Global Patent Races and National Patent Policy — On the Optimal Non–Obviousness Standard

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Abstract

A two–country framework is used to model a situation in which patent races are global, but patent policy remains national as far as the non–obviousness standard (NOS) is concerned. We find that countries having higher abilities to innovate tend to choose stronger NOSs. However, Against the intuitive perception that identical countries would choose the same NOS, we find that even identical countries choose different NOSs to their mutual benefit. It is argued that the international differentiation of NOSs tends to be too narrow to be optimal. Hence, a harmonisation of the NOSs should not be a goal of future international negotiations.

1 Introduction

The Agreement on "Trade–Related Aspects of Intellectual Property" (TRIPs) (World Trade Organization, 1994) provides a minimum standard for the protection of Intellectual Property Rights (IPRs) across the territory of the signatory states. This is a major result in a world that increasingly becomes globalised, but where patent law has traditionally been shaped on a national basis.

Certainly, there are pros and cons for notion that further harmonisation is necessary to reap the full benefits of the system from an international point of view. In the European Union e.g., the advantages and disadvantages of a full–fledged European patent have been debated for a long time.[1] The introduction of a European patent would go far beyond the achievements of the TRIPs Agreement or the European Patent Convention in that all differences concerning the administrative *and* judical process would be eliminated. For the European Union this seems to be the next logical step since the explicit goal is that the European nations grow firmly together. If the European economies converge, surely the national patent policy instruments, such as the NOS, utility or novelty requirement would converge as well.

[1] While the European Patent Office is empowered to issue patents on behalf of the European Member Countries, the patents are still bound by the national territory.

The present paper investigates this hypothesis for the case of the NOS. A two–country framework is employed to model the incongruity of global patent races and national patent policy. This provides for both possibilities that identical countries indeed choose the same policy instrument or that international differentiation of the policy instruments are mutually beneficial. This framework also allows to draw conclusions on the special case where industrialised and developing countries are concerned.

We find that if one of the countries has no research abilities, it is indifferent as to the introduction of a patent system and the particular level of the NOS. This result is not surprising since the welfare created by the introduction of new products or technologies is entirely appropriated by the foreign inventors. We find evidence that the country with the higher research ability tends to choose the stronger NOS. However, identical countries will generally not set the same NOS — differentiation of the NOSs is to their benefit. The rationale behind this result is that the country imposing the stronger NOS shelters larger (more valuable) inventions against being rendered irrelevant by subsequent, medium–sized inventions. Hence, by the international differentiation of NOSs it can be guaranteed that on average larger inventions receive higher rewards than medium–sized ones.

The paper proceeds as follows: Section 2 introduces the basic framework. Section 3 studies the situation in which only one of the two countries changes the NOS. This section also lays the foundation for the subsequent section in which a simultaneous decision on the NOS is considered. Section 5 discusses some policy implications and concludes.

2 The basic framework

Essentially, the model presented here is a synthesis of the ones introduced by Hunt (1999, 2002) and Weiss (2005b) on the one hand and Weiss (2004, 2005a) on the other hand. In particular, the following situation is considered: There are two countries i, $i = A, B$. Both countries grant patents for the subject matter in question.[2] In each country, there are n_i firms engaging in an infinite sequence of global patent races. Research is an uncertain task; and uncertainty refers to two distinct features: Firstly, the completion date of an invention is a chance event. Secondly, the invention's improvement over the prior art is a random variable.

2.1 Sequential patent races

Uncertainty in research takes different forms. When firms undertake research projects, they aim at more or less specific targets within a certain time period. The research targets defines the technology field as well as the intended improvement over the prior art. Yet, neither aspect can precisely be laid out beforehand. The invention, e.g. a new material, a new function in a software program or a more efficient way to produce a certain drug,

[2] Henceforth, we frequently refer to country A (B) as the foreign (home) country.

Figure 1: A sequence of patent races

may have the properties sought for, but also additional, surprising ones.[3] Moreover, the invention may take less or more time than expected. Here, only two aspects of uncertainty in research projects are considered: development time and improvement over the prior art.

Time is considered to be a continuous variable; and the time horizon is infinite. In Figure 1, the dates t_k are regarded to be stochastic and mark the points in time when an invention is made.

The time span between two successive discoveries is a patent race.[4] Each patent race ends when a new invention has arisen upon which the next race starts. In Figure 1 e.g., the first patent race ends with the discovery of the first invention at t_1 so that the patent race covers a time of length $t_1 - t_0$. Since the discoveries' arrival dates are stochastic, the actual duration of patent races varies and, hence, the economic patent life of the former invention.

An infinite sequence of global patent races can be modelled as follows: Let a Poisson process determine the duration τ_k, $k \in \mathbb{N}$, of the kth patent race.[5] Then, $\{\tau_k\}_{k=1}^{\infty}$ is a sequence of variables which are independently, identically distributed with exponential distribution $P[\tau_{1i} > t] = e^{-\lambda_i t}$ for a firm of country i (Davis, 1993, p. 37). The parameter λ_i, $\lambda_i \geq 0$, is the innovation efficiency common to all firms situated in country i and exogenously given. Accordingly, while all country i firms have the same research ability, foreign competitors may have a higher or a lower expertise in generating inventions, i.e. $\lambda_i \neq \lambda_j$ is allowed. The discoveries' arrival times are given by $t_k := \sum_{j=1}^{k} \min\{\{\tau_{jl}\}_{l=1}^{n_A} \cap \{\tau_{jm}\}_{m=1}^{n_B}\}$.

Further, note that a firm can be in one of four states z — (1) being the incumbent in both countries (z^B), (2) being the incumbent in the country imposing the stronger non–obviousness standard (NOS) (z^S), (3) being the incumbent in the country with the weaker NOS (z^W) or (4) being a challenger in both countries (z^C). A firm is a challenger in the kth race if it was unsuccessful in creating a patentable invention in the $k-1$st patent race. In contrast, the firm occupies the incumbency during the kth patent race if it made a patentable discovery in the $k-1$st race.

