Competitive disadvantage through non–existing software patents

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Abstract

In a model of sequential patent races, it is examined whether or not introducing a patent law in the home country is beneficial to the firms and the society as a whole given the foreign country already offers patent protection. Before the first patent race starts, the firms and the foreign country share interests. For a given total number of firms, the welfare effect depends on the relative competition profit. For medium values of the latter, the foreign country as well as the firms gain and the home country loses by introducing the patent law. In a Cournot and a Bertand model with a homogeneous product, the home country will never benefit from the introduction of patent protection.

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1 Introduction

In September 2003, the first reading of the 'Proposal for a Directive of the European Parliament and of the Council on the patentability of computer–implemented inventions' took place (European Commission, 2002). The Directive aims at harmonising the members' law and at legalising the praxis of granting software(–related) patents. The preparations of the first reading was accompanied by partly heated discussions in nearly all groups of society. The Economic and Social Committee as well as the Committees on 'Culture, Youth, Education, the Media and Sport' as well as on 'Industry, External Trade, Research and Energy' worked out detailed comments which were presented at the reading.[1] Representatives of the software and computer–related industries as well as CEO's

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[1] See Economic and Social Committee (2003) and the document of the European Commission (2003) on the Committees' opinions.

of individual firms argued for or against the Directive which, in general, would legalise (even pure) software patents.

Representatives of the Open Source community put forth that software patents are likely to bar innovation activity and endanger free and Open Source software.[2] In addition, their existence would be at stage and small start–up firms had no chance at all to enter the market if the Directive were to be introduced. On the other hand, the representatives of the software and computer industry claimed that excluding (pure) software from patent protection violates the TRIPs agreement (World Trade Organization, 1994, Article 27). Moreover, especially European software firms would suffer a competitive disadvantage vis à vis their U.S. rivals from the non–existence of software patents.

The arguments of the representatives of the software and computer industry seem plausible at the first glance. Yet, how do the mechanisms work? There are several ways in which the decision on the patentability of software may affect firms. Among them are the 'bargaining–chip' argument and the traditional one about earning possibilities. The former expresses the idea that holding patents may strengthen a party's position in e.g. cross–licensing agreements.[3] In which particular country the patent is obtained should be insignificant. As a signatory state of the TRIPs agreement, the U.S. grants patents to domestic as well as foreign firms.[4] Hence, European firms have the opportunity to patent their discoveries already so that it is hard to see why European firms should suffer a disadvantage from not being able to gather bargaining chips.

The present paper deals with the earning possibility argument. It is examined under which circumstances firms as well as the society as a whole benefit from the introduction of patents for computer–implemented inventions, given patent protection is offered in a foreign country. Computer–implemented inventions are characterised by two peculiarities: they are often sequential and cumulative.[5] To incorporate the former characteristic, a model of sequential patent races is employed. Discoveries are uncertain; and each discovery improves the preceding one by a fixed amount. In case, a patent is not available, the latest discovery can be imitated immediately and costlessly. Therefore, if the home country does not introduce the patent law, every firm may offer the latest product on the

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[2] In an empirical study, Bessen and Hunt (2003) examine the effects of the legal changes in the U.S. patent system on R&D incentives. They find evidence for the hypothesis that software patents reduce firms' R&D.

[3] See Shapiro (2000); Hall and Ham Ziedonis (2001) for the 'bargaining–chip' argument.

[4] According to the Article 3 (1) of the TRIPs agreement: "Each Member shall accord to the nationals of other Members treatment no less favourable than that it accords to its own nationals with regard to the protection".

Bessen and Hunt (2003) find that roughly 30 percent of software patents issued in the U.S. are obtained by non–U.S. firms or residents.

[5] Here, innovations are regarded to be sequential when they follow upon each other in time. Although they may or may not infringe upon each other, the product is covered by one patent. In contrast, innovations shall be called cumulative when more than one discovery is contained in a product.

domestic market and earn a competition profit. Throughout the main part of the analysis, it is assumed that the competition profit and the total number of firms are not interrelated. Here, the principal mechanisms are revealed. In a second part, the results are evaluated for the using the standard Bertrand and Cournot oligopoly framework.

For a given number of firms it is demonstrated that they support the introduction of a patent law if the difference between the monopoly and the competition profit is high before the first patent race started. After the first race is over, the winner and the losers of the last patent race have different profit prospects depending on the home country's decision on patent protection. Then, the winner and the losers of the last patent race disagree on the desirability of patent rights if the difference between the monopoly and the competition profit is moderate for a given number of firms.

Before and after the first patent race started, the home countries welfare shows pattern similar to the desirability of patents for firms. However, since the home country has to take the effects on the consumers' surplus into account, it does not necessarily offer protection of discoveries if the competition profit is zero due to fierce product market competition. For the introduction of a patent law to be welfare enhancing, two conditions have to be satisfied: (1) The expected monopoly profit of a domestic firm has to be higher than the total competition profits accrued by all firms with certainty if the patent law is not introduced. Put differently, the firms' surplus has to increase due to the introduction of the law. (2) The resulting increase in the firms' surplus has to be higher than the decrease in the consumers' surplus due to the monopolisation of the product market.

Section 2 introduces the basic framework. The main results concerning the firms' 'disadvantage' are derived in 3. The home and the foreign countries' welfare are analysed in section 4. Section 5 specifies the derived results for a Cournot and a Bertrand oligopoly producing a homogeneous good; and section 6 concludes.

2 The model

There are two countries A, B. Country A (the foreign country) offers patent protection to domestic and foreign firms. Country B (the home country) has to decide whether to introduce a patent for computer–implemented inventions. I examine country B's decision problem for sequential patent races in a simplified variant of Hunt's (1999) model.

Consider a market, e.g. the one for computer chips. All firms engage in a sequence of global patent races. The kth patent race ends when a firm makes a discovery. The latter can be thought of as an improvement of the computer chip. The extent of the improvement is assumed to be fixed and every discovery is patentable. If the inventor does not or cannot patent the discovery, it immediately becomes common knowledge. Then, the discovery is imitated by all competitors at zero costs. Since research is a cost–intensive activity it is reasonable for the winner to apply for a patent in all countries offering this protection.

