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Imitation, patent protection and welfare*

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Abstract: Once a new technology has been invented, there is a credible threat of imitation when patents are long and imitation cost is low. When imitation is credible, the innovator has an incentive to postpone technology adoption for relatively high cost of imitation. The possibility of licensing eliminates or at least reduces the incentive for delayed technology adoption and may increase or decrease social welfare. Further, this paper explains the advantages of two types of licensing contracts, viz. a forward contract on licensing and a simple licensing contract. We show the implications of the availability of the licensing contracts on social welfare and optimal patent protection.

Key words: Imitation, Innovation, Licensing, Patent protection, Welfare
JEL Classifications: D45, L12, O33

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Imitation, patent protection and welfare

1 Introduction

Imitation of new technologies plays an important role when R&D is costly and patent protection is imperfect. Theoretical[1] and empirical[2] literature on intellectual property rights have addressed this issue. One of the most important results within this literature concerns the free rider problem of an entrant that copies the technology. Anticipating imitation, an innovating firm will generally under-invest in new technologies. In contrast to previous work, this paper explains under-investment in new technologies not as the choice to innovate or not, but as the choice to adopt a new technology now or later. In a dynamic model in which the lifecycle of a new technology is limited, it is shown under which combinations of patent length and cost of imitation an incumbent firm has an incentive to delay technology adoption.

The paper extends the literature on delayed innovation (Katz and Shapiro, 1987) and delayed technology adoption (Choi and Thum, 1998). While Katz and Shapiro (1987) focused on the possibility of reduction in the cost of technology development, Choi and Thum (1998) concentrated on network externalities to examine the delay in innovation and technology adoption respectively. This paper shows a new effect, i.e. delayed technology adoption in order to eliminate the threat of imitation. Further, while Choi and Thum (1998) considered delayed technology adoption from the consumer's point of view, this paper explains delayed technology adoption from the producer's point of view. Within our framework the optimality of immediate technology adoption can be interpreted as the optimality of minimizing product development time that is required for a successful market entry. On the other hand, waiting with technology adoption points at on-going product development until entry is optimal. With this interpretation, the paper sheds additional light on the discussion about scheduling product development (e.g. Ulrich et al., 1993).

[1] Early explicit modeling of imitation started with Benoit (1985).

[2] Empirical documentation of imitation costs and patents is given in Mansfield et al. (1981) and Levin et al. (1987). A recent overview on the benefits and costs of patent protection is given by Mazzoleni and Nelson (1998).

Since we abstract from the possibility of maintaining the technology secret[3] unless the incumbent firm decides to delay technology adoption, there is nothing the incumbent can do to prevent imitation by an entrant when imitation costs are relatively low. Further, when imitation cost is very high, the entrant has no incentive to copy. Hence, for these imitation costs the incumbent has no incentive to delay technology adoption. But, for intermediate levels of imitation costs, delay is an optimal strategy to prevent imitation. However, the range of imitation costs for which each strategy is optimal appears to depend critically on the level of patent protection. Thus, taking into account a positive relationship between product complexity and imitation cost[4], this outcome predicts especially underinvestment in technologies with moderate complexity.

This paper builds upon Gallini (1992) who proposes a model where imitators can invent around the patent at a certain cost. From a welfare perspective she shows that short patents are optimal. Our model extends her analysis by introducing both licensing and strategic postponement of technology adoption as instruments to discourage imitation. Thus, this paper proposes a new strategic effect of a patent system at the time of technology adoption. Hence, while considering the costs and benefits of a patent regime on the incentive for innovation, one should be careful about the possibility of strategic postponement.

We analyze the implications for welfare and extend the earlier results by Deardorff (1992) and Gallini (1992) suggesting a negative relation between patent protection and welfare. The possibility of delay in technology adoption reduces welfare even more when imitation cost is not too low. The reason for this result is that delay in technology adoption as to prevent imitation leads to a later realization of payoffs and to monopolization, and thus to a reduction in consumer surplus. Hence the possibility of delay gives an additional argument against long patents.

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[3] Takalo (1998) shows that keeping the innovation secret is optimal when imitation is likely to be successful and patent life is long.

[4] Pepall and Richards (1994) find a positive relation between product quality and imitation cost. We suppose that higher quality products involve more complex technologies.

Furthermore, the paper extends the literature on licensing and R&D (see, e.g., Katz and Shapiro, 1985, 1987) by analyzing the impact on the postponement strategy of 'simple' licensing contract and 'forward' contract on licensing (defined later). We show that licensing is more profitable for the firm than delayed technology adoption if licensing involves a forward contract. Moreover, the forward contract on licensing increases welfare when the incumbent would delay if licensing were not feasible. The reason is that forward licensing increases competition and prevents delay of technology adoption. This is in line with Maurer and Scotchmer (2002) who find that the negative effects of increasing patent life may be overturned if licensing is feasible. However, in the absence of a forward contract, simple licensing does not Pareto-dominate a delaying strategy for cost of imitation that is relatively high, though not high enough to make imitation incredible. For this range of imitation costs delayed technology adoption is still beneficial to the firm. Thus, we find that, in the absence of a forward contract, a simple licensing contract reduces the range of imitation costs over which a delaying strategy is privately optimal rather than eliminates the incentive to delay completely as for the forward contract.

Though the topics are treated from a theoretical viewpoint, the industries where imitation may occur are within the new economy where lifecycles are short and imitation cost is relatively low. For example Priceline.Com, which developed an E-commerce system in which buyers indicate the price they are willing to pay for a product (e.g. airline tickets), states that "it won't be easy […] to enforce its patent against the legal firepower of firms like Microsoft and AOL."[5] And indeed shortly after the introduction Priceline.Com started a lawsuit against Microsoft claiming that it was copying its technology. The paper predicts that licensing deals can make the firms better off when imitation is easy. So, it is reasonable to understand the company's next step in which it sets up licensing deals with other potential copiers, for example, Budget Rent A Car Corporation.

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[5] Quoted from The Economist, August 15, 1998.

Though it is hard to find empirical evidence for the strategy of adoption delay for the obvious reason that nothing really happens, there is abundant evidence of technologies that are patented but not (yet) used. The existence of so-called sleeping patents was first analyzed by Gilbert and Newbery (1982). By patenting new technologies before potential competitors a monopolist can maintain its monopoly power. In a recent article in Business Week, Moore (2000) suggests that only 3% of all patents are actually used, so the majority of the patents is filed for strategic reasons.

This paper is organized as follows. Section 2 presents the basic model of imitation and patent protection without the possibility of licensing. In Section 3 we extend the basic model with licensing. Section 4 discusses about the optimal patent length. We provide a possible extension of the basic model in section 5. Section 6 concludes the paper.

2 Model

Suppose there are two firms. Label these firms as incumbent and entrant. Assume that the incumbent has the knowledge about a basic technology whereas the entrant does not have this knowledge (cf. Benoit, 1985). Furthermore, assume that the incumbent gets a patent protection of length P once it brings or adopts the technology. After technology adoption by the incumbent, the entrant can imitate or invent around the technology to incorporate the basic knowledge. Such imitation costs the entrant a fixed amount denoted by I. However, once the patent has expired, i.e. after time P, the entrant has free access to the technology. We assume that the entrant would have free access to the technology once the incumbent decides to adopt if there were no patent protection. Therefore, it is always optimal for the incumbent to take the patent when adopting its technology.

Suppose that the lifecycle of the technology ranges from time 0 to N[6], and that the common discount rate is given by r. The invented technology, if used by a single firm only, yields a flow of profit M to that firm. In the case of imitation, both firms can produce the good with the technology and each firm gets a flow of profit $D < M$. We analyze a two-stage game where in the first stage the incumbent decides when to adopt. In the second stage the entrant chooses its optimal strategy given the timing of adoption by the incumbent. As usual the game is solved backwards.

To convey the basic message of the paper in the simplest way, the following analysis will mostly ignore the cost of technology adoption. However, in due course of analysis, we will also highlight the implications of costly technology adoption on the results of this paper.