The random variables $\tau_k \in \mathbb{R}_0$ and $z_k \in \{z^B, z^S, z^W, z^C\}$ together define a jump process, where $z_0 = z^C$ is additionally imposed. Hence, all firms are challengers before the first patent race has been concluded. Consequently, an infinite sequence of patent races

[3] A prominent example is that of Pfitzer's Viagra which was originally developed as a treatment for heart diseases. However, the side–effects observed during the clinical test phase proved to be overwhelming so that the succeeding approval was not sought as a treatment for heart diseases.

[4] Earlier works on patent races include Loury (1979) and Lee and Wilde (1980). For an excellent overview see Reinganum (1992).

[5] See eg. Ross (1992) for the description of Poisson Processes.

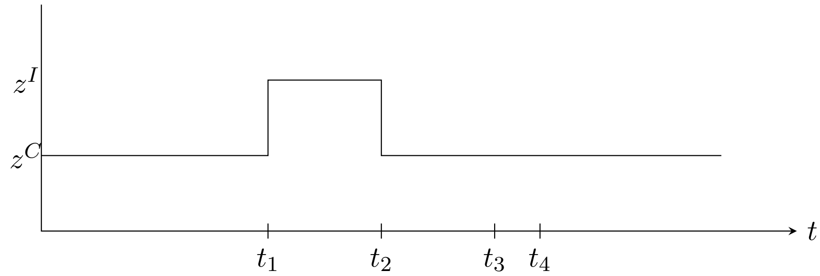


Figure 2: A sample path for firm i

is a piecewise–deterministic–process (PDP) (Davis, 1993, ch. 24) associated by the jump process which is defined by (τ_k, z_k). A sample path for firm i is presented in Figure 2.

2.2 Patentability and the non–obviousness standard

Not every invention automatically qualifies for a patent. Patent systems in most countries require an innovation to be useful, new and non–obvious. The latter criterion is met if an expert of ordinary skills in the respective field of technology cannot readily deduct the solution of the problem by knowing the previous art (Merges and Duffy, 2002, ch. 8). This non–obviousness standard prevents patents to be issued for trivial inventions i.e. which only slightly improve existing products or technologies. Therefore, it encourages inventors to pursue larger, (socially) more valuable improvements and protects them once they are granted a patent.[6]

Assume the kth patent race ends with the appearance of the kth invention in the respective technology line. Let u_k denote the improvement of the kth invention over the $k + 1$st one. The improvements u_k are randomly drawn from the interval $[0, \bar{u}]$. The corresponding distribution and density functions are denoted by $F[u_k]$ and $f[u_k]$. The random process is exogenous and stationary in the sense that it is independent of a firm's research history, innovation effort and time. We postulate that firms of both countries draw the improvement size from the same distribution function.In particular, this means that the properties of the distribution depend on the product or technology line rather than on the innovator's origin or expertise.[7]

Then, a NOS is a parameter s_i, $i = A, B$, so that patent protection in country i is only available for inventions satisfying $u_k \in [s_i, \bar{u}]$. All other inventions, i.e. with $u_k \in [0, s_i)$, are not patentable under the patent system in country i. Since an invention is only patentable in country i if $u_k \geq s_i$, an invention of a given size maybe eligible for a patent in one country, but not in the other. Without loss of generality, consider the case of $s_A < s_B$, i.e. the NOS in country B is higher than that in country A. Then, the

[6] By assigning patent rights to inventions making only slight improvements upon a previous, large one, the rents of the first innovator may decline. As a consequence, inventors have no incentive to pursue larger improvements.

[7] Especially when one of the countries is a developing one, this assumption may be questioned.

probability that a given invention is patentable in country A (B) is given by $\theta_A := 1 - F[s_A]$ ($\theta_B := 1 - F[s_B]$) with $\theta_A > \theta_B$. Consequently, three cases can be distinguished: (i) $u_k < s_A < s_B$ so that the invention is not patentable in either country. This event occurs with probability $1 - \theta_A$. (ii) $s_A \leq u_k < s_B$ so that the discovery qualifies for a patent in country A but not in country B. For any given innovation, the corresponding probability is $\theta_A - \theta_B$. (iii) If $s_A < s_B \leq u_k \leq \bar{u}$, the discovery is patentable in both countries. The event occurs with probability θ_B. Analogous considerations apply for a situation in which $s_A > s_B$.

In case the countries set a uniform NOS, i.e. if $s_A = s_B$, markets become indistinguishable as far as patents are concerned: A given invention is either patentable or unpatentable in both countries. Accordingly, the probability that the discovery is patentable is $\theta_A = \theta_B$.

It is instructive to compare the case in which countries decide for a uniform NOS and the one in which the NOSs are diverging. When the NOSs are identical in both countries, the latter protect the same inventions. In contrast, if the NOSs are different the country applying the stricter NOS issues fewer, but (socially) more valuable patents. The other country grants more patents, but for inventions that have a lower average value. Consequently, markets differ in the latter situation. Since larger inventions arise on average less frequent, the country setting the higher NOS protects them not only against imitation, but also guarantees on average a longer patent life and, thus, higher returns. As every inventor will apply for a patent in all countries where the invention meets the NOS, cross–border profit flows will be observed.

2.3 Demand and prices

Following Hunt (2002), demand is supposed to be completely inelastic and normalised to one. Consumers are identical; and their reservation price for each new generation of a product or technology is identical to the invention's improvement u_k.

Firms are engaged in Bertrand competition and production takes place at no costs.[8] Let U_{k+1}, $U_{k+1} := \sum_{l=1}^{k} u_l$ denote the cumulated improvements embodied in the latest technology. If the kth invention is patentable, the innovator is the only firm able to offer a product having quality U_{k+1}. Therefore, the incumbent of the $k+1$st patent race is able to charge the consumers' reservation price u_k for the product. Since all inventions prior to the kth one can be exercised by all firms once the kth invention is made, the challengers can offer a product having quality U_k. As long as the number of firms exceeds three, Bertrand competition ensures that the challengers obtain a zero gross profit, i.e. the price becomes zero.

In case the invention is unpatentable because it does not satisfy the NOS, the invention becomes common knowledge and can be used by all firms. In this situation, the firm

[8] Almost all information goods share this feature: there are sunk costs of obtaining the information but reproducing it is possible at unit costs close to zero.

having made the last *patentable* invention remains the incumbent. The incumbent is the only firm that can draw an advantage from the unpatentable invention. In particular, it is assumed that the inventor of the last patentable discovery offers a product of quality U_{k+1}.