If a patent is granted the inventor obtains the exclusive right to produce and market the invention. For simplicity, the statutory patent life is assumed to be infinite. However, the economic patent life ends when the next discovery is achieved. In addition, it is postulated that the patents do not infringe on each another.

In each country, there are n_i, $i = A, B$, firms. A country i–based firm is exclusively owned by individuals living in i. Let n denote the total number of firms, so that $n = n_A + n_B$. The innovation process is stochastic in the sense that the time upon which the discovery occurs is uncertain. In particular, it is assumed that the discoveries arrive according to a Poisson process with parameter λ. This parameter is exogenously given and common to all firms. Therefore, firms cannot influence the individual probability to make a discovery. The instantaneous probability for an individual firm to discover the next chip generation is given by $\lambda e^{-\lambda t}$. In contrast, the instantaneous probability that a competitor succeeds in inventing first is given by $(n-1)\lambda e^{-\lambda t}$. A Poisson process is memoryless in that the probability of discovering the next leading technology is independent of the past innovation success. Hence, the knowledge generated during the innovation process is a public good and has the same productivity in all firms.

Engaging in research is associated with fixed costs K per unit of time, whereas patent protection is assumed to be costlessly available. The winner of a patent race obtains a monopoly position in all countries offering patent protection. The flow profit for the monopoly is π_i^m, $i = A, B$, in the respective markets. If the home country decides against a patent law all firms offer the innovator's product at the domestic market. In this case, each loser of the race obtains a flow profit of $\pi_B^c \geq 0$. If the firms' strategic variable is the price flow profits are driven to zero and $\pi_B^c = 0$. However, profits may be positive if firms compete in quantities. In addition, it is assumed that $\pi_i^m \geq \pi_B^c$. Otherwise no firm would engage in a patent race. For the time being, it is postulated that the competition profit is independent of the total number of firms so that it varies freely in the interval $[0, \pi_B^m]$. Clearly, by specifying the product market competition, a precise relationship between the competition profit and the total number of firms is derived. Two examples are studied in section 5.

2.1 No patent protection in country B

If the home country does not introduce the patent law, no firm is granted a patent in the domestic market. Since an unprotected discovery immediately becomes common knowledge, all firms are able to offer the inventor's product at market B. However, the foreign country grants exclusive rights to all firms so that domestic as well as foreign firms may obtain a monopoly position in A.

Let V^I and V^C denote the value of having discovered the $k-1$st innovation (being an incumbent in the kth race) and the value of having not discovered the latest innovation (being a challenger in the kth race). Assuming that the values are stationary, i.e. they are the same in all patent races, the value functions have to obey the following Bellman equations

$$rV_n^C = \pi_B^c - K + \lambda(V_n^I - V_n^C),$$
$$rV_n^I = \pi_A^m + \pi_B^c - K + (n-1)\lambda(V_n^C - V_n^I).$$

The subscript n indicates that country B offers no patent protection. According to the first equation, the return on the money equivalent of the value to enter the next patent race as a challenger equals the sum of the instantaneous net profit $\pi_B^c - K$ and the expected gain from winning the next patent race $V_n^I - V_n^C$ which occurs with probability λ. The incumbent of the next race receives the monopoly profit in market A. Since he is unprotected in country B, he earns the competition profit π_B^c in the domestic market. Therefore, the net flow profit is given by $\pi_A^m + \pi_B^c - K$. The second equation describes that the return on the money equivalent of the value of being the incumbent in the next race equals the sum of the instantaneous profits and the expected loss from losing the incumbency during the next race. The latter event takes place with probability $(n-1)\lambda$.

The equations can be used to explicitly solve for the value functions

$$V_n^C = \frac{\pi_B^c - K}{r} + \frac{\lambda}{r+n\lambda}\frac{\pi_A^m}{r}, \qquad (1)$$
$$V_n^I = \frac{\pi_B^c - K}{r} + \frac{\lambda}{r+n\lambda}\frac{\pi_A^m}{r} + \frac{r}{r+n\lambda}\frac{\pi_A^m}{r}.$$

As long as the home country does not have a patent law, every firm offers the latest technology at market B. Thus, the incumbent as well as every challenger receives a net flow profit of $\pi_B^c - K$ in this market with certainty. This accounts for the fact that the first terms of the continuation values V_n^C and V_n^I are identical. They are the present value of the net profit earned in market B.

The remaining terms in equation (1) are related to the profits obtained in market A. On average, every firm spends a fraction $\lambda/(r+n\lambda)$ of time as incumbent in future. As a monopoly, the incumbent earns a flow profit π_A^m. $(n-1)\lambda/(r+n\lambda)$ is the average time spent as a challenger. However, as market A is monopolised by the incumbent, the challengers obtain zero profits in this market. Consequently, the second terms of the continuation values are the expected present values of the profits earned in A during future races. The last term of the continuation value V_n^I signifies that the difference between an incumbent and a challenger is the position in the next patent race. While the incumbent receives the monopoly profit the challenger earns nothing.

2.2 Patent law in country *B*

In case country B decides for a patent law, the inventor of the latest technology obtains a patent and the monopoly position in country *A and B*. The challengers compete in the subsequent patent race, but are unable to offer a product at either market.

Under those circumstances, the value functions have to satisfy

$$rV_p^C = -K + \lambda(V_p^I - V_p^C),$$
$$rV_p^I = \pi_A^m + \pi_B^m - K + (n-1)\lambda(V_p^C - V_p^I).$$

Here, the subscript p stands for 'patent protection' in country B. The interpretation of the equations parallels the one of the previous section. The difference consists in the altered flow profits. Since both markets are monopolised, a challenger has a negative net flow profit $-K$, whereas the winner of the patent race obtains $\pi_A^m + \pi_B^m - K$. Solving the system of equations for the continuation values yields

$$\begin{aligned} V_p^C &= -\frac{K}{r} + \frac{\lambda}{r+n\lambda}\frac{\pi_A^m + \pi_B^m}{r}, \\ V_p^I &= -\frac{K}{r} + \frac{\lambda}{r+n\lambda}\frac{\pi_A^m + \pi_B^m}{r} + \frac{r}{r+n\lambda}\frac{\pi_A^m + \pi_B^m}{r}. \end{aligned} \tag{2}$$

The first term is the present value of the research costs which all firms have to bear. The second term of the equations in (2) is the expected present value of the total profits earned as an incumbent in future races. The future earning possibilities are identical to an incumbent and a challenger so that the second terms are the same in both equations. Again, the last term of V_p^I is the incumbent' present value of profits received in the next race.