2.1 entrant's decision

Assume that the incumbent adopts its technology at time A. If the entrant chooses to imitate the technology and to compete with the incumbent then the market will be a duopoly as of this period.[7] In that case, the net discounted lifetime payoff to the entrant is $\int_A^N De^{-rs}ds - e^{-rA}I$, which can be rewritten as

$$e^{-rA}[\frac{D(1-e^{-r(N-A)})}{r} - I]. \tag{1}$$

On the other hand, if the entrant does not imitate the incumbent's technology then it can produce only when the patent expires. Then the discounted lifetime payoffs to the entrant are

$$\begin{aligned} &e^{-rA}\frac{D(e^{-rP} - e^{-r(N-A)})}{r}, \quad \text{for } A+P<N \\ &0, \quad \text{for } A+P \geq N. \end{aligned} \tag{2}$$

The entrant will imitate the incumbent's technology as long as the payoff under imitation is higher than the payoff under no-imitation. From expressions (1) – (2), it is clear that the

[6] N is assumed to be non-random, but results easily carry over to the case where N follows an exponential distribution, and the firms are risk-neutral.
[7] If the entrant imitates the technology then it will do so at the time of the adoption by the incumbent.

entrant has an incentive for imitation when $\frac{D(1-e^{-rP})}{r} > I$ for $A+P<N$ or $\frac{D\left(1-e^{-r(N-A)}\right)}{r} > I$ for $A+P \geq N$. Therefore, for

$$\frac{D(1-e^{-rP})}{r} < I \text{ and } A+P<N \tag{3}$$

or for $\frac{D\left(1-e^{-r(N-A)}\right)}{r} < I$ and $A+P \geq N$ we can say that the entrant has no incentive for imitation.

2.2 incumbent's decision

If there is no credible threat of imitation, it is optimal for the incumbent to adopt its technology at the beginning ($A=0$)[8]. In this case, the incumbent will face the competition from the entrant only when the patent expires.[9] When condition (3) does not hold, and the entrant has an incentive to imitate the incumbent's technology, the incumbent can eliminate the threat of imitation by delaying technology adoption since the lifetime of the technology is finite. Let A^* denote the time at which the entrant's discounted payoff up to N is equal to the imitation cost. So, delaying until at least time A^* will prevent any entry of rivals. That is, at $A=A^*$, we have

$$\frac{D(1-e^{-r(N-A)})}{r} = I\,. \tag{4}$$

Any delay for less than A^* will not eliminate the threat of imitation because $\frac{D(1-e^{-r(N-A)})}{r} > I$. Obviously, the incumbent would needlessly forgo monopoly profits if it

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[8] This can be proved as follows. When the incumbent adopts the technology at A then the profit of the incumbent is given by $\int_{A}^{A+P} Me^{-rs}ds + \int_{A+P}^{N} De^{-rs}ds$, which equals $e^{-rA}\left[\frac{M}{r}+e^{-rP}\left(\frac{D-M}{r}\right)\right]-\frac{D}{r}e^{-rN}$. Since the term in square bracket is positive, profit is maximized for $A=0$.

[9] We assume that patent life is smaller than the lifecycle of the new technology ($P<N$), and will not analyze $P \geq N$.

delays longer than A^*. Hence, if the incumbent delays its technology adoption then it will do so exactly up to A^*.

From condition (4), we see that the imitation cost equals the discounted duopoly profit of the entrant over the time period $[A^*, N]$. Recall from condition (3) that the entrant has an incentive to imitate when $\frac{D(1-e^{-rP})}{r} > I$. Combining this result with expression (4), we find that the adoption date that discourages imitation must satisfy $N < A^* + P$. So technology delay dissuades imitation only if the delay plus the statutory life of the patent exceed the lifetime of the technology. Technology delay in order to discourage imitation, even though it reduces the effective patent life, might be an explanation for why technologies do not last the full-term of the patent[10]. Since patent protection is active during the entire (remaining) lifecycle of the technology, the payoff to the incumbent between period A^* and N, discounted to time 0, is equal to

$$\frac{M(e^{-rA^*} - e^{-rN})}{r}, \tag{5}$$

and, from expression (2), the discounted payoff to the entrant is 0.

Since any postponement by the incumbent to less than A^* does not eliminate the threat of imitation, the incumbent will adopt the technology either right at the beginning or at A^*. Given the threat of imitation, if the incumbent adopts its technology at the beginning, its discounted lifetime payoff is

$$\frac{D(1-e^{-rN})}{r}. \tag{6}$$

From expressions (5) and (6) we can say that the incumbent prefers to delay its technology adoption if and only if

$$\frac{M(e^{-rA^*} - e^{-rN})}{r} > \frac{D(1-e^{-rN})}{r}. \tag{7}$$

[10] We are grateful to an anonymous referee for pointing this out.

From the conditions in (4) and (7) (where condition (7) holds with equality) we can derive the critical value of the imitation cost that makes the incumbent indifferent between the delayed technology adoption and the technology adoption at the beginning. This critical value of the imitation cost is given by

$$I^C = \frac{D^2(1-e^{-rN})}{r[D+e^{-rN}(M-D)]}. \tag{8}$$

We know that if the imitation cost is more than the discounted lifetime payoff of the entrant over the lifetime of the product, i.e. if $I > \frac{D(1-e^{-rN})}{r}$, then imitation is not a feasible option. Hence, for imitation to be a feasible option the imitation cost should be less than the upper bound given by $\frac{D(1-e^{-rN})}{r}$. Simple calculation shows that the critical value of the imitation cost given in equation (8) is less than $\frac{D(1-e^{-rN})}{r}$ and, hence, it lies within the feasible region of the imitation costs.

2.3 a graphical interpretation

Figures 1 and 2 explain the above discussion. In 'Fig. 1', the curve $0H$ represents the combinations of the patent lives and the imitation costs such that the discounted payoff of the entrant over the patent life equals the imitation cost, that is the combinations of P and I for which equation (3) holds with equality. Hence, for the combinations of patent lives and the imitation costs below (above) the curve $0H$, the discounted payoffs of the entrant over the patent life are higher (lower) than the imitation costs. Therefore, for all the combinations of patent length and imitation cost those are located at the left of $0H$, imitation is a non-credible threat. If the imitation costs are higher than GH then imitation is a non-credible threat for any patent life. But, for imitation costs less than GH, threat of imitation is non-credible provided the combinations of imitation costs and the patent lives fall in the area $0GH$. Therefore, if the imitation costs and the patent lives are such that the combinations fall at the left of $0H$, then the industry is characterized by monopoly during the patent life and duopoly when the patent expires. The term (M,D) in 'Fig. 1' stands for the initial monopoly and the subsequent duopoly.

If the combinations of the imitation costs and the patent lives fall in the area $0NH$ then the threat of imitation is credible. Hence, for these patent lengths and imitation costs, the incumbent can eliminate the threat of imitation only if it delays technology adoption up to A^*. However, the incumbent will delay its technology only if delay generates more profit than technology adoption at the beginning. The line AB in 'Fig. 1' represents the imitation cost that makes the incumbent indifferent between delayed technology adoption and immediate technology adoption.[11] Therefore, if the combinations of the imitation costs and the patent lengths fall in the area ABH then the incumbent does not adopt its technology at the beginning, but adopts its technology at time A^*. The term $(0,M)$ in 'Fig. 1' highlights that there is no initial production and monopoly for the incumbent afterwards.

On the other hand, if the combinations of the imitation costs and the patent lives fall in the area $0NBA$, then the incumbent does not benefit from the delay strategy. In this area the incumbent is better off if it adopts its technology at the beginning, because the imitation cost is so low that the incumbent has to wait a relatively long period until it eliminates the threat of imitation and receives the benefit from monopoly. Therefore, the industry is characterized by a duopoly in all periods. The term (D,D) in 'Fig. 1' represents this outcome.

Figure 2 illustrates the relationship between A^* and I for a given patent life. The line NM shows the adoption date that prevents entry as a function of the imitation cost. However, delaying adoption is not always an optimal strategy. For instance, for $0 < I < I^C$ delay is not profitable since only a very long period of delay would prevent

[11] So the line represents $I = I^C$.

imitation. Also for $I > I'$ delaying is not optimal since there is no credible threat of imitation. The line $0I^{C}JK\,I'M$ illustrates the optimal adoption date.

Thus we see that if imitation cost is rather high, imitation is not an attractive option to the entrant, and the incumbent adopts its technology at the beginning. If imitation cost is rather low, delaying tactics are too expensive and so the incumbent adopts immediately while the entrant copies. For imitation costs neither too low nor too high, delaying is attractive when imitation is credible. For the range of imitation cost for which delay is attractive, the amount of delay is a decreasing function of imitation cost. The idea is that, since the discounted payoff of the entrant over the patent life covers the imitation cost, the entrant has an incentive for imitation. The incumbent can eliminate the threat of imitation only by delaying up to a time period that makes the imitation cost equal to the discounted payoff of the entrant. If the imitation cost is relatively high, then the incumbent needs to wait a relatively small period of time in order to eliminate the threat of the imitation. But, for relatively low imitation cost, the incumbent needs to wait a relatively long period in order to eliminate the threat of imitation, which is relatively costly. The following proposition summarizes the above discussions.