2.4 The society's states

When considering patent races, one generally has to distinguish two situations: the ex–ante and the ex–post one. The ex–ante situation comprises all points in time where the first patent race has not been concluded. Then, all firms are identical. In contrast, an ex–post situation refers to points in time where the first patent race ended so that firms find themselves in different states. If a firm has made a patentable invention during the kth race, it will be an incumbent in the $k+1$st race. All unsuccessful firms are challengers.

First consider the ex–post situation and let z and y denote a firm's and a society's state. If both countries apply the same NOS ($s_A = s_B$), the foreign and the domestic markets are indistinguishable as far as patentability is concerned. Then, only two positions are relevant: A firm having made a patentable invention during the kth race is the incumbent ($z = z^I$) in both markets during the $k+1$st race. All other firms are challengers ($z = z^C$). Identical states can be found for the society. Either country i hosts the incumbent ($y = y^I$) or all i–firms are challengers ($y = y^C$).

When both countries choose different NOSs, the home country has either a stronger ($s_B < s_A$) or a weaker ($s_B > s_A$) NOS. Under these circumstances, the home country issues either less ($s_B < s_A$) or more ($s_B > s_A$) patents than the foreign country. As a consequence, a firm may be the incumbent in the foreign but not in the domestic market. Thus, from an individual firm's point of view, there are four states z_k as defined above. For a firm, all states are mutually excluding. In case there is more than one firm in a country, i.e. $n_i > 1$, the incumbency in market A and B may be occupied by different firms of country i. Hence, a society may be in five different states:

- y^{B_1}: one firm is the incumbent in both markets and the $(n_i - 1)$ remaining firms are challengers;
- y^{B_2}: one of the firms in country i is the incumbent in market A, another country i–firm holds the monopoly position in country B and $(n_i - 2)$ firms are challengers;
- y^S: one firm is the incumbent in the high quality market and $(n_i - 1)$ firms are challengers;
- y^W: one firm holds the monopoly position in the low quality market and $(n_i - 1)$ firms are challengers;
- y^N: all n_i firms are challengers.

2.5 The firms' profits and the society's welfare

Due to the assumptions on the consumers preferences and the market structure, the incumbent in market i is able to appropriate the entire consumers' surplus. Consequently, instantaneous welfare is solely determined by firms' profits. Clearly, a firm's expected earnings prospects depend on the firm's position in the current patent race. Let c denote the fixed research expenses per period. The function $\bar{\pi}^d(u, s_A, s_B)$ is the flow profit net of investment costs a firm in position z^d, $d = B, S, W, C$ can expect to earn. The function $\pi^d(u, s_A, s_B, c) := \bar{\pi}^d(\cdot) - c$ is the corresponding gross flow profit. To facilitate notation, $\pi^d(u, s_A, s_B, c)$ is abbreviated by π^d henceforth. In addition, let ϕ and ρ be defined as $\psi := \max\{s_A, s_B\}$ and $\rho := \min\{s_A, s_B\}$. Obviously, the countries set a uniform NOS if $\psi = \rho$.

First, consider the position z^N. A firm in this position is a challenger in both markets. Due to patent protection, the firm cannot offer a product incorporating the latest technology so that it receives no positive revenues. Hence, a challengers' profit is given by

$$\pi^N = \pi^C = -c, \quad \text{for } \psi \geq \rho. \tag{1}$$

Next, take the example of position z^B. The firm has made a large invention and occupies the monopoly position in both countries. It charges a price equal to the invention's improvement over the previous one. The expected price conditional on the invention being a large one, i.e. $u_k \geq \psi$ is given by $\int_\psi^{\bar{u}} u_k f[u_k] \mathrm{d}u_k / (1 - F[\psi])$. Since the range of the improvement size is stationary over all patent races and the firms face a unit demand in both countries, the expected instantaneous profit reads

$$\pi^B = \pi^I = 2 \int_\psi^{\bar{u}} u_k \frac{f[u_k]}{1 - F[\psi]} \mathrm{d}u_k - c, \quad \text{for } \psi \geq \rho. \tag{2}$$

Now turn to position z^W indicating that the firm holds the monopoly position in the country imposing the weaker NOS. Thus, the firms has made a small invention that does not qualify for a patent in the country applying the stricter NOS. Then, the expected price conditional on the invention being small is $\int_\rho^\psi u_k f[u_k] \mathrm{d}u_k / (F[\psi] - F[\rho])$. In case the NOSs are identical in both countries, i.e. when $\psi = \rho$, any invention meeting the NOS implies that the inventor starts the next patent race as the incumbent in both countries. Hence, the expected instantaneous profits are determined with

$$\pi^W = \begin{cases} \displaystyle\int_\rho^\psi u_k \frac{f[u_k]}{F[\psi] - F[\rho]} \mathrm{d}u_k - c & \text{for } \psi > \rho, \\ \displaystyle 2\int_\psi^{\bar{u}} u_k \frac{f[u_k]}{1 - F[\psi]} \mathrm{d}u_k - c & \text{for } \psi = \rho. \end{cases} \tag{3}$$

Finally, consider a firm in position z^S. Here, the firm is the sole supplier in the market imposing the stricter NOS, but a challenger in the one applying the weaker NOS. Consequently, the expected price charged by the firm can be written as $\int_\psi^{\bar{u}} u_k f[u_k] \mathrm{d}u_k / (1 - F[\psi])$. In case the countries choose a uniform NOS, i.e. if $\psi = \rho$, the firm finds itself in the position of a challenger since its invention becomes either obsolete in both countries or in neither of the two. Thus, the expected profit ensues with

$$\pi^S = \begin{cases} \displaystyle\int_{\psi}^{\bar{u}} u_k \frac{f[u_k]}{1-F[\psi]} \mathrm{d}u_k - c & \text{for } \psi > \rho, \\ -c & \text{for } \psi = \rho. \end{cases} \tag{4}$$

From the definition of the expected profits in (1)–(4), certain relations among the profit functions can be derived:

Lemma 1. *The following conditions can directly be verified from the functions in (1)–(4):*

(1) If $\psi = \rho$, then

$$\pi^B = \pi^W = \pi^I, \quad \pi^N = \pi^S = \pi^C \quad \textit{and} \quad \pi^B > \pi^C.$$

(2) If $\psi > \rho$, then

$$\pi^B > \pi^S > \pi^W > \pi^N, \quad \pi^I > \pi^W.$$

For illustrative purpose, take the foreign country B's point of view according to which the foreign NOS s_A is given. The first result verifies that markets become indistinguishable when the home country applies the same NOS as the foreign country. Consequently, z^B and z^W as well as z^S and z^C collapse.