3 The firms' 'disadvantage'

The present section deals with the question of whether country B–based firms suffer a disadvantage from the non–existence of a patent protection in their home country. In order to derive the desired results, the situation in which the home country introduces the patent law is compared to the situation in which it does not. Since the analysis is symmetric on the firm level, identical arguments apply to country A–based firms.

In general, a country B–firm favours patent protection if the continuation value under protection exceeds the one for a situation without a patent law in the home country. Formally, the difference $V_p - V_n$ has to be positive, where $V_p - V_n$ measures the desirability of patent protection in the home country. Whether or not a firm prefers a patent law may depend on its position in the next patent race. Let z be defined as $z = \pi_B^c/\pi_B^m$. Then, z is the competition profit relative to the monopoly one and takes values in the interval of $[0,1]$. The next result specifies the conditions for protection to be desirable.[6]

Proposition 1. *Let* $z^C(n) \equiv \lambda/(r+n\lambda)$ *and* $z^I(n) \equiv (r+\lambda)/(r+n\lambda)$. *Then,*

$$V_p^C - V_n^C \geq 0 \iff z \leq z^C, \tag{3}$$
$$V_p^I - V_n^I \geq 0 \iff z \leq z^I. \tag{4}$$

[6] The proof for this an all other results are derived in the appendix.

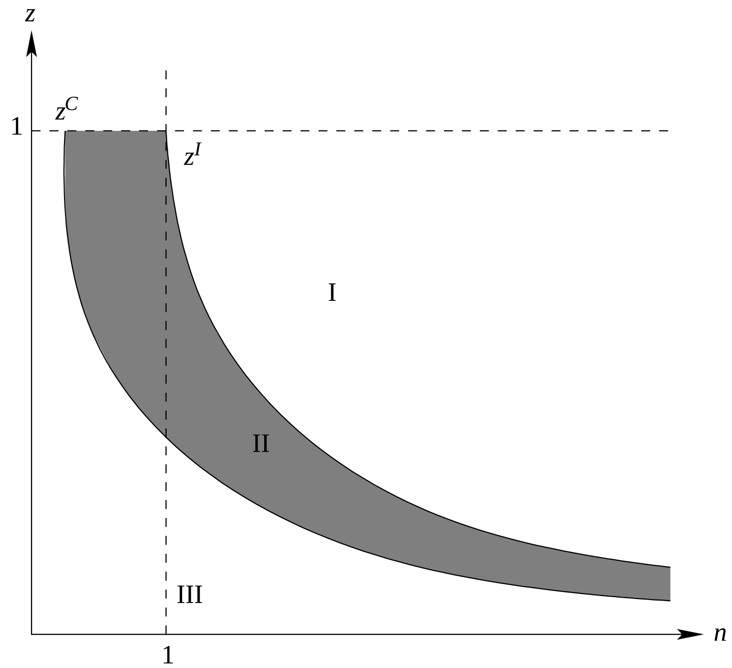

Figure 1: Different evaluation of the patent law

According to (3) and (4), $z^C(n)$ ($z^I(n)$) gives the relative competition profit for which a challenger (an incumbent) is indifferent between a situation with and without a patent law in the home country for a total number of firms n. Then, the proposition states that for a given n an incumbent as well as a challenger favours the patent law if the relative competition profit is comparably small. In particular, the difference between the monopoly profit and the competition profit needs to be sufficiently large.

The functions $z^C(n)$ and $z^I(n)$ are drawn in figure 1. They are negatively sloped in the n/z–diagram. Consequently, for the firms to remain indifferent between the home country's choices, a larger number of firms has to correspond to a smaller relative competition profit z. To see why this result applies, note that every firm receives the competition profit π_B^c with certainty when the home country does not introduce the patent law. If a patent law exists in B, only an incumbent is able to accrue a positive profit π_B^m, since the challengers are not able to sell products in a monopolised market. Due to the stochastic nature of the innovation process, the event of becoming an incumbent is uncertain and the probability is the lower the more firms are participating in a patent race. Hence, for a firm to stay indifferent between the home country's choices, the reward from being an incumbent in the next patent race has to increase, i.e. z has to decline, when the number firms increases.

Both functions approach the horizontal axis as the total number of firms grows large. This property demonstrates that an incumbent as well as a challenger prefers patent protection when product market competition drives profits to zero. It can also be seen in figure 1 that neither firm would support a patent law if the difference between the competition and the monopoly profit were negligible.

In addition, figure 1 shows that the graph $z^C(n)$ lies below the one of $z^I(n)$. The intuition is straightforward. All firms receive flow profits π_B^c with certainty if discoveries are unprotected in the home country. In contrast, if the country introduces the patent law the payoff prospects are different for an incumbent and a challenger. Although all firms are equally likely to gain incumbency in future, the latter occupies the monopoly position and earns the larger profit in the next patent race. Given the total number of firms, the challenger's reward from becoming an incumbent has to be higher (z has to be lower) compared to the incumbent's reward if the firms are to be indifferent between the country's choices.

From the properties of the functions $z^C(n)$ and $z^I(n)$, the following result can be derived:

Corollary 1. *(1) A challenger and an incumbent are better off without a patent protection in region I of figure 1.*

(2) The incumbent prefers the introduction of a patent law, but the challenger does not in region II of figure 1.

(3) A challenger and an incumbent favour a patent protection in region III of figure 1.

To see why all firms gain from the non–existence of patent protection in region I, it is instructive to consider the special case of $z = 1$. Under patent protection, only the incumbent earns a positive profit $\pi_B^c = \pi_B^m$. Since winning the patent race is an uncertain event, the expected profit to an incumbent is lower than $\pi_B^m = \pi_B^c$. However, the latter is the profit that all firms receive with certainty if there is no patent law. Therefore, patent protection cannot be desirable to an incumbent or a challenger under those circumstances.