Proposition 1 (i) When the entrant's discounted payoff over the patent life does not cover the imitation cost, i.e. $\frac{D(1-e^{-rP})}{r} < I$, the incumbent adopts its technology at the beginning.

(ii) When the entrant's discounted payoff over the patent life covers the imitation cost, i.e. $\frac{D(1-e^{-rP})}{r} > I$, (i) the incumbent adopts its technology at the beginning provided condition (7) is not satisfied, (ii) the incumbent delays its technology adoption and adopts its technology at A^{*} provided condition (7) is satisfied.

Often it is argued that the imitation cost has a positive relationship with patent breadth (e.g., see Gallini, 1992). Therefore, the incentive for delayed technology adoption by the incumbent is strong for patent breadth that is neither so small such that imitation cannot be avoided nor so high that imitation is not credible. Further, consistent with Benoit (1985), a longer patent life leads to a larger incentive to imitate and to a lower payoff to the incumbent, ceteris paribus. In addition we have shown that by delaying the incumbent can lessen the profit loss caused by imitation.

2.4 implications for welfare

Thus far the literature showing the welfare implications of imitation has focused on the reduced incentives to innovate and adopt new technologies. From this perspective, strategies to reduce imitation such as shorter patent life, keeping technology secret and delaying technology adoption could be socially desirable. Staving off imitators not only increases the private benefit of the innovator, it also prevents the spending of imitation cost which could be spent more productively in innovative areas. This result may not be true when the cost of innovation or technology adoption is sufficiently low such that the innovator always has the incentive to innovate or adopt new technologies. Hence, the cost of technology adoption has an important impact on social welfare.

2.4.1 costless technology adoption

Like the previous section, this subsection assumes that technology adoption is costless and hence, the incumbent always has the incentive to adopt the new technology.[12] The next subsection shows the implications of higher cost of technology adoption on social welfare.

From the analysis of the previous section we found that delay has a large negative impact on welfare. For example, one can look at the points Y and Y' given in 'Fig. 1'. These points have the same imitation costs, but in Y' the patent life is longer. At Y, the entrant has no incentive for imitation and so the incumbent adopts its technology at the beginning and enjoys its monopoly up to the patent life. But, at Y', the incumbent faces the imitation threat and in this situation the incumbent finds it optimal to delay its technology adoption. This delay in technology adoption implies no initial production up to A^* and monopoly of the incumbent for the remaining periods. Hence, in this situation, welfare increases with relatively shorter patent protection.

However, if one considers Q and Q' then one may find that a longer patent life increases welfare. At Q, imitation is not a credible threat and the incumbent adopts its technology at the beginning, but at Q' imitation is a credible threat. Therefore, at Q', the industry becomes a duopoly from the beginning. If the welfare gains from duopoly over monopoly are sufficient to compensate the loss to society from the imitation cost, then higher welfare is achieved at Q' rather than at Q. Since the imitation costs are low in the cases where imitation plays a role, it is likely that the condition is satisfied, and hence that welfare increases.

We conclude that short patents are socially preferred when the cost of imitation is neither so low that delay is not optimal nor so high that imitation is not credible, more specifically for $I^C < I < G$. So adoption delay in response to long patents gives an additional argument for shorter patents. Hence, we can have the following proposition.

[12] The analysis of this subsection will hold even for positive but sufficiently low cost of technology adoption such that the incumbent always has the incentive for technology adoption, i.e. for $C < \frac{D(1-e^{-rN})}{r}$, where C is the cost of technology adoption.

Proposition 2 Suppose the cost of technology adoption is such that the incumbent always has the incentive to adopt the new technology.

(i) If the cost of imitation is sufficiently low ($I < I^C$) then relatively long patents encourage imitation and delay is not beneficial to the incumbent. Relatively longer patents increase social welfare.

(ii) For intermediate values of the cost of imitation ($I^C < I < G$) and relatively long patents it is beneficial for the incumbent to delay its technology adoption. This delay significantly reduces social welfare. In this case shorter patents increase social welfare.

2.4.2 costly technology adoption

Now we examine how the results will be influenced if the cost of technology is not sufficiently low such that the incumbent does not have the incentive to adopt the new technology always, i.e. $C > \frac{D(1-e^{-rN})}{r}$.

As before, if the cost of imitation is sufficiently low, i.e. $I < I^C$, and the patent is relatively long then delay is not optimal to the incumbent and imitation would occur. Since the net payoff is negative under costly technology adoption, the incumbent will not adopt the new technology. Only if patents are sufficiently short, imitation will not be credible and the incumbent will get a monopoly advantage up to patent expiry. If this monopoly advantage is sufficiently large then the incumbent's profit offsets the cost of technology adoption. Hence, in this situation, we find that welfare could be higher under relatively short patent protection.

In the previous section, we have seen that, in case of sufficiently low cost of technology adoption and moderate cost of imitation ($I^C < I < G$), a relatively long patent can reduce welfare by inducing the incumbent to delay technology adoption. This result may not be true for higher cost of technology adoption. This is shown in Figure 3 for a particular cost of imitation, which is greater than I^C. The line $abcd$ shows the discounted gross profit (i.e. not including the cost of technology adoption) of the incumbent for different patent lengths. The patent length X^* shows the patent length that makes the entrant indifferent between imitation and waiting until patent expiry. We have drawn the line ab as a straight line for convenience. The point a corresponds to the situation where there is an infinitesimally short patent protection and the incumbent earns duopoly profit throughout the lifetime of the product. As the patent protection increases up to X^*, the profit of the incumbent rises since now the incumbent is getting more monopoly benefits. If the patent length is greater than X^* then the threat of imitation is credible for this cost of imitation. Since we are considering a situation where $I > I^C$, here the incumbent will adopt the strategy of delayed technology adoption. Hence, for $P > X^*$, there will be no production up to time A^* and the incumbent is the monopoly afterwards. Since delayed technology adoption is profitable to the incumbent, the profit of the incumbent at c is higher than the profit of the incumbent at a. Further, the profit of the incumbent at c is lower than the incumbent's profit at b because of the cost of the delaying strategy. For convenience, we have drawn the curve cd as the gross profit discounted to X^* for patents longer than X*.

If the cost of technology adoption is V^* then we see that any patent length longer than X^* provides higher social welfare compared to the patent lengths lower than P' since, for patents lower than P', the incumbent will not adopt the new technology. But if we compare the patent lengths $P \in (P', X^*)$ with $P > X^*$, then, like the previous subsection, welfare is higher under relatively short patents. To summarize, if the costs of imitation is sufficiently low, i.e. $I < I^C$, then relatively short patents are preferred. If the costs of technology adoption are moderate, i.e. $I^C < I < G$, then a patent that is just long enough to cover the adoption cost is socially preferred.

3 Licensing

In the previous section we have shown that if imitation is an attractive option to the entrant, then it may induce the incumbent to delay its technology adoption. The purpose of this section is to show that if the incumbent has the licensing option then this may eliminate the incumbent's incentive for delayed technology adoption. Hence, licensing may prevent the incumbent from waiting with technology adoption in order to reap monopoly profits later.

In the spirit of Katz and Shapiro (1985), Marjit (1990), Mukherjee (2001a, b) and many others we consider a fixed fee licensing. The key argument for considering such a fixed fee is to avoid a free rider problem that may arise when the entrant can imitate costlessly immediately after taking the license. Alternatively, because of the lack of information necessary to implement any output royalty the incumbent may prefer a fixed fee patent licensing contract. Furthermore, assume that the incumbent will give a take-it-or-leave-it offer to the entrant and the entrant will accept any offer as long as it does not make the entrant worse off.

Moreover, it is assumed that the industry profit decreases when the number of firms competing with the same technology increases. This implies that the monopoly profit, M, is greater than the duopoly industry profit, $2D$. The assumption immediately implies that licensing is not profitable for the incumbent on or after A^*. Hence, if there is any licensing then it must be before A^*. Following the same logic, the incumbent will never license its technology when imitation is not a credible threat. Therefore, licensing is feasible in all areas in 'Fig. 1' except the (M,D) area. Next, we will examine two types of licenses, a forward contract on licensing and a 'simple' licensing contract, in the specific areas.

3.1 forward contract on licensing

In this subsection we consider a forward contract on licensing in which the incumbent transfers the technology at a predetermined date in the future. We assume that the forward contract only may involve a fixed fee that is paid when the technology is delivered. For the moment we assume furthermore that the contract is not vulnerable to moral hazard problems. Since licensing can only be a profitable strategy when imitation is credible we restrict the analysis to the combinations of I and P where imitation is credible.