The second result applies when the domestic NOS differs from the foreign one. It states that the expected profits from being an incumbent in both markets is always higher than the expected earnings received from only one market. In addition, being the monopolist in the market with the stricter NOS yields a larger expected profit than the same position in the market with the weaker NOS. Finally, being an incumbent in either market is more profitable than being a challenger in both markets.

The results are a consequence of the assumptions concerning the consumers' preferences and the Bertrand competition. In absence of demand effects due to price variations, there is always a positive relationship between the expected price and the expected profit. Since products incorporating larger inventions can be sold at higher prices, profits earned in the country enforcing the stricter NOS are on average larger than the ones received in the other country.

It is worth noting that, while the functions π^B and π^C are continuous, the functions π^S and π^W are not. Both functions have a discontinuity at $\psi = \rho$.

As usual, a country's welfare comprises the consumers' and the firms' surplus. Due to the specific demand and market structure presumed here, the incumbent is always able to appropriate the entire consumers' surplus. Thus, a country's instantaneous welfare just equals the sum of the domestic firms' profits:

$$\begin{aligned}
\omega_i^{B_1} &= \pi^B + (n_i - 1)\pi^N, \\
\omega_i^{B_2} &= \pi^L + \pi^S + (n_i - 2)\pi^N, \\
\omega_i^{L} &= \pi^L + (n_i - 1)\pi^N, \\
\omega_i^{S} &= \pi^S + (n_i - 1)\pi^N, \\
\omega_i^{N} &= n_i \pi^N,
\end{aligned} \tag{5}$$

where ω_i^d is short for $\omega_i(y^d)$.

Again, the familiar pattern can be found for the instantaneous welfare:

Lemma 2. *By the definition of a country's state and the profit functions (1)–(4), it immediately follows that:*

(1) if $\psi = \rho$

$$\omega_i^{B_1} = \omega_i^{B_2} = \omega_i^{W} = \omega_i^{I}, \quad \omega_i^{N} = \omega_i^{S} = \omega_i^{C}, \quad \omega_i^{I} > \omega_i^{C}.$$

(2) If $\psi = \rho$

$$\omega_i^{B_1} > \omega_i^{B_2} > \omega_i^{S} > \omega_i^{W} > \omega_i^{N}, \quad \omega_i^{I} > \omega_i^{I}.$$

The Lemma verifies that the situation of a uniform NOS across countries is a special case of a situation of internationally diverging NOSs. Now consider the case of internationally differentiated NOSs. The Lemma verifies that a country's welfare increases with the number of incumbencies hold by its firms. In addition, a country is better off when domestic firms have achieved large rather than small inventions.

Note also that states y^{B_1}, y^{B_2} and y^N necessarily involve cross–border profit flows which are directed either inwards (y^{B_1} or y^{B_2}) or outwards (y^N). In contrast, in positions y^S and y^W, cross–country profits flows can only be observed if domestic firms hold the monopoly position in the foreign market. In those situations, inflows and outflows of profits occur simultaneously, where the country those firm is the incumbent in the market imposing the stricter NOS experiences net inflows.

2.6 The social value functions

In an ex–post situation, a country's discounted expected welfare stream depends on its position during the current patent race. Let W_i^d denote the social welfare function. Then, they have to satisfy the following system of equations:

$$
\begin{aligned}
rW_i^{B_1} =& \omega_i^{B_1} + \mathfrak{h}_i^l \theta_\psi (W_i^N - W_i^{B_1}) + \mathfrak{h}_i^w \Delta\theta (W_i^{B_2} - W_i^{B_1}), \\
rW_i^{B_2} =& \omega_i^{B_2} + \mathfrak{h}_i^l [\theta_\psi (W_i^N - W_i^{B_2}) + \Delta\theta (W_i^S - W_i^{B_2})] \\
& + \mathfrak{h}_i^w \theta_\psi (W_i^{B_1} - W_i^{B_2}), \\
rW_i^S =& \omega_i^L + \mathfrak{h}_i^l \theta_\psi (W_i^N - W_i^S) \\
& + \mathfrak{h}_i^w [\theta_\psi (W_i^{B_1} - W_i^S) + \Delta\theta (W_i^{B_2} - W_i^S)], \\
rW_i^W =& \omega_i^S + \mathfrak{h}_i^l \theta_\rho (W_i^N - W_i^W) + \mathfrak{h}_i^w \theta_\psi (W_i^{B_1} - W_i^W), \\
rW_i^N =& \omega_i^N + \mathfrak{h}_i^w [\theta_\psi (W_i^{B_1} - W_i^N) + \Delta\theta (W_i^W - W_i^N)].
\end{aligned}
\tag{6}
$$

Here, the hazard rates are $\mathfrak{h}_i^w$ and $\mathfrak{h}_i^l$ are defined by $\mathfrak{h}_i^w := n_i\lambda_i$ and $\mathfrak{h}_i^l := n_j\lambda_j$ respectively. Note that $\mathfrak{h}_i^w = \mathfrak{h}_j^l$ and $\mathfrak{h}_i^l = \mathfrak{h}_j^w$.