In region III, a patent law is beneficial to all firms. Consider the case of $z = 0$. Without a patent protection all firms earn the competition profit $\pi_B^c = 0$. If the domestic market is monopolised, the challengers receive zero profits as well. In contrast, the winner of the last patent race obtains the monopoly profit. As long as the monopoly profit is strictly positive, the expected return from incumbency is strictly positive as well and, hence, exceeds the competition payoff. Since all firms have a positive probability of winning a patent race in future, all firms support the introduction of a patent law.

An interesting situation arises for (n, z)–combinations belonging to region II. Here, the incumbent and the challengers disagree about the desirability of patent protection. For a given relative competition profit, the total number of firms is too high so that the probability of winning a patent race in future is relatively low. Consequently, the expected profit from gaining incumbency in future is lower than the certain competition profit; and the challengers prefer discoveries to remain unprotected. However, the winner of the last patent race obtains the monopoly profit during the next race if the patent law is introduced.

The difference between the monopoly and the competition profit is just sufficient to make a patent law desirable for the next race's incumbent.

Proposition 1 and Corollary 1 apply to situations in which the first patent race has already taken place. Before the sequence of patent races starts, a firm does not know whether it will be an incumbent or a challenger in the first race. Hence, ex–ante, a firm's value to participate in the first patent race differs from V^I and V^C. Let V denote the value of entering the first race. Then, V can be determined by $V = \lambda V^I + (n-1)\lambda V^C$. Using the appropriate value functions V^I and V^C, the value of participating in the first race is given by

$$V_p = \frac{\lambda}{r}\left[\pi_A^m + \pi_B^m - nK\right]$$
$$V_n = \frac{\lambda}{r}\left[\pi_A^m + n\pi_B^c - nK\right].$$

This immediately leads to the next result.

Proposition 2. *Let* $z^F(n) \equiv 1/n$. *Then,*

$$V_p - V_n \geq 0 \quad \Longleftrightarrow \quad z \leq z^F(n). \tag{5}$$

Even before the first patent race starts, a firm supports the introduction of a patent law if the relative competition profit is not too large and, hence, the difference between the monopoly and the competition profit relatively high. Conversely, if the difference between the monopoly and the competition profit is small a firm prefers discoveries to remain unprotected. Again, the function $z^F(n)$ marks the combinations (n,z) for which a firm is ex–ante indifferent between the existence and non–existence of patent protection in the home country. Since the value of participating in the first patent race is the linear combination of the value of being an incumbent and a challenger respectively, the graph of $z^F(n)$ lies in region II of figure 1. Accordingly, in the limiting situations, firms behave alike independent of whether or not the first race started. In particular, this means that a firm ex–ante supports patent protection when the competition profit approaches zero and votes against a patent law if the difference between the monopoly and competition profit becomes small before the first race starts.

Following Proposition 1 and 2, it can be argued that domestic firms suffer from the non–existence of patent protection when the competition profit is low compared to the monopoly one for a given number of firms. In addition, after the first patent race has taken place, the incumbent and the challengers may disagree about the desirability of a patent law according to Corollary 1. However, it has to be pointed out that domestic firms do not experience a competitive disadvantage vis à vis their foreign rivals since the model is symmetric at the firm level, i.e. the foreign firm suffers as well.

4 Welfare analysis

Even if all firms agree on the desirability of a patent protection a society as a whole may well arrive at a different conclusion because it will take the consumers' surplus into account. The present section studies how the introduction of a patent law affects country B's and A's welfare.

Assume that the consumers' surplus can be described by a function $S(n)$. Then, $n = 1$ marks a situation where the corresponding market is monopolised and the consumers' surplus is $S(1)$. When $n > 1$, the product market is (im)perfectly competitive and the consumers' surplus is $S(n)$. Without a threat of entry, the monopoly charges a higher price and offers a lower quantity than firms in a competitive environment so that $S(n') > S(n'')$ for all $n' > n'' \geq 1$.

As an i–based firm is exclusively owned by inhabitants of i, the profit of the firm is payed as dividends to the individuals in i. Therefore, the total welfare is the sum of the consumers' surplus and the profits of the n_i firms. As the firms' expected profit may differ after the first patent race has taken place, we have to distinguish the countries' welfare before and after the first patent race starts.

4.1 Country *B*'s welfare

Consider the kth patent race. Independent of whether or not the home country has a patent law, the country's welfare depends on the origin of the next race's incumbent. Therefore, country B's welfare has to be derived for the cases in which a domestic and a foreign firm have made the latest invention.

Assume that country B does not protect discoveries. Then, all n firms will imitate and sell the latest discovery at the domestic market. Let W denote country B's welfare. The social value W_n^I and W_n^C from hosting and not hosting the incumbent have to satisfy

$$rW_n^I = S(n) + \pi_A^m + n_B(\pi_B^c - K) + \frac{n - n_B}{n}\lambda[W_n^C - W_n^I],$$
$$rW_n^C = S(n) + n_B(\pi_B^c - K) + \frac{n_B}{n}\lambda[W_n^I - W_n^C],$$

If a country B–based firm is the incumbent, the instantaneous welfare of the home country consists of the consumers' surplus $S(n)$, the incumbents' monopoly profit received in country A and the total net profits $n_B(\pi_B^c - K)$ earned by firms at the domestic market. According to the first equation, the return on the money equivalent of the social value W_n^I equals the sum of the instantaneous welfare and the expected welfare loss arising when a foreign firm is winning the next patent race. The latter event occurs with probability $n_A\lambda/n = (n - n_B)\lambda/n$. If all n_B firms are challengers they earn zero profits in the monopolised market A. Then, the instantaneous welfare of country B is the sum of the consumers' surplus $S(n)$ and the net profits obtained by the n_B firms in the domestic market $n_B(\pi_B^c - K)$. The second equation requires the return on the money equivalent W_n^C to be identical to the sum of the instantaneous welfare and the expected welfare gain derived if one of the n_B firms wins the next patent race. This event takes place with probability $n_B\lambda/n$. Using both equations to solve for the social value functions yields

$$
\begin{aligned}
W_n^C &= \frac{1}{r(r+\lambda)}\left[\frac{n_B}{n}\lambda\pi_A^m + (r+\lambda)\left\{S(n)+n_B(\pi_B^c-K)\right\}\right],\\
W_n^I &= \frac{1}{r(r+\lambda)}\left[\left(r+\frac{n_B}{n}\lambda\right)\pi_A^m + (r+\lambda)\left\{S(n)+n_B(\pi_B^c-K)\right\}\right].
\end{aligned} \tag{6}
$$