Let us first consider the $0NBA$ area of 'Fig. 1' where delay is not optimal and the entrant imitates the technology. When the incumbent offers the forward contract on licensing, the incumbent allows the entrant to use the technology free of charge but from time period $(N - A^*)$. Since $I = \int_0^{N-A^*} De^{-rs} ds$, the entrant has no longer an incentive to imitate the technology under this forward contract. The free forward contract on licensing can be viewed as a voluntary reduction in patent life by the incumbent to $(N - A^*)$ from P. Graphically, the forward contract in the $0NBA$ area means a horizontal shift towards the $0A$ line, which represents the combinations of P and I for which the entrant is indifferent between imitation and no imitation.

Next, we focus on the ABH area in 'Fig. 1' where it is optimal for the incumbent to delay technology adoption. Thus, we assume that the conditions $\frac{D(1-e^{-rP})}{r} > I$ and $(M - D)(e^{-rA^*} - e^{-rN}) > D(1 - e^{-rA^*})$ hold. These conditions imply that imitation is an attractive option to the entrant and delaying strategy is optimal for the incumbent in absence of licensing. Under the assumption that the incumbent has the full bargaining power the forward contract on licensing involves an incumbent who offers to transfer the use of technology from $(N - A^*)$ on to the entrant, and an entrant who pays a licensing fee of $L = \int_{N-A^*}^{N} De^{-rs} ds$ to the incumbent in exchange for the transfer. Hence, in this case the licensing contract is not offered for free.

It is easy to check that the entrant has the incentive to agree on this contract and has no incentive to imitate between 0 and $(N - A^*)$. This licensing contract gives the incumbent a monopoly payoff over $[0, N - A^*]$ and duopoly payoff afterwards. Hence, total payoff of the incumbent under licensing is greater than the incumbent's total payoff under delayed technology adoption, which is only monopoly profits over $\left[A^*, N\right]$. Therefore, this licensing contract always makes the incumbent better-off compared to a situation with 'no-licensing and adopting the technology at A^*'.

3.2 *no forward contract on licensing*

If the cost of enforcing the licensing contract is sufficiently high or the cost of renegotiating the licensing contract is sufficiently low then the incumbent may not have an incentive to transfer its technology to the entrant at $(N - A^*)$ even if the incumbent initially agreed to transfer its technology to the entrant at $(N - A^*)$. More precisely, this happens if the entrant does not have an incentive to imitate at $(N - A^*)$ [13] and the monopoly profit of the incumbent over $[N - A^*, P]$ is greater than the sum of the duopoly profit over $[N - A^*, P]$ and the licensing fee $L = \int_{N-A^*}^{N} De^{-rs} ds$, i.e. $\int_{N-A^*}^{P} (M - D)e^{-rs} ds > \int_{N-A^*}^{N} De^{-rs} ds$. Therefore, as the entrant knows that the incumbent will not transfer the technology at $(N - A^*)$, the entrant will have an incentive for imitation at time 0 even if it agrees on the forward contract on licensing. Hence, under these circumstances, the forward contract on licensing does not prevent the entrant from imitation and hence is not a feasible option for the incumbent.

However, even if forward contract on licensing is not feasible, welfare can be increased by a simple licensing contract where the incumbent transfers the technology and the entrant pays the licensing fee both at the beginning. The incumbent prefers this type of licensing contract at the beginning to 'no-licensing and technology adoption at A^*' when

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[13] This happens when $\int_{0}^{P-(N-A^*)} De^{-rs} ds < I = \int_{0}^{N-A^*} De^{-rs} ds$ or $2(N - A^*) > P$.

$$z + \frac{D(1-e^{-rN})}{r} > \frac{M(e^{-rA^*} - e^{-rN})}{r}, \tag{9}$$

where z denotes the licensing fee. Note that without licensing the incumbent delays its technology adoption in order to reap more benefits at a later stage. Therefore, the payoffs to the incumbent and to the entrant under delayed technology adoption are $\int_{A^*}^{N} Me^{-rs} ds$ and 0 respectively and these payoffs act as reservation payoffs under licensing. Now, under licensing, the incumbent gives a take-it-or-leave-it offer to the entrant. Assuming that the entrant accepts any offer that gives the entrant at least its reservation payoff, the incumbent charges $\int_{0}^{N} De^{-rs} ds$ as the licensing fee.[14] Thus, with $z = \int_{0}^{N} De^{-rs} ds$, condition (9) reads

$$\frac{2D(1-e^{-rN})}{r} > \frac{M(e^{-rA^*} - e^{-rN})}{r}, \tag{10}$$

where the value of A^* is given by equation (4). Substituting equation (4) into (10) we can say that a combined technology adoption and licensing at the beginning is profitable for the incumbent provided that the difference between immediate adoption with licensing and delayed adoption is positive where the difference is defined by

$$k = \frac{2D(1-e^{-rN})}{r} - \frac{e^{-rN}MI}{(D-Ir)}. \tag{11}$$

Taking the first derivative of k with respect to I we find that the value of k decreases as I increases. Therefore, higher imitation cost reduces the incentive for technology adoption and licensing at the beginning compared to delayed technology adoption with no-licensing. The incumbent gives a take-it-or-leave-it offer if it decides technology licensing. Hence, it extracts lifetime surplus generated in the entrant's firm and this licensing fee does not depend on the imitation cost. However, the imitation cost affects the reservation payoff of the incumbent by

[14] In deriving the region within which licensing is optimal, the assumption of this extreme bargaining structure is not critical. Except for the imitation cost where the incumbent is indifferent between licensing and delaying technology adoption, the incumbent and the entrant may bargain over the

affecting the value of A^*. Higher imitation cost reduces A^* and increases the reservation payoff of the incumbent. Thus, it reduces the gain from licensing and technology adoption at the beginning compared to delayed technology adoption with no-licensing. In other words, if without licensing the incumbent must wait a relatively long time in order to get the monopoly benefit, then competition throughout the lifetime may be an attractive option to the incumbent provided the future loss from competition is outweighed by the initial licensing fee. Hence, the effectiveness of licensing to eliminate the inefficiency created from delayed technology adoption decreases with higher imitation cost.

Setting equation (11) equal to zero and solving for I we get the critical value of the imitation cost that makes the incumbent indifferent between 'technology adoption and licensing at the beginning' and 'delayed technology adoption without licensing'. The critical value of the imitation cost can be written as

$$\bar{I} = \frac{2D^2(1-e^{-rN})}{r[2D+e^{-rN}(M-2D)]} \quad . \tag{12}$$

It is easy to check that $\bar{I} > I^C$ and $\bar{I} < \frac{D(1-e^{-rN})}{r}$. Therefore, we can say that if the imitation cost is more than $\bar{I}$, then the incumbent prefers delayed technology adoption to licensing. Here, due to sufficiently higher imitation costs the incumbent has to wait relatively shortly in order to eliminate the threat of imitation. Hence, the incumbent can get the monopoly benefit relatively quickly. On the contrary, when $I < \bar{I}$, imitation costs are too low to warrant a short optimal delay, and the incumbent opts for licensing.

3.3 *a graphical interpretation*

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license agreement for all other relevant imitation costs as long as eq. (9) is satisfied, since licensing

Figure 4 shows the industry structure under the two forms of licensing for different combinations of I and P. The line $A'B'$ illustrates the imitation cost $\bar{I}$ for which the incumbent is indifferent between a simple licensing contract and delay. Hence, in the $0NB'A'$ area there is immediate competition when the incumbent and the entrant agree on a simple licensing contract. This is characterized by (D,D) in the 'Fig. 4'. For a forward contract there is an initial period of monopoly for the incumbent and a subsequent duopoly in this area. This is characterized by (M,D) in the 'Fig. 4'. In the $A'B'H$ area the forward contract is still profitable for the incumbent, but the simple licensing contract is not profitable. Since, for imitation costs in $A'B'H$, the incumbent's profits from delay exceed the profits from simple licensing contract, in this situation, the incumbent will delay technology adoption when it has the option for simple licensing contract only. So, under simple licensing contract, the industry can be summarized as $(0,M)$.

3.4 privately preferred licensing contract

In the previous analysis we have considered two different types of licensing contracts. In this subsection, we will examine whether the incumbent prefers a forward licensing contract or a simple licensing contract.

We have seen that simple licensing is profitable provided $I < \bar{I}$, while forward licensing contract is profitable for $I < G$. Therefore, it is trivial that the incumbent will prefer a forward licensing contract compared to a simple licensing contract for $I \in (\bar{I}, G)$.

