). Under such circumstances, the high fixed cost of second-stage research makes trade secret protection more effective when a firm pursues an entry deterrence strategy and makes the patentability of the first-stage research less desirable (see Proposition 3).

We can derive several policy implications from our analysis. The implication of Proposition 1 is that even if trade secrecy protects intermediate technology, its patentability remains beneficial when research costs are high. The possibility of such a technology spilling over reinforces the case for patentability (Proposition 2). On the other hand, patentability should be rejected when the intermediate technology covers a mere "idea" that is easy to acquire. Assuming a high value of the final technology, Proposition 3 suggests that reducing the marginal cost of the first-stage research relative to the marginal cost of development by, for example, offering a subsidy or tax breaks, makes nonpatentability of intermediate technology more desirable. In addition, we have shown that a high interest rate is more likely to make the patentability of intermediate technology desirable (Proposition 3).

The analysis has focused on the range of parameter values for which entry deterrence is better than accommodation in the second stage. (See Appendix 6.) We have analyzed the case with entry accommodation in Aoki and Nagaoka (2005) and have shown that the basic trade-off for patentability is the same, although it is very difficult to characterize analytically the exact conditions that guarantee that patentability will improve welfare.

Because we have assumed constant returns to scale in our model, having more firms engage in invention will not increase the return from invention. This means that a patentee firm capable of undertaking its own second-stage innovation, i.e., a vertically integrated firm, will not gain by licensing another firm to undertake the second-stage investment. If the patentee is unable to undertake its own second-stage invention, for example, if it is an independent inventor or a firm that does not have downstream assets, it will not gain by licensing to more than one firm.

We have developed the analysis on the assumption that the owner of the intermediate technology is an integrated firm, able to engage in second-stage invention. If only the firms specializing in research can engage in first-stage research and only ex post licensing is feasible, the patentability of the intermediate technology becomes more socially desirable because under most circumstances, a firm must share the profit from the second-stage research with the licensee. Our analysis, including the welfare results, is also valid when the patentee is able to appropriate all the rent. This would be the case if there were free entry into the licensee market, or if the patentee were able to make a take-it-or-leave-it offer. Any other license process, such as strategic or Nash bargaining, will result in the nonintegrated inventor's rent being reduced, which weakens first-stage incentives. In addition, our analysis assumes that profit-oriented organizations would conduct the first-stage research and use basic research. Of course, this is not always the case. Most notably, universities conduct first-stage research and use it as a tool for further research. Although the patentability of basic research may provide a source of income for universities, there is a great concern that long-run adverse effects may arise if research tool patents limit access to research tools. According to the recent ruling on Madey vs. Duke, research exemption is not applicable even if the second-stage research is pure research and not conducted for profit.[17] This implies that an analysis of the patentability of the basic research of nonprofit organizations requires an examination of the distribution of rents between the first and second stages of research, even though the rent may not be pecuniary.

# 5 References


Aoki, R. and S. Nagaoka, 2002, "The Utility Requirement and the Patentability of Basic Research," CIRJE Discussion Paper Series F-160, University of Tokyo, July 2002.

Aoki, R. and S. Nagaoka, 2005, "When Entry Accommodation is Optimal—A Note to Accompany 'The Utility Standard and the Patentability of Intermediate Technology'," Mimeograph, Hitotsubashi University.

Aoki, R. and D. Reitman, 1992, "Simultaneous signaling through investment in an R&D game with private information, " *Games and Economic Behavior*, Vol.4, pp.327–346.

Chang, H.F., 1995, "Patent scope, antitrust policy and cumulative invention," *RAND Journal of Economics*, Vol.26, No.1, pp.34–57.

Denicolo, V., 1999, "The optimal life of a patent when the timing of invention is stochastic," *International Journal of Industrial Organization*, Vol.17, pp.827–846.

Denicolo V., 2000, "Two-stage patent races and patent policy," *RAND Journal of Economics*, Vol.31, No.3, pp.488–501.


[17] The Court of Appeals of the Federal Circuit overturned a lower court decision and found infringement by Duke University because it used equipment patented by John M.J. Madey in the pursuit of its legitimate business objectives, "including educating and enlightening students and faculty," as well as securing "lucrative research grants," and thus was not entitled to the experimental use defense (307 F.3d. 1351, October 2002). The Supreme Court has refused to hear the case, making this decision final (June 2003).

Denicolo, V. and P. Zanchettin, 2002, "How should forward protection be provided?" *International Journal of Industrial Organization*, Vol.20, No.6, pp.801–827.

Gallini, N. and S. Scotchmer, 2001, "Intellectual property: When is it the best incentive system?" in *Invention Policy and the Economy*, Vol.2, Adam Jaffe, Joshua Lerner and Scott Stern eds., MIT Press.