Explicit expressions of the social continuation values are obtained by solving the above system. In order to express the social welfare functions in an convenient way, additional variables are introduced. Let $\phi_{\rho\psi}$ be $\phi_{\rho\psi} := r + \theta_\psi \mathfrak{h}_i^l + \theta_\rho \mathfrak{h}_i^w$. The function $\bar{W}_i$ denotes the 'core' value of the social welfare functions and is defined as $\bar{W}_i := [\theta_\psi\{\mathfrak{h}_i^w W_i^{B_1} + \mathfrak{h}_i^l W_i^N\} + \Delta\theta\{\mathfrak{h}_i^w W_i^W + \mathfrak{h}_i^l W_i^N\}]/\phi_\rho$. This core value $\bar{W}_i$ is the society's equivalent to firms' core value and measures the social welfare of a patentable invention. The social core value can be expressed as:

$$
\begin{aligned}
\bar{W}_i = \frac{1}{r\phi_\psi\phi_\rho\phi_{\rho\psi}} \big[& \phi_{\rho\psi}\{\theta_\psi \mathfrak{h}_i^w (\omega_i^{B_1} - \omega_i^S) + \theta_\rho \phi_\rho (\mathfrak{h}_i^w \omega_i^S + \mathfrak{h}_i^l \omega_i^N\} \\
& + \Delta\theta\theta_\psi \mathfrak{h}_i^w \{\theta_{\rho\psi} \mathfrak{h}_i^w (\omega_i^{B_2} - \omega_i^S) + \phi_\psi \mathfrak{h}_i^l (\omega_i^S - \omega_i^N) \\
& + \Delta\theta \mathfrak{h}_i^l \mathfrak{h}_i^w (\omega_i^L - \omega_i^N)\}\big] .
\end{aligned}
\tag{7}
$$

Then, the social welfare functions satisfying system (6) are given by:

$$
\begin{aligned}
W_i^d =& \bar{W}_i + w_i^d, \quad d \in \{B_1, B_2, L, S, N\}, \\
w_i^{B_1} =& \frac{\omega_i^{B_1}}{\phi_\rho} + \frac{\Delta\theta}{\phi_\psi\phi_\rho\phi_{\rho\psi}} [\mathfrak{h}_i^l \phi_\rho (\omega_i^{B_1} - \omega_i^S) + \mathfrak{h}_i^w \phi_{\rho\psi} (\omega_i^{B_2} - \omega_i^N) \\
& + \Delta\theta \mathfrak{h}_i^l \mathfrak{h}_i^w (\omega_i^L - \omega_i^N)] \\
w_i^{B_2} =& \frac{\omega_i^{B_2}}{\phi_\rho} + \frac{\Delta\theta}{\phi_\psi\phi_\rho} [\mathfrak{h}_i^w (\omega_i^{B_2} - \omega_i^S) + \mathfrak{h}_i^l (\omega_i^L - \omega_i^N)] \\
W_i^S =& \frac{\omega_i^L}{\phi_\rho} + \frac{\Delta\theta}{\phi_\psi\phi_\rho} [\mathfrak{h}_i^w (\omega_i^{B_2} - \omega_i^S) + \mathfrak{h}_i^l (\omega_i^L - \omega_i^N)] \\
W_i^W =& \frac{\omega_i^S}{\phi_\rho}, \\
w_i^N =& \frac{\omega_i^N}{\phi_\rho}.
\end{aligned}
\tag{8}
$$

The structural similarity of the social continuation values to the firms' value functions are obvious: The society's social welfare consists of the state–independent core value $\bar{W}_i$

measuring the value of a patentable invention and the position–specific parts. The latter comprise the welfare accumulated during the current patent race, i.e. the first term of w_i^d, and the part of the social welfare that can only be accrued if the NOSs differ across countries, i.e. the second term of $w_i^{B_1}$, $w_i^{B_2}$ and W_i^S.

Again, the corresponding welfare functions for a uniform NOS are derived as the special case of $\psi = \rho$ which is confirmed by the following result:

Lemma 3. *The social continuation values have the same properties as the instantaneous welfare functions, i.e.*

(1) if $\psi = \rho$

$$W_i^{B_1} = W_i^{B_2} = W_i^W = W_i^I, \quad W_i^N = W_i^S = W_i^C, \quad W_i^I > W_i^C.$$

(2) If $\psi > \rho$

$$W_i^{B_1} > W_i^{B_2} > W_i^S > W_i^W > W_i^N, \quad W_i^I > W_i^W.$$

The policymakers objective function in determining the NOS, however, is the ex–ante social welfare function. Given the definitions of a country's position in an ongoing patent race, it can be defined as $W_i^0 := \mathfrak{h}i^w\{\phi_\psi W_i^{B_1} + \Delta\theta W_i^W + (1-\phi_\rho)W_i^N\} + \mathfrak{h}_i^l W_i^N$. Using the core value, the ex–ante social welfare function can be simplified to:

$$W_i^0 = \phi_\rho \bar{W}_i + (1-\theta_\rho)(\mathfrak{h}_i^l + \mathfrak{h}_i^w)W_i^N. \tag{9}$$

3 Unilateral decision

In this section, the home country's decision on the optimal level of the NOS is studied where the foreign country's NOS is exogeneously given.

Due to the stochastic nature of the innovation process, countries switch between different positions after the first patent race has taken place just as firms do; and the countries will experience position–specific welfare streams. In general, the policymakers' decision can separately be examined for the ex–post and the ex–ante situation. However, as the countries continuously move between different positions in an ex–post situation, the optimal choice would be time inconsistent (cf. Weiss, 2005b): the policymaker would like to change the optimal NOS whenever the country's position changes. Clearly, such behaviour does not establish an economic framework in which private firms may reliably undertake research efforts. Consequently, it is assumed that governments of both countries are far–sighted and base their decisions on the ex–ante welfare function.

A government may unilaterally set the NOS, e.g. because it extended the patentable subject matters and some NOS has to be imposed or because domestic firms improved their research abilities so that an adjustment is desirable. In in either case, the foreign country's NOS s_j is regarded to be exogenously given. Then, the domestic policymaker's decision problem consists in setting a NOS s_i so that the ex–ante social welfare function

W_i^0 is maximised. As it can be seen from equation (9) the ex–ante welfare function consists of two parts: (a) where $s_i \in [s_j, \bar{u}]$ and (b) where $s_i \in [0, s_j)$.

Lemma 4. *Concerning the properties of the ex–ante welfare function, we find:*

(1) For $\mathfrak{h}_i^w = n_i = 0$, W_i^0 *equals zero.*

(2) For $\mathfrak{h}_i^w, \mathfrak{h}_i^l > 0$, W_i^0 *is continuous at* $s_i = s_j$.