Both licensing contracts are profitable to the incumbent for $I < \bar{I}$. The forward licensing contract allows the incumbent to keep the monopoly advantage for the initial $(N - A^*)$. On the other hand, the market becomes duopoly from the beginning under the simple licensing contract. It is easy to check that this monopoly benefit under forward

makes both firms better off. However, the range of I for which licensing is optimal is unaffected.

licensing contract makes the forward licensing contract preferable to the incumbent compared to the simple licensing contract.[15] Hence, the following proposition is immediate.

Proposition 3 The incumbent always prefers the forward licensing contract to the simple licensing contract.

3.5 *implications for welfare*

3.5.1 costless technology adoption

When imitation is credible, we have shown that simple licensing is not profitable for relatively higher cost of imitation, i.e. for $I \in (\bar{I}, G)$. In this case of intermediate imitation costs, the incumbent would opt for delayed technology adoption if only the simple licensing contract available. But forward licensing contract will eliminate the possibility of delayed technology adoption and will induce the incumbent to produce from the beginning. Hence, forward licensing increases welfare in the $A'B'H$ area.

In the $0NB'A'$ area where imitation costs are relatively low both types of licensing contract are feasible. When the costs of imitation are between I^C and $\bar{I}$ then both licensing contracts are profitable to the incumbent and both contracts prevent welfare loss from delayed technology adoption. However, we find that immediate competition under simple licensing makes the simple licensing contract socially desirable compared to the forward licensing contract.

If the costs of imitation are less than I^C then we have shown that the market structure will be duopoly for all the periods without the possibility of licensing and that the

[15] For $I < I^C$, the profit of the incumbent under forward and simple licensing contract are given by $\int_0^{N-A^*} Me^{-rs} ds + \int_{N-A^*}^{N} De^{-rs} ds$ and $\int_0^{N} De^{-rs} ds + \int_0^{N-A^*} De^{-rs} ds$ respectively since $I = \int_0^{N-A^*} De^{-rs} ds$.
For $I \in (I^C, \bar{I})$, the profit of the incumbent under forward and simple licensing contract are given by $\int_0^{N-A^*} Me^{-rs} ds + \int_{N-A^*}^{N} 2De^{-rs} ds$ and $\int_0^{N} 2De^{-rs} ds$.

entrant incurs the cost of imitation. If licensing is possible, both types of licensing contracts will reduce the loss created by the cost of imitation. However, while the market structure becomes a duopoly in all periods under the simple licensing contract, forward licensing contract creates a monopoly for the initial $(N - A^*)$ periods. It is easy to check that this immediate monopoly under forward licensing contract makes social welfare lower under the forward licensing contract as compared to a simple licensing contract and no licensing at all.

3.5.2 costly technology adoption

Since the analysis for the impact of the costly technology adoption on welfare in presence of licensing will be similar to the subsection 2.4.2, we will only briefly discuss the difference created by technology licensing.

If licensing is an option, we have shown that it improves the profitability of the incumbent when imitation is credible compared to the previous analysis where licensing was not considered. Hence, the possibility of licensing when imitation is credible increases the incentive to innovative. Further we have shown that the incumbent will always prefer forward licensing to simple licensing. The provision of the forward licensing contract not only prevents the incumbent from delaying technology adoption, it also provides the incumbent with a payoff that is at least as high as the payoff it would get when there is a non-credible threat of imitation. In fact, when $I > I^C$, the incumbent's total payoff under forward licensing is higher than its maximal payoff in the case of a non-credible threat of imitation. Thus, if technology adoption is profitable whenever imitation is non-credible, the incumbent will also find it profitable to adopt the new technology if imitation is credible and forward licensing is possible.

The possibility of costly technology adoption, however, may change the conclusion regarding the effect of different types of licensing on social welfare. It has already been shown that the profit of the incumbent is higher under forward licensing than under simple licensing. Therefore, there could exist a cost of technology adoption such that the incumbent will adopt the technology if forward licensing contract is available but will not adopt the technology if simple licensing contract is available. This implies that here welfare is higher under forward licensing than under simple licensing or no licensing.

For example, consider the costs of imitation below I^C. Here the incumbent receives a payoff equal to $\int_0^N De^{-rs}ds + \int_0^{N-A^*} De^{-rs}ds$ under the simple licensing contract since $I = \int_0^{N-A^*} De^{-rs}ds$. Under forward licensing contract, the incumbent earns $\int_0^{N-A*} Me^{-rs}ds + \int_{N-A*}^{N} De^{-rs}ds$. Given the cost of imitation this payoff is equal to the maximal payoff for the incumbent in this case. If the costs of technology adoption are between these two profits then we find that welfare is higher under the forward licensing contract. The following proposition summarizes the discussions of this section.

Proposition 4 (i) If forward licensing contract is an option to the incumbent then the incentive for new technology adoption is never reduced compared to the situation of a non-credible imitation threat.

(ii) Suppose the costs of technology adoption are such that the incumbent always has the incentive to adopt the new technology.

(a) The welfare-optimal form of licensing is a forward contract for relatively high imitation cost ($I > \overline{I}$) and a simple contract for relatively low imitation cost ($I < \overline{I}$).

(b) Welfare under forward licensing is lower compared to the situation with no licensing for $I < I^C$. Hence, for these costs of imitation, there exists a conflict between private incentive and social incentive for licensing.

(iii) Forward licensing could be the welfare-optimal form of licensing for $I < \overline{I}$ when the cost of technology adoption is sufficiently large.

One comment with regard to the proposition should be made about the impact of N. In today's rapidly evolving markets cycle-times of new technologies become shorter. Therefore, it is worthwhile to consider the impact on our results of the cycle-time. Firstly, note that the combinations of P and I in which the entrant has no incentive for imitation, as given by condition (3), is unaffected by the cycle-time. When N decreases, the line NH shifts to the left, and the lines GH, $A'B'$ and AB shift downward. Therefore, as N decreases, it reduces both the areas for non-credible and credible imitation threat. However, the shape of $0H$ shows that the shrinkage of the area is less under non-credible threat of imitation (i.e. the area above $0H$) compared to credible threat of imitation (i.e. the area below $0H$). So, the potential loss in welfare from delay as well as the potential welfare gains from licensing become less immediate with shrinking lifecycles.

4 Implications for the optimal patent life

So far we have done our analysis for a given level of patent lengths. The purpose of this section is to examine how our analysis can shed some light on the literature on optimal patent length. We analyze the optimal patent length with the help of Figure 5 and Figure 6 for $I < I^C$ and $I \in (I^C, G)$. We have drawn these figures in a similar way of 'Fig. 3'. Further, we consider the possibility of forward and simple licensing contracts.

4.1 for $I < I^C$

Figure 5 illustrates this case. We have drawn 'Fig. 5' in a similar way of 'Fig. 3' except now, for $P > X^*$, we examine the payoff of the incumbent with the possibility of licensing.

Let us first consider the payoff of the incumbent with the possibility of forward licensing contract. The line ghf shows the payoff of the incumbent under forward licensing. Therefore, it is clear that the optimal patent length will be determined by the length of the patent that makes the payoff of the incumbent equal to the cost of technology adoption whenever the cost of technology adoption is greater than g. This is because here as we increase the patent length up to X^*, we increase the periods of initial incumbent monopoly, which has a negative impact on social welfare. Hence, for costs of technology adoption V^* and V^{**}, the optimal patent lengths are P^* and P^{**} respectively. For costs of technology adoption lower than g, the optimal patent length is 0.

If only the simple licensing contract is an option then the payoff of the incumbent is given by the $ghqs$. We know that the market becomes a duopoly from the beginning in this situation if the patent length is greater than X^*. Hence, the welfare for patent lengths greater than X^* is equal to the welfare corresponding to the 0 patent length. So, if the costs of technology adoption are lower than g, welfare will be the same for a patent length equal to 0 or greater than X^*. But, for costs of technology adoption greater than the value at g but less than q, optimal patent length is any value greater than X^*. This is because for any patent length between 0 and X^* there will be a period of initial monopoly and, to induce technology adoption, the optimal patent length cannot be equal to 0. Finally, if the cost of technology adoption is greater than q, then the incumbent will not adopt the new technology for a patent length greater than X^*. Hence, in this case the optimal patent length will be the patent length that will just induce the incumbent to adopt the new technology. Thus, there are situations where optimal patent life reduces with higher cost of technology adoption. This finding is in contrast to previous literature where it has been shown that optimal patent life is increasing in the R&D cost (see, e.g. Denicolò, 1999).