Now, suppose that country B offers patent protection. Under these circumstances, both markets are monopolised by the firm that won the last patent race. Accordingly, all challengers earn zero flow profits in both markets. Then, country B's social value functions have to obey

$$
\begin{aligned}
rW_p^I &= S(1)+\pi_A^m+\pi_B^m-n_BK+\frac{n-n_B}{n}\lambda[W_p^C-W_p^I],\\
rW_p^C &= S(1)-n_BK+\frac{n_B}{n}\lambda[W_p^I-W_p^C].
\end{aligned}
$$

If both countries protect discoveries the consumers' surplus is $S(1)$. Given a domestic firm is the incumbent in the next patent race, the instantaneous welfare of B is the sum of the consumers' surplus and the net monopoly profits accrued in both markets $\pi_A^m+\pi_B^m-K$. In contrast, if a foreign firm wins the current patent race the n_B firms have a negative net profit of K during the next race. Then, the instantaneous welfare of B is $S(1)-n_BK$. The difference between the above equations and the ones applying to the non–protection regime is the instantaneous welfare for B. Therefore, the interpretation of those equations parallels the preceding ones. Solving for the social value functions ensues in

$$
\begin{aligned}
W_p^C &= \frac{1}{r(r+\lambda)}\left[\frac{n_B}{n}\lambda(\pi_A^m+\pi_B^m) + (r+\lambda)\left\{S(1)-n_BK\right\}\right],\\
W_p^I &= \frac{1}{r(r+\lambda)}\left[\left(r+\frac{n_B}{n}\lambda\right)(\pi_A^m+\pi_B^m) + (r+\lambda)\left\{S(1)-n_BK\right\}\right].
\end{aligned} \tag{7}
$$

A government aiming at maximal welfare will introduce a patent law if and only if doing so results in a welfare gain, i.e. if $W_p - W_n > 0$. Given the equations in (6) and (7) we find:

Proposition 3. *Country B's welfare gain from introducing the patent law has the following properties:*

$$W_p^I - W_n^I \geq 0 \iff -[S(1)-S(n)] \leq \frac{r+\lambda n_B/n}{r+\lambda}\pi_B^m - n_B\pi_B^c, \tag{8}$$

$$W_p^C - W_n^C \geq 0 \iff -[S(1)-S(n)] \leq \frac{\lambda n_B/n}{r+\lambda}\pi_B^m - n_B\pi_B^c. \tag{9}$$

The proposition shows under which conditions a policymaker is willing to introduce a patent law depending on whether or not a domestic firm wins the current patent race. In general, the government weighs social costs and social benefits.

Condition (8) describes country B's problem if a domestic firm is the incumbent in the next race. According to this condition, patent protection leads to a welfare gain if the potential social benefits – the right–hand side (rhs) of the second inequality – outweighs the social costs – the left–hand side (lhs) of the second inequality. The social costs stem from monopolising a competitively organised market. Here, the consumers suffer a welfare loss of $S(1) - S(n) < 0$. On the other hand, there are potential gains from the introduction of a patent law associated with monopoly profits exceeding the competition profit in the domestic market. If country B introduces the patent law, the average fraction of time in which a domestic firm occupies incumbency in future is $(\lambda n_B/n)/(r+\lambda)$. Since a domestic firm will hold the monopoly position in the next race, the total expected firms' surplus is $\pi_B^m(r+\lambda n_B/n)/(r+\lambda)$ under patent protection. Without patent protection, the firms' surplus is $n_B\pi_B^c$ with certainty. Therefore, the rhs of the second inequality is the expected social gain derived from the introduction of the patent law. The interpretation of condition (9) follows analogous steps.

Note that, although $\pi_B^m \geq \pi_B^c$, the firms' surplus from the introduction of patent protection need not to be positive turning the potential social benefits into additional social costs. This can be seen in condition (9). Rewriting the rhs of the second inequality yields

$$n_B\pi_B^m\left[\frac{1}{n}\frac{\lambda}{r+\lambda} - z\right].$$

The bracket term becomes negative as the total number of firms grows large. Clearly, a society would never consider to offer patent protection under those circumstances.

A comparison between conditions (8) and (9) reveals that country B's potential social benefits due to the introduction of a patent law are always larger if the incumbent is a domestic firm. In particular, this implies that if the firms' surplus decreases when the incumbent is a foreign firm, the firms' surplus either decreases by a smaller amount or even increases if the incumbent is a domestic firm. Consequently, there are parameter constellations for which country B's decision to introduce a patent protection depends on whether or not a domestic firm is the incumbent. This is comparable to region II of figure 1, where an incumbent and a challenger disagree on the desirability of a patent law. Dissimilar to the firms' point of view, a society would not necessarily introduce a patent law if the competition profit were zero. The divergence of evaluation stems from the fact that a society takes the consumers' benefits $S(n) - S(1)$ from a non–monopolised market into account which are strictly positive.

Before the first patent race takes place, a country does not know whether a domestic or foreign firm wins the first race. The ex–ante expected social welfare can be determined by $W = \lambda(n_B W^I + (n-n_B)W^C)/n$. Given the equations in (6) and (7), the ex–ante welfare is derived with

$$W_n = \frac{\lambda}{rn}\left[n_B\pi_A^m + n\{S(n) + n_B(\pi_B^c - K)\}\right],$$

$$W_p = \frac{\lambda}{rn}\left[n_B(\pi_A^m + \pi_B^m) + n\{S(1) - n_B K\}\right],$$

for country B's choices.