(3) For $\mathfrak{h}_i^w, \mathfrak{h}_i^l > 0$, W_i^0 *has decreasing differences at* $s_i = s_j$.

A situation as described in Lemma 4.1 resembles that of a developing country: firms have no research ability, i.e. $\lambda_i = 0$ and, consequently, there are no firms that could participate in global patent races, i.e. $n_i = 0$.[9] The Lemma asserts that, in absence of the chance that a domestic firm wins a future patent race, a developing country is indifferent towards a patent system. The consumers' surplus generated by the introduction of new products or processes is completely appropriated by the foreign inventors. As a consequence, a developing country is also indifferent as to the NOS it shall introduce.[10]

Proposition 1. *If a country unilaterally decides on the optimal NOS, an equilibrium is ensured:*

(1) If $\mathfrak{h}_i^w = n_i = 0$, *any NOS in the range of* $[0, \bar{u}]$ *is optimal.*

(2) If $\mathfrak{h}_i^w > 0$ *there exists a unique* $s_i^* \in [0, \bar{u}]$ *that maximises equation (9) for any* $s_j \in [0, \bar{u}]$.

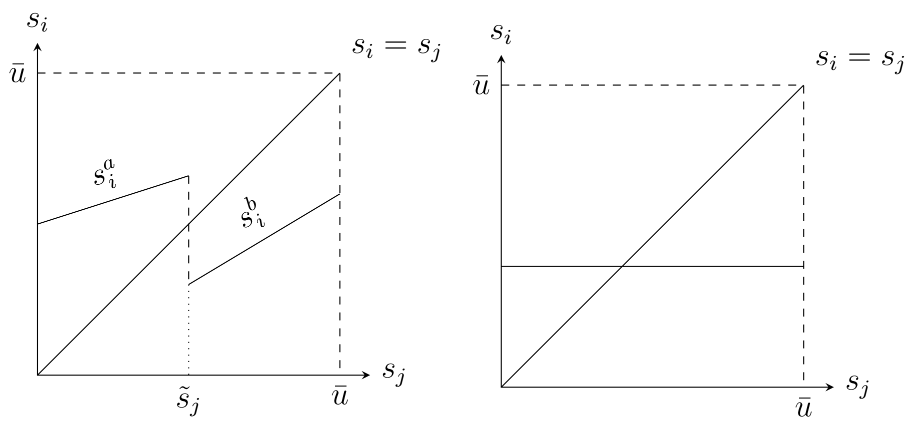
Concerning the properties of the optimal NOS, the following can be discerned:

Proposition 2. *For* $\mathfrak{h}_i^w > 0$, *Figure 3 shows the optimal NOS as a function of the foreign NOS* s_j.

A direct consequence of the Proposition is that choosing the foreign NOS will never be an optimal policy for the domestic (industrialised) country, no matter how similar or dissimilar both countries are. To understand the rationale behind the tendency for towards differentiation, it is important to notice both the level of the instantaneous profits and the duration (effective patent term) over which they can be earned that society's welfare depends on the domestic firm's determine society's welfare. Increasing the level of instantaneous profits can be achieved by raising the domestic NOS. Since larger inventions occur less frequently, this policy also prolongs the effective patent term. With global

9 Clearly, countries such as China or India do not belong into this category any longer. Rather, one may picture the poorest countries as specimen of this case. However, keeping the TRIPs Agreement in mind which binds a signatory state to minimum standards of IPRs protection, this special case is not without interest.

10 This does, however, not imply that a patent system is neutral from an overall perspective. If foreign firms permanently monopolise the developing country's market, there is a continuous outflow of profits that affects the country's current account and, thus, the country's economic development.



(a) $\mathfrak{h}_i^l > 0$ (b) $\mathfrak{h}_i^l = 0$

Figure 3: The optimal NOS for the domestic country

patent races and national patent policy, however, patent policy instruments are a two–edged knife as long as both countries have research abilities. Then, a stronger domestic NOS has positive effects on domestic *as well as* foreign welfare.

While the foreign NOS s_j is small, larger inventions are still frequently enough so that choosing a higher domestic NOS pays, i.e. the positive effects on the domestic welfare dominate. When s_j becomes large, setting a still larger domestic NOS implies that eligible inventions become rare. Although this policy increases the instantaneous profits as well as the effective patent term and, therefore, may still be optimal for national patent races, it has a severe disadvantage too: it prolongs the average time until a domestic firm makes a eligible invention when the market is currently monopolised by a foreign firm. Hence, cross–border profit flows directed abroad are higher *and* occur longer. Consequently, as the foreign NOS increases, the domestic country is more and more reluctant to set a higher domestic NOS until the disadvantage of raising foreign welfare along with the domestic one dominates.

Weiss (2005b) establishes a positive relationship between the research efficiency and the number of firms on the one hand and the NOS on the other hand. For the international framework considered here, a comparable result cannot be obtained. Yet, the reverse result cannot be proved either. Thus, the domestic NOS might still be an increasing function of the domestic hazard rate $\mathfrak{h}_i^w$, i.e. the domestic research efficiency and the domestic number of firms, for certain or even all parameter values.

The reason for the potential breakdown of the intuitive result that a larger domestic hazard rate calls for a stronger domestic NOS lies also in the incongruity of national patent laws and global patent races. To see this, it is expedient to elaborate on the rational of this result. Whenever the society's hazard rate increases either because the firms are more productive in generating inventions or because there are more firms participating in the patent races, the pace of the patent races accelerates. As a consequence, the expected time during which inventors are able to collect their reward becomes shorter and the expected return on investment shrinks. This is true for all inventions, i.e. for small and large ones. Although society does not care about the identity of the current incumbent, firms' profits are part of the social welfare. Hence, society as a whole is affected if a small inventions renders a large one irrelevant. Therefore, society is better–off by counterbalancing the acceleration of patent races by increasing the NOS to guarantee a minimum reward for large contributions.