4.2 for $I \in (I^C, G)$

Let us consider 'Fig. 6' for this situation. If the incumbent has the option for both types of licensing then we know that the incumbent will always prefer the forward licensing contract. In this situation, the payoff of the incumbent is given by $g'h'm'f'$. Hence, the discussion about the optimal patent length is similar to the subsection 4.1 except for the following situation. Here the possibility of forward licensing enables the incumbent to earn a profit which is greater than the maximal payoff of the incumbent without any types of licensing. Therefore, if the costs of technology adoption are between the values at h' and m' then the incumbent will not adopt the technology without the possibility of licensing whereas the incumbent will adopt the technology when there is a possibility of forward licensing. Hence, the possibility of forward contract increases the incentive for technology adoption and increases welfare. In this situation, the optimal patent length is greater than $X'*$.[16]

If the incumbent can only opt for simple licensing, then we know that there will not be any licensing if $I > \bar{I}$. Hence, it is easy to argue that in this situation, the optimal patent length will be the one that will just give the incumbent a positive net profit.

For $I < \bar{I}$, the payoff of the incumbent under simple licensing is given by $g'h'q's'$. In 'Fig. 6' we have assumed that $\int_0^{N-A^*} Me^{-rs} ds + \int_{N-A^*}^{N} De^{-rs} ds > \int_0^N 2De^{-rs} ds$. Here the analysis will be similar to the previous subsection. The optimal patent length will be 0 or (just) greater than $X'*$ for costs of technology adoption less than g'. The optimal patent length will be greater than $X'*$ for costs of technology adoption are between the values at g' and q'. For costs of technology adoption between the values at q' and h', the optimal patent length will be the patent length that will just provide net positive profit to the incumbent.

If $\int_0^{N-A^*} Me^{-rs} ds + \int_{N-A^*}^{N} De^{-rs} ds < \int_0^N 2De^{-rs} ds$ then the horizontal line $q's'$ in 'Fig. 6' will be above the point h' and like the forward licensing contract the simple contract will also increase the incentive for technology adoption compared to a situation with no licensing. Hence, here for any costs of technology adoption between the values at g' and q' the optimal patent length will be greater than $X'*$.

[16] The meanings of X^* and $X'*$ are same. In this situation, we use $X'*$ to imply that we are

In the above analysis we have considered the optimal patent length for a given cost of imitation. If the cost of imitation increases then it is clear from the previous sections that the length of patent that will make the entrant indifferent between imitation and no imitation will increase. Therefore, higher costs of imitation will move the point X^* to the right in 'Figs 5 and 6'. Hence, from the above analysis it is evident that if the costs of technology adoption are such that, given the cost of imitation, the incumbent does not have the incentive for adopting the new technology then higher costs of imitation could encourage the incumbent to adopt the new technology by making the imitation non-credible. Considering the relationship between the cost of imitation and patent breadth, thus patent breadth may have the influence on technology adoption and on social welfare.

Finally, it is interesting to note that in our model maximum patent breadth, i.e. the amount of imitation cost that makes imitation non-credible for any patent life, may not be optimal when the cost of technology adoption is sufficiently high (i.e. higher than g or g' in 'Figs 5 and 6') and the incumbent has the option on a simple licensing contract only. If the imitation cost is sufficiently high so that imitation is never credible then there is no possibility of imitation and the incumbent always enjoys monopoly benefit up to the statutory life of the patent.[17] As noted already, in this situation optimal patent length will be such that the incumbent is just willing to adopt the technology. Now consider that the incumbent has the option on a simple licensing contract only. If we reduce patent breadth such that imitation is credible, then this amount of imitation cost will induce the incumbent to license its technology at the beginning. Given that the incumbent can cover the cost of technology adoption under simple licensing, the market structure will be duopoly from the beginning. Hence, with the possibility of only simple licensing, the patent breadth that encourages imitation may create higher welfare compared to the maximum patent breadth that eliminates the threat of imitation. Further, in this situation, if we further decrease patent breadth, we

considering different costs of imitation.

[17] Note that under the assumption of sufficiently high cost of technology adoption patent life cannot be at the minimum level.

reduce the incumbent's payoff from licensing until at a certain patent breadth technology adoption by the incumbent is not optimal anymore. The finding that welfare may be a non-monotonous function of patent breadth is in contrast to the previous literature (see, e.g. Gallini, 1992; Denicolò, 1996).

If the incumbent has the option to license under a forward contract, then the impact of patent breadth will be reduced dramatically as, in this situation, the incumbent will be able to receive the maximum payoff corresponding to an imitation cost whenever imitation is credible.

5 Discussion

So far we have assumed that the entrant can get the technology only through imitation or through licensing. In this section we briefly discuss the situation where the entrant can get the production technology through its own R&D.

We assume that with probability p the entrant can invent a production technology between the time period 0 and N. We assume that the R&D process requires $R > I$ amount of investment. This assumption is motivated by the general perception that imitation is often a cheaper way for upgrading the technology of a firm so that the cost of doing R&D is higher than the cost of imitation for the entrant. Further, we assume that if the entrant succeeds in R&D then both firms will operate in the market and get a profit flow of D.[18]

It is easy to understand that the entrant has no incentive to do R&D whenever imitation is non-credible. If imitation is non-credible, it implies that the cost of imitation is greater than the gain from imitation. Since the success of conducting R&D is uncertain and also the cost of R&D is higher than the cost of imitation, the entrant will not invest in R&D whenever imitation is non-credible.

If the cost of imitation is sufficiently low ($I < I^C$) and imitation is credible, then we have seen in section 2 that the incumbent will adopt the new technology at the beginning.

Therefore, in this situation, imitation helps the entrant to get the benefit of the superior technology from the beginning. So, even if the threat of imitation is credible but the costs of imitation are sufficiently low then the entrant will have no incentive to invest in R&D and our results will not be affected.

Next, consider the situation where imitation is credible and the costs of imitation are not sufficiently low, i.e. $I \in (I^C, G)$. We found that in this situation the incumbent would engage in forward licensing contract and would charge a licensing fee that would extract all the profit from the entrant since the reservation payoff of the entrant was 0. If the entrant has the possibility of doing R&D then it increases the reservation payoff of the entrant and will prevent the incumbent to charge a licensing fee that will extract all the profit of the entrant. However, it is easy to argue that in this situation, even if the incumbent provides the technology to the entrant at free of cost, it is still better for the incumbent compared to delayed technology adoption. This is because the incumbent's payoff from delayed technology adoption and from forward licensing contract with zero licensing fee will be $\int_{A^*}^{N} Me^{-rs} ds$ and $\int_{0}^{N-A*} Me^{-rs} ds + \int_{N-A*}^{N} De^{-rs} ds$ respectively. Straightforward calculation shows that the payoff to the incumbent will be higher under forward licensing than under delayed technology adoption. Hence, even in this situation, the possibility of R&D by the entrant will not affect our results.

However, our results would be influenced if the incumbent does not have the possibility of writing a forward licensing contract. We have already seen that the incumbent will not license its technology under simple licensing contract if $I \in (\overline{I}, G)$ and will prefer to adopt the strategy of delayed technology adoption. If the entrant has a sufficiently higher probability of inventing a new technology before N, then it will significantly reduce the expected profit of the incumbent from delayed technology adoption. Hence, this possibility

[18] One can think that even if the entrant gets the knowledge to produce the good, this knowledge is sufficiently different from the incumbent's knowledge so that both firms can use their own technology.

will encourage the incumbent to adopt its technology at the beginning and to license the technology to the entrant with a licensing fee equal to the cost of imitation.

We have seen in section 3 that if the costs of imitation are moderate, i.e. $I \in (I^C, \overline{I})$, the incumbent has the incentive for engaging in simple licensing contract. However, the possibility of R&D by the entrant increases the reservation payoff of the entrant and reduces the expected profit of the incumbent. If the possibility of R&D by the entrant reduces the incumbent's profit from delayed technology significantly then the incumbent will not be willing to delay its technology adoption without licensing. In this situation, however, the incumbent will license its technology to the entrant at a licensing fee equal to the cost of imitation. If the entrant's probability of success in R&D is not sufficiently high, the incumbent will prefer delayed technology adoption even if there is a possibility of doing R&D by the entrant. While industry profit under licensing does not change with the possibility of doing R&D by the entrant, industry profit under the strategy of delayed technology adoption reduces with the possibility of doing R&D by the entrant since now it reduces the monopoly advantage of the incumbent. Hence, it increases the incentive for licensing. The following proposition summarizes the above discussions.

Proposition 5 Suppose the cost of R&D by the entrant is higher than the cost of imitation.