Proposition 4. *Let* $z^S(n) \equiv 1/n - [S(n) - S(1)]/[n_B \pi_B^m]$. *Before the first patent race starts,* $W_p - W_n \geq 0$ *if and only if*

$$(10) \qquad -[S(1) - S(n)] \leq \frac{n_B}{n}\pi_B^m - n_B \pi_B^c \iff z \leq z^S(n).$$

Again, condition (10) shows that the government of B is only willing to offer patent protection if the potential social benefits – the rhs of the first inequality – are larger than the social costs due to monopolising the domestic market. Similar to conditions (9) and (8), the society may decide against a patent law before the first race starts even though the competition profit is zero. This can also be seen in the second inequality by noting that $z^S(n)$ may become zero for a finite total number of firms. Condition (10) differs from the ones in (9) and (8) since the ex–ante potential social benefit is the weighted average of the ones when the incumbent's origin is known.

According to conditions (5) and (10), the firms' and the society's ex–ante evaluation of the patent protection may differ.

Corollary 2. *Figure 2 verifies that the following statements are valid before the first patent race starts.*

(1) The government never introduces the patent law if the firms prefer the non-existence of protection(region I).

(2) When the government introduces a patent law, no firm finds the non-existence profitable (region III).

(3) There are situations in which the firms prefer a patent protection, however, the government does not offer it (region II).

4.2 Country *A*'s welfare

Country A's welfare is also affected by the home country's decision on the introduction of a patent law. However, the effects on the foreign countries' welfare differs since the product market in A is always monopolised due to the existence of an own patent law. Consequently, the foreign consumers' surplus is independent of country B's choice. Then, the sole source of the foreign country's change in welfare stems from a change in the foreign firms' surplus.

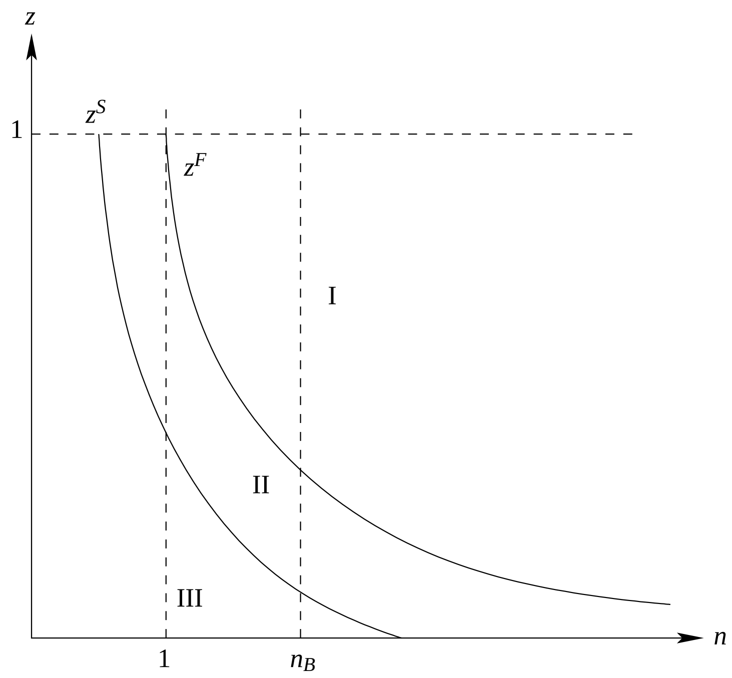

Figure 2: Different ex–ante evaluation of the patent law

Taking analogous steps as the ones in the previous section, country A's ex–ante social welfare with and without a patent protection in country B can be derived with

$$\begin{aligned} \bar{W}_p &= \frac{\lambda}{r}\left[\frac{n-n_B}{n}(\pi_A^m+\pi_B^m)+S(1)-(n-n_B)K\right], \\ \bar{W}_n &= \frac{\lambda}{r}\left[\frac{n-n_B}{n}\pi_A^m+S(1)+(n-n_B)(\pi_B^c-K)\right]. \end{aligned} \tag{11}$$

Proposition 5. *Country A gains from a patent protection in the home country, i.e.* $\bar{W}_p - \bar{W}_n \geq 0$*, if and only if*

$$z \leq z^F(n).$$

The proposition states that the foreign country's ex–ante evaluation of a patent law is identical to the firms' ex–ante point of view. This result is in line with intuition. As the foreign country already offers protection for discoveries, the foreign consumers' surplus does not change if the domestic firm introduces a patent law. Therefore, the firms' and the foreign country's interest are the same. In particular, this implies that the foreign and the domestic country interests diverge in region II of figure 2.

5 Example: Cournot and Bertrand competition

In the previous sections, it has implicitly been assumed that the competition profit is independent of the total number of firms. This may be a reasonable assumptions for some forms of product market competition, e.g. the Bertand model of a homogeneous product. However, for other forms of product market competition, this assumption is too strong. Therefore, the present section re–examines the derived results for the example of a Cournot and a Bertrand oligopoly producing a homogenous good. Likewise, the above results can be evaluated once a particular model of the product market has been specified.

Firstly, consider the case of Cournot competition. Suppose that the discoveries improve the quality of a given product as in the case of chip generations. Let Q_k denote country B's total industry output in the kth patent race so that $Q_k = \sum_{i=1}^{n} q_{ik}$.[7] The inverse demand function for the kth race is given by

$$p_k(Q_k) = a_k - Q_k. \tag{12}$$

The reservation price a_k may differ between patent races if consumers are willing to pay more for high quality goods, i.e. the next chip generation. Since an unprotected discovery is instantly imitated, all firms share the same production technology which is assumed to exhibit constant returns to scale. Then, the cost function for the kth patent race can be written as $C_{ik}(c_k, q_{ik}) = c_k q_{ik}$. It is postulated that the unit cost may depend on the product's quality.

Let S_k, $S_k = a_k - c_k$, denote the market size if the equilibrium price equals the unit costs for the kth patent race. Since the firms are identical in the home country under non–protection, the monopoly and competition profit are given by

$$\pi_k^m = \left(\frac{S_k}{2}\right)^2, \quad \pi_k^c(n) = \left(\frac{S_k}{n+1}\right)^2. \tag{13}$$

The relative competition profit was defined as $z = \pi_B^c/\pi_B^m$. Using the profit functions from (13) ensues in

$$\tilde{z}(n) = \frac{4}{(n+1)^2}. \tag{14}$$

For every possible total number of firms n, $n \in [1, \infty)$, the function determines the relative competition profit z compatible with the Cournot model of a homogeneous product. If there is only one firm the competition profit equals the monopoly one so that the relative competition profit is one as well. As the number of firms approaches infinity, the relative competition profit shrinks to zero. The function $\tilde{z}(n)$ is negatively sloped and convex in a n/z–diagram. Note also that the function $\tilde{z}(n)$ is the same for all patent races and independent of the market size.