Gans, Joshua S., David H. Hsu and Scott Stern, 2002. "When does start-up invention spur the gale of creative destruction?" *RAND Journal of Economics*. Vol.33, No.4, pp.571–586.

Grady, Mark F. and Jay I. Alexander, 1992, "Patent law and rent dissipation," *Virginia Law Review*, Vol.78, No.305.

Grossman G. M. and C. Shapiro, 1987, "Dynamic R&D competition," *The Economic Journal*, Vol.97, No.386, pp.372–387.

Harhoff, Dietmar, Pierre Regibeau, and Katharine Rockett, 2001, "Some simple economics of GM foods," *Economic Policy* Vol.16, No.3, pp.263–300.

Heller, Michael A. and Rebecca S. Eisenberg, 1998, "Can patents deter invention ? The anticommons in biomedical research," *Science* Vol.280, Issue 5364, pp.698–701.

Matutes, C., P. Regibeau and K. Rockett, 1996, "Optimal patent design and the diffusion of inventions," *RAND Journal of Economics*, Vol.27, No.1, pp.60–83.

Merges R. P., 1997, *Patent law and policy: cases and materials*, Contemporary legal education series.

O'Donoghue, T., 1998, "A patentability requirement for sequential invention," *RAND Journal of Economics*, Vol.29, No.4, pp.654–679.

O'Donoghue, T., S. Scotchmer, and J-F. Thisse, 1998, "Patent breadth, patent life, and the pace of technological progress," *Journal of Economics and*

*Management Strategy*, Vol.7, No.1, pp.1–32.

Scotchmer, S., 2004, Invention and Incentives, MIT Press.

Scotchmer, Suzanne and Jerry Green, 1990, “Novelty and disclosure in patent law,” *RAND Journal of Economics*, Vol.21, No.1, pp.131–146.

# Appendix

### 1. Derivation of condition (2) from Assumption 1

Because the firms are ex ante symmetric, the profit functions for the leader and the follower are the same, $\pi_(x, y) = x/(x+y+r) - c_D x - f_D$ ,where $x$ is a firm's own investment and $y$ is that of a rival. Denote the best-response function defined from this profit function by $R(y)$. When intermediate technology is patentable, the leader invests as a monopolist; i.e.,$x_m = R(0)$. Equation (2) is the same as:

$$\pi(R(0), 0) > 0. \tag{14}$$

The entrant invests at the best-response level given the incumbent's investment. The monopoly investment not being entry blocking means:

$$\pi(R(x_m), x_m) > 0. \tag{15}$$

This is Assumption 1. Because $\pi(x, y)$ is decreasing in $y$ and $x_m > 0$ , (15) implies (14). That is, Assumption 1 implies equation (2).

### 2. Proof of Lemma 4

*Proof.* In the following, $X(\theta)$ means $X$ is a function of parameter $\theta$ that 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 (11):

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

Thus, we have:

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

As $X_R^N < X_R^P$, 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:

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

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

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

□

**3. Proof of Proposition 1**

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

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

Together, we have:

$$\frac{X_D^P}{X_D^N} \geq \frac{rk}{(k^2+2k)r} = \frac{1}{k+2}. \tag{16}$$

From Lemma 1, under which condition (12) holds, we have:

$$X_0, x_b > x_m,$$

which implies: [18]

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

Together with (16), we have:

$$\frac{P(X_D^P)}{P(X_D^N)} > \frac{1}{(k+2)}. \tag{17}$$

Using (11), we have:

$$\frac{P(X_R^P)}{P(X_R^N)} = \frac{X_R^P}{X_R^N} \times \frac{r + X_R^N}{r + X_R^P}$$
$$= \frac{\sqrt{\pi_D^P}(\sqrt{\pi_D^P} - \sqrt{f_R}) - c_R r}{\sqrt{\pi_D^N}(\sqrt{\pi_D^N} - \sqrt{f_R}) - c_R r} \times \frac{\sqrt{\pi_D^N}(\sqrt{\pi_D^N} - \sqrt{f_R})}{\sqrt{\pi_D^P}(\sqrt{\pi_D^P} - \sqrt{f_R})}. \tag{18}$$

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 approaching infinity as $c_R r \to \sqrt{\pi_D^N}(\sqrt{\pi_D^N} - \sqrt{f_R})$. Note that $\pi_D^N = (1-\gamma)\pi_b$ is independent of $c_R$. For a sufficiently large $c_R$:

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

[18] Recall that D-stage investment with no patenting was $X_0$ with spillovers and $x_b$ without. $X_D^N$ is defined by:

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

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

Then, using (17), we have, for such a value of $c_R$:

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

Note that such a value of $c_R$ satisfies condition (12).