This rationale still holds true in an international setting which explains why the findings of Weiss (2005b) cannot disproved for the international framework. However, since firms in country i are exclusively owned by citizens of this country, a higher NOS not only protects larger inventions achieved by domestic firms but also those generated by foreign ones. Yet, foreign firms' profits do not contribute to domestic welfare. By strengthening the domestic NOS to counteract the effects of a higher domestic hazard rate, the drain of profits earned in the domestic market increases as well. This effect could only be neutralised if the cross–border profit flows into the domestic country increase by the same amount. Although the isolated increase of the domestic hazard rate also puts domestic firms in a better position than their foreign competitors abroad so that the inflows of profits will also rise, it is a chance event that inflows and outflows exactly balance. Therefore, it can at least be expected that the positive relationship between the domestic NOS and the domestic hazard rate is at least weaker as compared to a purely national framework.

4 Simultaneous choice

We now turn to situations in which both countries simultaneously choose their NOSs. Although Congress and to a certain degree the Supreme Court can effect larger changes in the NOS, they seldom do so. Surely, those rare events are best represented by a unilateral decision on the NOS. Patent law is, however, largely shaped by the numerous decisions on single cases. Hence, continual and sometimes hardly perceptible changes are made on a day–to–day basis. Those decisions are, perhaps, better represented by a simultaneous choice of the NOSs.

The result on the simultaneous choice of the NOSs immediately follow from Proposition 2 and in particular from Figure 3:

Proposition 3. *(1) For* $\mathfrak{h}_i^w > 0$, $\mathfrak{h}_j^w = n_j = 0$, *a continuum of equilibria exist with* $s_i^* \in (0, \bar{u})$ *and* s_j^* *taking any value on* $[0, \bar{u}]$.

(2) For $\mathfrak{h}_i^w, \mathfrak{h}_j^w > 0$, *existence and uniqueness of a pure strategy equilibrium is not ensured.*

Again, the first case refers to a situation where country i is an industrialised country while country j is a developing one with no research abilities. The findings merely confirm the previous results derived on a unilateral decision that the developing country is indifferent concerning the domestic NOS.

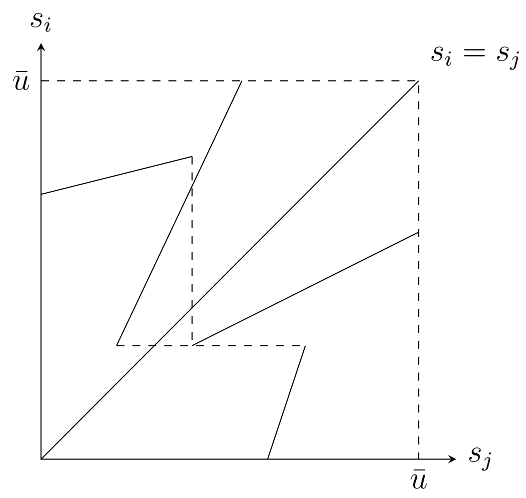


Figure 4: Non–existence of a pure strategy equilibrium

Unfortunately, the fact that the ex–ante welfare function has decreasing differences at the point $s_i = s_j$ leads to the second result, i.e. that for some parameter constellations a pure strategy equilibrium need not exist. Figure 4 pictures one situation in which a pure strategy equilibrium fails to exist. Although a mixed strategy equilibrium will exist even under those parameter constellations, it comes with the usual entail: mixed strategy equilibria do not possess a neat interpretation.[11] In addition, since the effect of the society's hazard rates on the policymaker's decision is ambiguous, it seems that one cannot verify the intuitive notion that the country having the larger hazard rate of winning future patent races also tends to set the stronger NOS.

The complexity of the model does leave us, however, not quite destitute. Consider the special case of an industrialised (home) country i and a developing (foreign) country j which however, has some small research ability, i.e. $n_j > 0$ and $\mathfrak{h}_j^w = \mathfrak{h}_i^l$ is small but positive. Then, we find:

Proposition 4. *If* $\mathfrak{h}_i^w > \mathfrak{h}_j^w$ *with* $\mathfrak{h}_j^w$ *small but positive, a unique equilibrium exists with* $s_i^* > s_j^* > 0$. *Figure 5 illustrates the situation.*

The proposition asserts that a unique equilibrium exists if there are huge differences in the development level of the countries. In addition, the Proposition and especially Figure 5 show that the country those firms are more productive in generating inventions will set the stronger NOS.

[11] There are several alternative interpretations of mixed strategy equilibria: (1) The latter can be understood as the average outcome of a series of identical decision problems. (2) A player's may be uncertain about how his adversary will decide or how rational the opponent is. (3) Equilibria in Bayesian games with incomplete information approach mixed strategy equilibria (Fudenberg and Tirole, 1993, pp. 230). The latter alternative gives a convincing reinterpretation of mixed strategy equilibria.

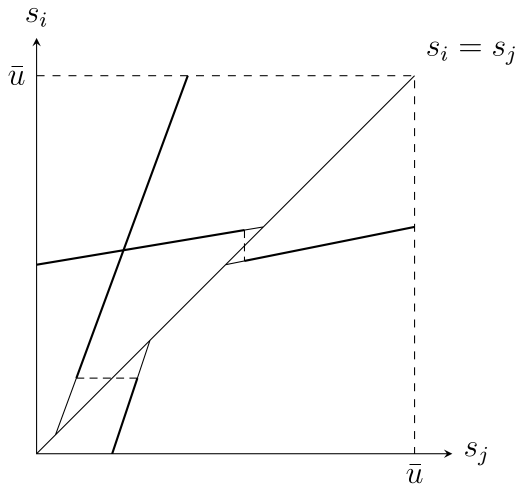


Figure 5: The optimal NOS for a developed and a developing country

5 Policy implications

The previous analysis yielded some interesting points that allow suggestions towards international negotiations on IPRs. Firstly, it has been demonstrated that transition countries will set lower NOSs as compared to industrialised countries. Probably, they will find it optimal to raise the NOS as their research abilities grow.

Secondly, the poorest countries are indifferent to a patent system or the level of the NOS. However, as the present analysis is a partial one, important pros and cons have been neglected. In case those countries do establish a patent system, they should be allowed a considerable discretion.

Lastly, it has been demonstrated that policymakers' of identical countries will generally not find it optimal to choose the same NOS. Hence, in an increasingly globalised world, international aspects have to be considered when shaping national policy.