Comparing the functions $z^F(n)$ and $\tilde{z}(n)$ shows that the difference is given by $z^F(n) - \tilde{z}(n) = (n-1)^2/[n(n+1)^2] > 0$. Therefore, the function $z^F(n)$ illustrating the (n, z)–combinations for which a firm is ex–ante indifferent between country B's choices lies above the one of $\tilde{z}(n)$. Consequently, before the first patent race starts, a firm always

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7 The country index is skipped as only country B is considered here.

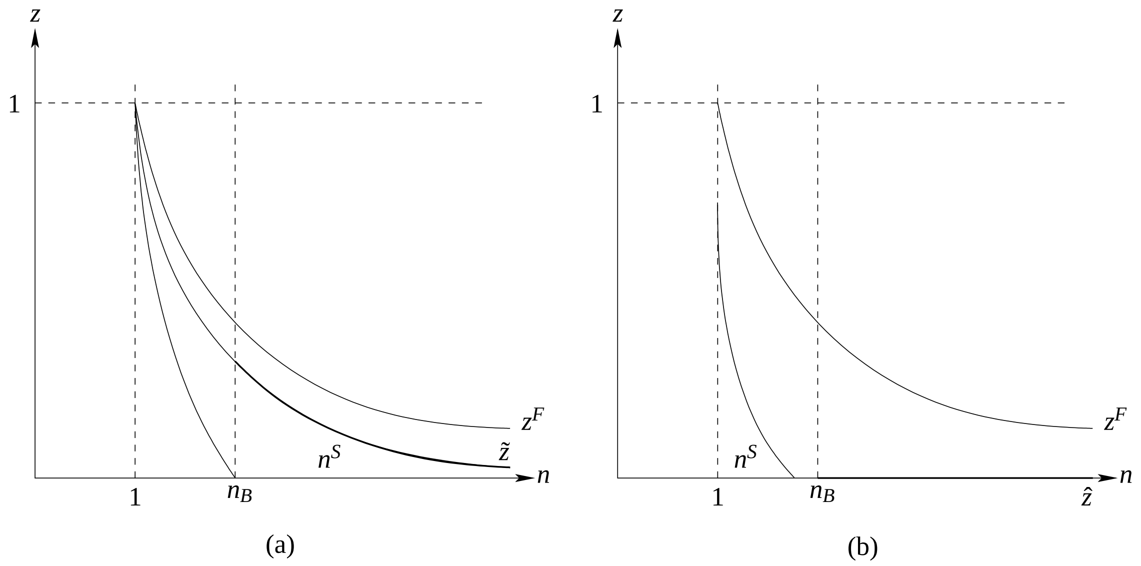

Figure 3: The Cournot and Bertrand case

prefers country B to introduce the patent law in the Cournot oligopoly with a homogeneous product.

Now consider the functions $z^S(n)$ and $\tilde{z}(n)$. The difference can be written as

$$\tilde{z}(n) - z^S(n) = \frac{(n-1)[n(n+1) + 2n_B + 2n(n-n_B)]}{2n_B n(n+1)^2} > 0.$$

Since the total number of firms has to exceed the number of firms in country B, the difference is always positive. Hence, before the first patent race starts, the government of the home country will never introduce the patent law if there is a Cournot oligopoly producing a homogeneous good. However, the country A's welfare would rise if the home country were to introduce the patent law since the foreign country takes the firms' point of view. The situation is illustrated in figure 3 (a).

With prices as the strategic variable in a homogeneous product market, the competition profit π_B^c is zero independent of the total number of firms. Therefore, the (n, z) combinations compatible with the Bertrand model are given by $\hat{z}(n) = 0$. In the Bertrand case, the function $z^S(n)$ simplifies to $z^S(n) = 1/n - 3/(2n_B)$. The function z^S intersects the horizontal axis at $n_B 2/3 < n_B$. Consequently, for a given number of domestic firms n_B, the home country will never increase it welfare by introducing a patent law. On the other hand, the firms as well as the foreign country would benefit from patent protection. The situation is illustrated in figure 3 (b).

In the Cournot and the Bertrand model of a homogeneous product, the home country does not find it worthwhile to introduce the patent law. However, other product market models may arrive at different conclusions.

6 Conclusion

In a simple decision model has been used to show under which circumstances firms and the society suffers from the non–existence of patent protection when the races are sequential and a foreign country has a patent law. Due to the stochastic nature of the innovation process, the firms' and the countries' evaluation of a patent law differs before and after the first race has taken place.

For a situation in which the first race has taken place, the following results have been derived: For a given total number of firms, all firms decline a patent protection when the relative competition profit is high. Likewise, the firms agree in the desirability of a patent law if the relative competition profit is low. For intermediate values of the latter, the winner and the losers of the last race arrive at different conclusions. While the difference between the monopoly and the competition profit is inadequate to compensate a challenger, it is sufficient for the incumbent as he occupies the monopoly position during the next race. For the home country, qualitatively similar results are derived. However, the introduction of a protection for discoveries negatively affects the consumers' surplus. Consequently, there are constellations in which firms and the home country disagree about the benefits of a patent law.

Before the first patent race has taken place, similar results are obtained. Given the total number of firms, firms and countries are not interested in a patent law if the relative competition profit is high. If the latter is low firms always vote for the law. In contrast, the home country may or may not gain by protecting discoveries depending on the precise total number of firms. Since the foreign country has a patent law, the consumers' surplus remains unchanged when the home country introduces patent protection. Therefore, the foreign country shares the firms' point of view so that the same results apply to country A.

Before and after the first patent race started, whether or not countries and firms benefit from patent protection rests on the exact combination of the total number of firms and the relative competition profit. It has been demonstrated that the home country on the one hand and the firms and the foreign country on the other hand may arrive at different conclusions. For the example of a Cournot and a Bertrand oligopoly producing a homogeneous good, it has been shown that the firms and the foreign country always desire the protection whereas the home country does not increase its welfare by doing so.