To show the existence of $c_R^*$ (which also satisfies (12)), we need to show that for a sufficiently small $c_R$, the ratio becomes less than 1. From Proposition 2, we have $X_D^P < X_D^N$, and thus $\frac{P(X_D^P)}{P(X_D^N)} < 1$. From (18), we have $\frac{P(X_R^P)}{P(X_R^N)} > 1$ converging to 1 as $c_R$ approaches zero. The monotonicity of $W^P/W^N$ (Lemma 4) implies the existence of $c_R^*$. This ends the proof of part (i). A similar argument when $\sqrt{f_R}$ approaches $\sqrt{\pi_D^N - \frac{c_R r}{\sqrt{\pi_D^N}}}$ shows the existence of $f_R^*$, which proves part (ii). Because we are making $f_R$ approach $\sqrt{\pi_D^N - \frac{c_R r}{\sqrt{\pi_D^N}}}$ from below, $f_R^*$ satisfies condition (12), and thus there are values of $f_R > f_R^*$ that also satisfy the condition.

Part (iii) follows from a similar argument, showing that:

$$\sqrt{\pi_D^N}(\sqrt{\pi_D^N} - \sqrt{f_R}) - c_R r \tag{19}$$

in (18) becomes zero when $c_D$ or $f_D$ becomes sufficiently large and close to the upper bound given by (12). Because they are approaching from below, there are values of $c_D^*$ and $f_D^*$ that satisfy condition (12), so that for all values of $c_D > c_D^*$ and $f_D > f_D^*$ that satisfy condition (12), (19) is sufficiently close to zero. The only caveat is that $k$ depends on $c_D$, meaning that when $c_D$ becomes large, the lower bound of (17) changes. Fortunately, it moves to make the constraint less binding (the right-hand side declines). Thus, we can still use the bounds and obtain the desired inequality. Because we are not able to claim monotonicity of $W^P/W^N$ with respect to development stage costs, we do not have a critical value as in parts (i) and (ii). □

**4. Proof of Proposition 2**

*Proof.* Because $P(X_R^N)$ is decreasing in $\gamma$ and approaches zero, there is always a value of $\gamma^P > 0$ such that:

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

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

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

. $\square$

**5. Proof of Proposition 3**

*Proof.* The following approximation holds for large $X$:[19]

$$P(X) = \frac{X}{X+r} \approx 1 - \frac{r}{X}. \tag{20}$$

For small values of $\theta_1$ and $\theta_2$, we have the following approximation:

$$\frac{1-\theta_1}{1-\theta_2} \approx 1 - \theta_1 + \theta_2. \tag{21}$$

Using (20) and (21), for sufficiently large values of $X_R^N$, $X_D^N$, $X_R^P$, and $X_D^P$, we have:

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

[19]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 a sufficiently large $X$ .

Although all investment levels are increasing in $v$, the convergence speeds of the reciprocals differ. We can make the following approximations for large values of $v$:

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

Thus, for sufficiently large values of $v$:

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

□

**6. Entry deterrence is optimal when $f_D$ is sufficiently large**

Incumbent's accommodation investment, $x_a^*$, maximizes:

$$\pi(x) \equiv \frac{vx}{x + x_e(x) + r} - c_D x - f_D, \tag{22}$$

where $x_e(x)$ is the solution to:

$$\max_{x_e} \frac{v x_e}{x_e + x + r} - c_D x_e - f_D,$$

which is:

$$x_e(x) = -x + r + \sqrt{\frac{v(x+r)}{c}}.$$

This is independent of $f_D$, and thus $x_a^*$ is independent of $f_D$. The accommodation profit $\pi_a \equiv \pi(x_a^*)$ depends on $f_D$ only through the last term in (22). Thus $\pi_m - \pi_a > 0$ is independent of $f_D$.

Consider $f_D$ that satisfies Assumption 1. As $f_D$ increases and approaches the critical value given by:

$$\frac{(\sqrt{v}-\sqrt{f_D})^2}{\sqrt{v}} = \sqrt{rc_D} \Leftrightarrow \sqrt{f_D} = \sqrt{v} + \sqrt[4]{vrc_D}, \tag{23}$$

$\pi_b$ approaches $\pi_m$, or equivalently, $\pi_b - \pi_m$ approaches 0. It follows that:

$$\pi_b - \pi_a = (\pi_b - \pi_m) + (\pi_m - \pi_a)$$

will eventually become positive as $f_D$ increases and approaches the critical value given by (23). Thus for a $f_D$ that satisfies Assumption 1 and is sufficiently close to the critical value given by (23), entry deterrence will always be better than accommodation.