(i) If the incumbent has the option of forward licensing or if imitation is not credible, then the possibility of undertaking R&D by the entrant does not change the conclusions of the previous sections.

(ii) If the incumbent has the option of simple licensing, then the possibility of doing R&D by the entrant reduces the incentive for delayed technology adoption and increases the incentive for licensing.

6 Conclusion

In this paper we consider technology adoption by an incumbent when it faces the threat of imitation from an entrant. If patent life is sufficiently short, the threat of imitation is not credible and the incumbent always adopts its technology at the beginning. However, in case of a relatively long patent life, imitation becomes a credible threat, and the incumbent may prefer to delay its technology adoption. This delaying strategy helps to eliminate the threat of competition by making imitation unattractive to the entrant. Thus, a relatively large patent protection may create an inefficiency by encouraging the incumbent to delay its technology adoption. Especially in the case of relatively long patents and low imitation cost, licensing enhances welfare by eliminating the incidence of unwanted imitation cost by the entrant and by creating competition from scratch. On the other hand, licensing will never be beneficial for the incumbent under relatively weak patent protection and high cost of imitation. In this case the entrant will prefer to wait until the patent expires.

When the incumbent is enabled to license the technology, the incumbent will prefer to engage in a forward contract on licensing. Under this forward contract on licensing, the incumbent allows the entrant to use the technology from a pre-specified time period. While this licensing contract is optimal for the incumbent, it reduces social welfare for technologies that are relatively easy to imitate (i.e. for relatively lower cost of imitation). Hence from a competition policy point of view, authorities may want to block forward licensing for relatively simple technologies. However, forward licensing contract improves welfare for sufficiently higher costs of imitation, which is not true for simple licensing contracts. Moreover, forward licensing may lead to more innovation. Hence, from a competition policy point of view, forward licensing would be encouraged for relatively complex technologies.

Considering the recent surge in internet-dominated technologies where lifecycles are short and imitation costs are low, instant copying is likely to occur frequently. In order to save the deadweight loss from imitation, the results call for licensing agreements between the innovator and potential entrants. Moreover, licensing will encourage adoption of slightly more complex technologies, such as computer hardware, where delay of technology adoption would be optimal without licensing agreements. However, if the entrant has the possibility to invent a technology through its own R&D then it may reduce the incentive for delaying strategy and may reduce the licensing fee extracted by the incumbent, if licensing occurs. Further, in this study we show that there may be non-monotonic relationship between the cost of technology adoption and optimal patent length.

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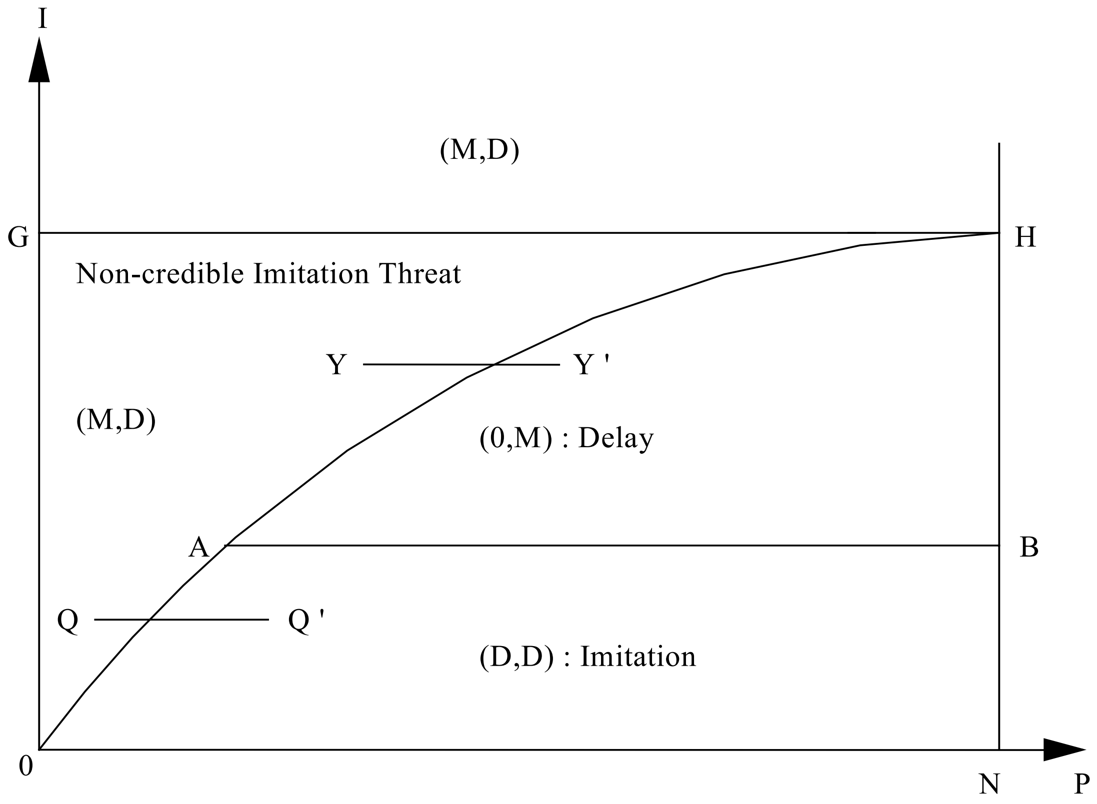

Fig. 1. The line OH represents the combinations of I and P for which the entrant is indifferent between imitation and waiting until patent expires. The line AB shows the cost of imitation, I^C, for which the incumbent is indifferent between waiting with adoption and immediate adoption. For imitation cost higher than G imitation is not credible for any P<N.

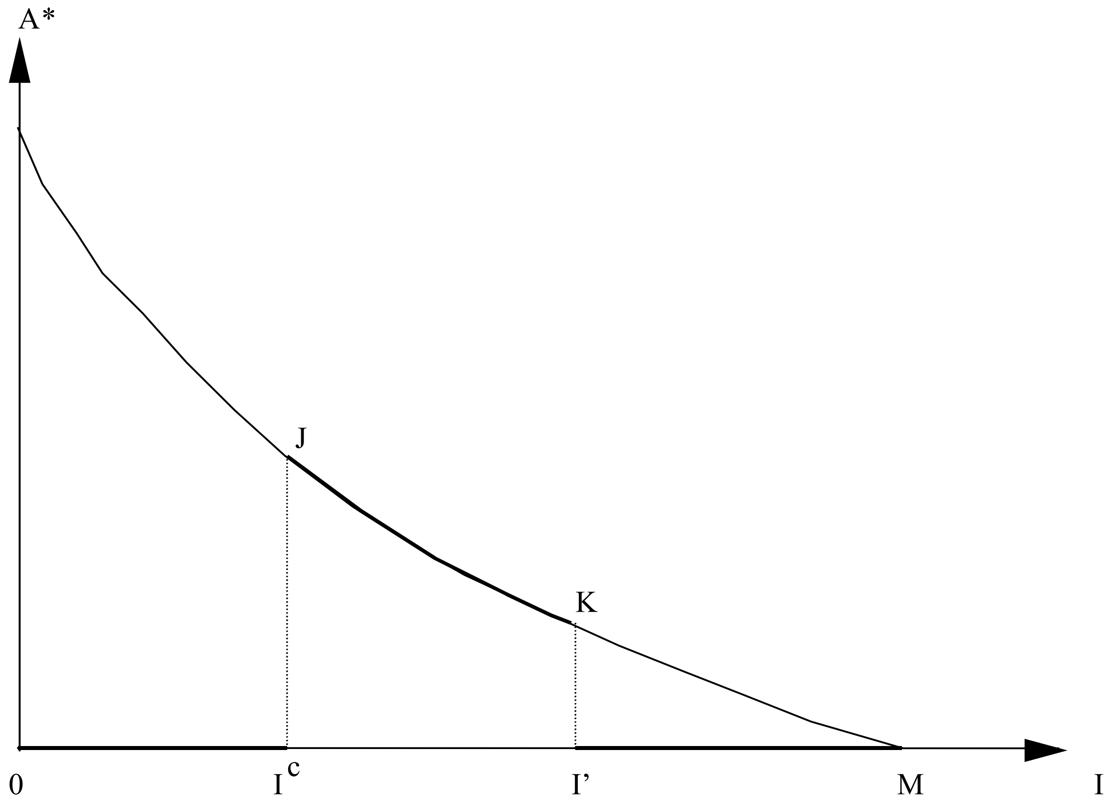

Fig. 2. The optimal adoption date, A^*, as a function of cost of imitation, I.