The disparity in the evaluation of the welfare effects between the countries can be seen in the positive externality generated by unilaterally offering patent protection to all firms in the foreign country. Thereby, the consumers' surplus shrinks in the foreign country due to the monopolisation of the market. However, in case a domestic firm is the incumbent, the higher monopoly profit is accrued by the domestic country. Yet, the latter enjoys a higher consumers' surplus as the domestic market is not monopolised.

Appendix

Proof of Proposition 1. Let $\beta_l \equiv \lambda/(r+n\lambda)$ and $\beta_u \equiv (r+\lambda)/(r+n\lambda)$. According to (1) and (2), $V_p^C - V_n^C$ is given by $V_p^C - V_n^C = [\beta_l \pi_B^m - \pi_B^c]/r = \pi_B^m[\beta_l - z]/r$. Then, $V_p^C - V_n^C \geq 0$ if and only if $z \leq \beta_l = z^C(n)$. By analogy, from (1) and (2) follows $V_p^I - V_n^I = [\beta_u \pi_B^m - \pi_B^c]/r = \pi_B^m[\beta_u - z]/r$. Therefore, $V_p^I - V_n^I \geq 0$ if and only if $z \leq \beta_u = z^I(n)$. □

Proof of Corollary 1. Let $z^C(n)$ and $z^I(n)$ be defined as above and $\mathbb{Z} \equiv \mathbb{R}_+ \times [0,1]$. Let $I^u \equiv \{(n,z) \in \mathbb{Z} | z \geq z^I(n)\}$ and $I^l \equiv \mathbb{Z} \setminus I^u$ be the upper and lower contour set of $z^I(n)$. Let the upper and lower contour set C^u and C^l corresponding to $z^C(n)$ be defined likewise. From the definition of $z^C(n)$ and $z^I(n)$ follows $z^C(n) < z^I(n)$ which implies $I^u \subset C^u$.

The region I in figure 1 is the upper contour set I^u. Since $z^I(n) > z^C(n)$, $V_p^I - V_n^I \leq 0$ and $V_p^C - V_n^C \leq 0$ according to Proposition 1.

Region III of figure 1 is the lower contour set C^l. From $z^C(n) < z^I(n)$ and Proposition 1 follows that $V_p^I - V_n^I \geq 0$ and $V_p^C - V_n^C \geq 0$.

Region II of figure 1 is the intersection set $C^u \cap I^l = \{\mathbb{R}_+ \times [0,1]\} \setminus I^u = C^u \setminus I^u$. The latter is non–empty since $z^C(n) < z^I(n)$. Then, $V_p^I - V_n^I \geq 0$ and $V_p^C - V_n^C \leq 0$. □

Proof of Proposition 2. According to the definition of V_p and V_n, $V_p - V_n = \lambda[\pi_B^m - n\pi_B^c]/r = n\lambda\pi_B^m[1/n - z]/r$. Consequently, $V_p - V_n \geq 0$ if and only if $z \leq 1/n = z^F(n)$. □

Proof of Proposition 3. Let $\Delta S(n) \equiv S(n) - S(1)$, $\delta^u \equiv (r + n_B\lambda/n)/(r+\lambda)$ and $\delta^l \equiv (n_B\lambda/n)/(r+\lambda)$. (6) and (7) imply $W_p^I - W_n^I = [\delta^u \pi_B^m - n_B\pi_B^C - \Delta S(n)]/r$. Then, $W_p^I - W_n^I \geq 0$ if and only if $\Delta S(n) \leq \delta^u \pi_B^m - n_B\pi_B^c$.

By analogy, (6) and (7) yield $W_p^C - W_n^C = [\delta^l \pi_B^m - n_B\pi_B^c - \Delta S(n)]/r$. Hence, $W_p^C - W_n^C \geq 0$ if and only if $\Delta S(n) \leq \delta^l - n_B\pi_B^c$. □

Proof of Proposition 4. Using the definition of W_p and W_n, $W_p - W_n = \lambda[\pi_B^m n_B/n - n_B\pi_B^c - (S(n) - S(1))]/r$. Then, $W_p - W_n \geq 0$ if and only if $S(n) - S(1) \leq \pi_B^m n_B/n - n_B\pi_B^c$ which proves the first inequality. The difference can be rewritten to $W_p - W_n = n_B\lambda\pi_B^m[1/n - z - \{S(n) - S(1)\}/(n_B\pi_B^m)]/r$. Then, $W_p - W_n \geq 0$ if and only if $z \leq 1/n - \{S(n) - S(1)\}/(n_B\pi_B^m) = z^S(n)$ which proves the second inequality. □

Proof of Corollary 2. Let $z^F(n)$, $z^S(n)$ and $\mathbb{Z}$ be defined as above. Let $F^u \equiv \{(n,z) \in \mathbb{Z} | z \geq z^F(n)\}$ and $F^l \equiv \mathbb{Z} \setminus F^u$ be the upper and lower contour set of $z^F(n)$. Let S^u and S^l be defined likewise. From the definitions of $z^F(n)$ and $z^S(n)$ follows $z^F(n) - z^S(n) > 0$ which implies $F^u \subset S^u$.

Region I is the upper contour set F^u. Since $z^F(n) > z^S(n)$, $V_p - V_n \leq 0$ and $W_p - W_n \leq 0$ by Proposition 2 and 4.

Region III is the lower contour set S^l. From $F^u \subset S^u$ follows $S^l \subset F^l$ so that $V_p - V_n \geq 0$ and $W_p - W_n \geq 0$ due to Proposition 2 and 4.

Finally, region II is the intersection $F^l \cap S^u$. According to Proposition 2 and 4 $V_p - V_n \geq 0$ and $W_p - W_n \leq 0$. □

Proof of Proposition 5. From (11), $\bar{W}_p - \bar{W}_n = (n - n_B)\lambda\pi_B^m[1/n - z]/r$. Hence, $\bar{W}_p - \bar{W}_n \geq 0$ if and only if $z \leq 1/n = z^F(n)$. □

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