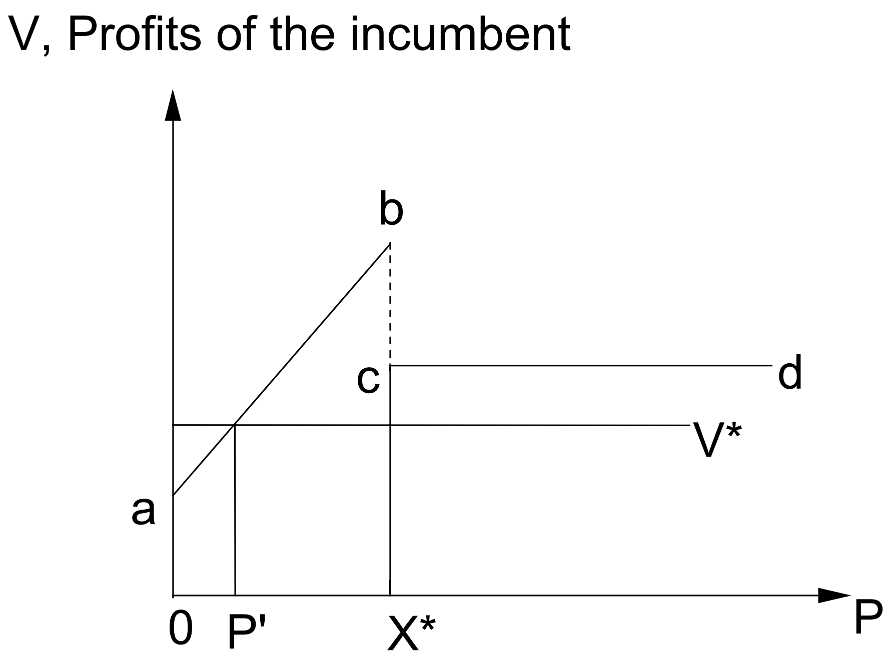

Fig. 3. Profits of the incumbent for a given I , where $I > I^C$.

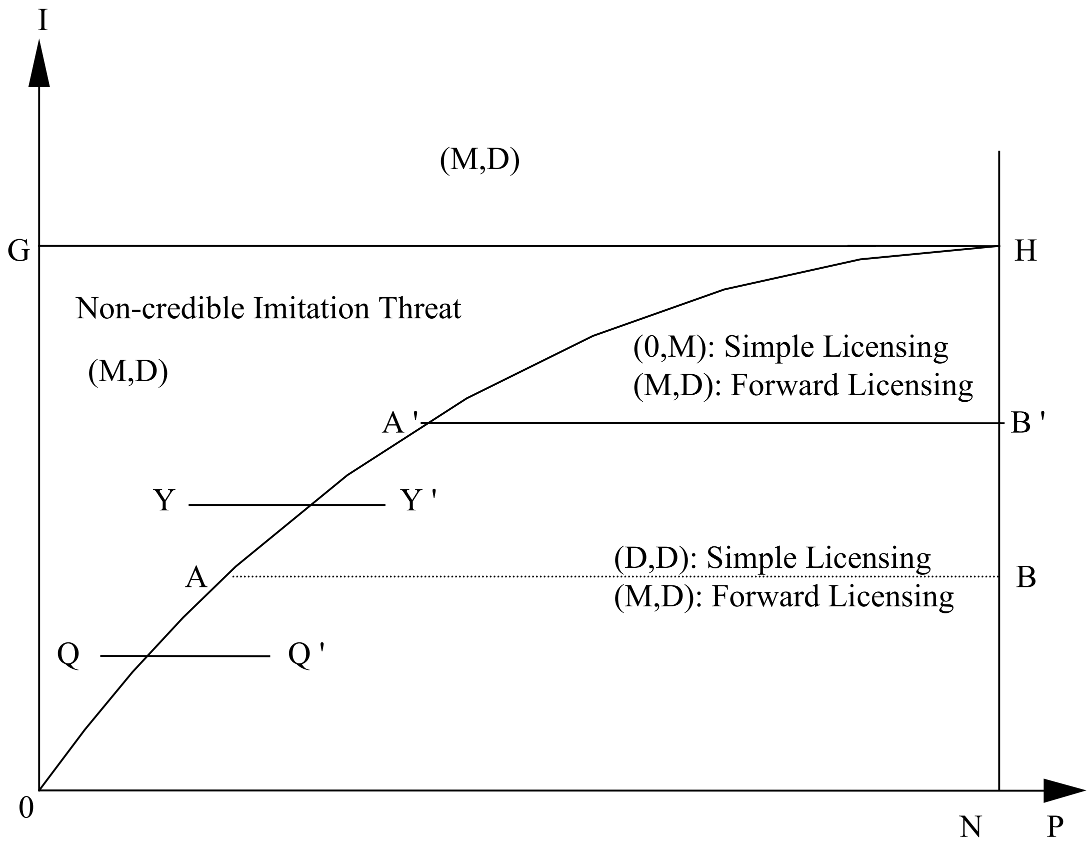

Fig. 4. Forward licensing reduces the incentive for delay whenever imitation is credible. Simple licensing is not optimal when the imitation cost is higher than $\bar{I}$, represented by the line A'B'.

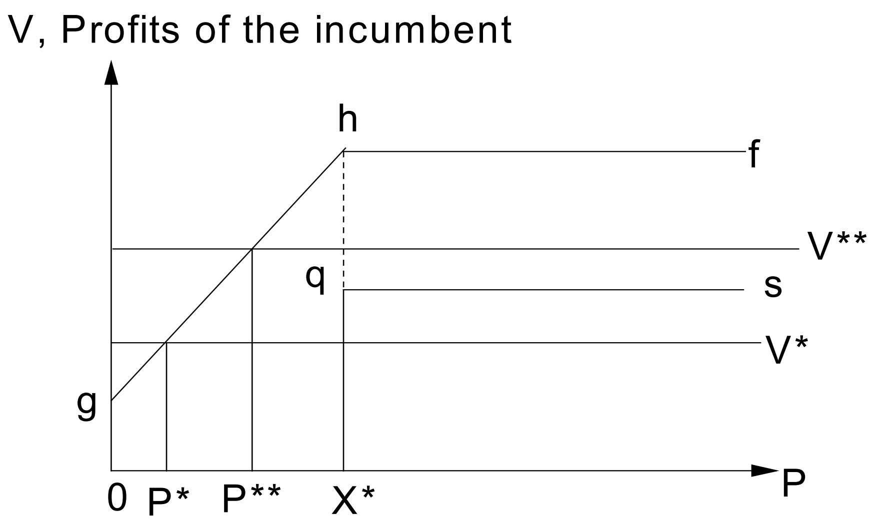

Fig. 5. Profits of the incumbent with licensing when $I < I^C$.

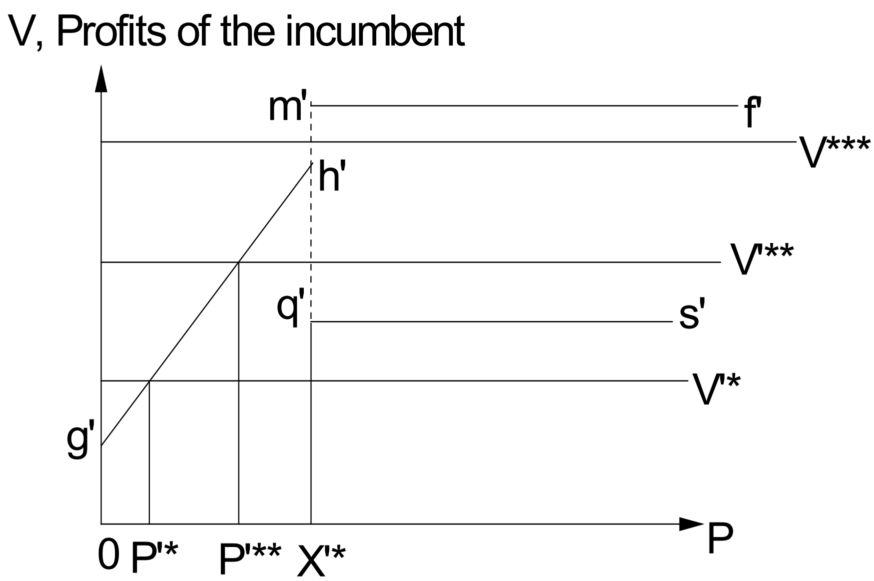

Fig. 6. Profits of the incumbent with licensing when $I \in (I^C, G)$. Ignore the line $q's'$ when $I \in (\bar{I}, G)$.