The fact that even identical countries will differentiate NOSs may seem unconvincing at the first glance, especially because cross–border profit flows are on average balanced in case of a uniform NOS. However, this leaves the important positive merits of differentiated NOSs out of account: Since larger inventions occur less frequently, the country setting the stronger NOS shelters larger inventions against being rendered irrelevant by medium–sized inventions without denying protection for the latter altogether. On the other hand, the country setting the weaker NOS ensures that medium–sized inventions receive protection, but denying patents for trivial, small inventions. Accordingly, an international differentiation of NOSs ensures that large inventions receive higher rewards than medium–sized ones; and small inventions get no reward. As long as both countries have a strictly positive hazard rate that one of the domestic firms may generate a (large) invention, this arrangement works to the benefit of both countries.

From an overall perspective, however, it might be suspected that this international differentiation of NOSs is too low since countries are negatively affected by the outflow of profits earned by foreign firms. A first–best solution could only be achieved if there was an international compensation system that recognises the positive externality of setting a higher NOS. Although conceivable from a theoretic point of view, it would be impossible to try a practical application. First and foremost, the uncertainty of the value of an invention deprives us from the sole basis on which such a system could possibly work. Secondly, even though the information were readily available the administration of such a system would be rather costly. In absence of the means to implement the first–best solution, at least there should not be undertaken any steps of harmonising the NOSs: the flexibility of the system is also its strength.

Appendix: Proofs to the Lemmata and Propositions

Lemma 4. **Part 1**: It is easy to see that the core value $\bar{W}_i$ as well as W_i^N become zero when $\mathfrak{h}_i^w = n_i = 0$.

Part 2: Evaluating the parts of the ex–ante welfare function at the point $s_i = s_j$ shows that both parts approach the value

$$\frac{1}{r}\left[\frac{2\mathfrak{h}_i^w\theta(r+\mathfrak{h}_i^w+\mathfrak{h}_i^w)}{\phi}\bar{\pi}^L - c(\mathfrak{h}_i^w+\mathfrak{h}_i^l n_i)\right]$$

so that the ex–ante welfare function must be continuous at that point.

Part 3: A function has decreasing differences if $\partial W_i^0(s_i, s_j'')/\partial s_i - \partial W_i^0(s_i, s_j')/\partial s_i < 0$ with $s_j' < s_j''$. Since

$$\lim_{\mu\longrightarrow 0}\frac{\partial W_i^0(s_i, s_i+\mu)}{\partial s_i} - \frac{\partial W_i^0(s_i, s_i-\mu)}{\partial s_i} = -\frac{2f[s_i]\mathfrak{h}_i^l\mathfrak{h}_i^w(r+\mathfrak{h}_i^l+\mathfrak{h}_i^w)\theta_i\bar{\pi}^L}{\phi_i^2} < 0,$$

the welfare function W_i^0 has decreasing differences across the point where $s_i = s_j$. □

Proposition 1. **Part 1**: This is a direct consequence of Lemma 4.

Part 2:

Case a: $s_i \geq s_j$. The FOC can be written as:

$$G_a(s_i) := \bar{\pi}^L\theta_i\left(\frac{\mathfrak{h}_i^l+\mathfrak{h}_i^w}{\phi_i^2}+\frac{\mathfrak{h}_i^l}{\phi_{ij}^2}\right) - s_i\left(\frac{1}{\phi_i}+\frac{1}{\phi_{ij}}-\frac{1}{\phi_j}\right) = 0,$$

where $\bar{\pi}^L$ stands for $\int_{s_i}^{\bar{u}} uf[u]\mathrm{d}u/\theta_i$. Obviously, $G_a(\bar{u}_i)$ is negative. On the other hand, $G_a(s_j)$ is positive for small values of s_j, i.e. $s_j \leq \overline{s}_j$ with

$$\overline{s}_j := \{s_j \in [0, \bar{u}] : G_a(s_j) = (2\mathfrak{h}_i^l + \mathfrak{h}_i^w)\theta_j\bar{\pi}^L - s_j\phi_j = 0\}.$$

Since $G_a(s_i)$ is a declining function of s_i, there exists an optimal NOS solving $G_a(s_i) = 0$ for $s_j \in [0, \overline{s}_j]$.

Case b: The FOC can be written as:

$$G_b(s_i) := \Delta\theta(\mathfrak{h}_i^l + \mathfrak{h}_i^w)\bar{\pi}^L + \frac{\phi_i^2}{\phi_{ij}^2}\theta_j \mathfrak{h}_i^w \bar{\pi}^L - s_i\phi_i = 0.$$

Evidently, $G_b(0)$ is positive while $G_b(s_j)$ is negative for $s_j \leq \underline{s}_j$ with

$$\underline{s}_j := \{s_j \in [0, \bar{u}] : G_b(s_j) = \theta_j \mathfrak{h}_i^l \bar{\pi}^L - s_j\phi_j = 0\}.$$

Again, an equilibrium exists as long as $s_j \in [\underline{s}_j, \bar{u}]$.

It is easy to verify that $\underline{s}_j < \overline{s}_j$ so that each of the cases a and b produces one candidate equilibrium in this interval. Denote the equilibrium for case a by s_i^a; and the one for case b by s_i^b. Let $\tilde{s}_j$ be defined as

$$\tilde{s}_j := \{s_j \in [0, \bar{u}] : W_i^0(s_i^a, s_j) = W_i^0(s_i^b, s_j)\}.$$

Then, the equilibrium NOS is given by:

$$s_i^* := \begin{cases} s_i^a & \text{for } s_j \in [0, \tilde{s}_j] \\ s_i^b & \text{for } s_j \in (\tilde{s}_j, \bar{u}]. \end{cases}$$

□

Proposition 2. The proof proceeds in 3 steps: (1) it is demonstrated that $s_i^*(s_j)$ is an increasing function of s_j for the cases (2) $s_i^*(s_j) \geq s_j$ and (2) $s_i^*(s_j) \leq s_j$; (3) it is verified that $s_i^a(\tilde{s}_j) > \tilde{s}_j$ and $s_i^b(\tilde{s}_j) < \tilde{s}_j$.

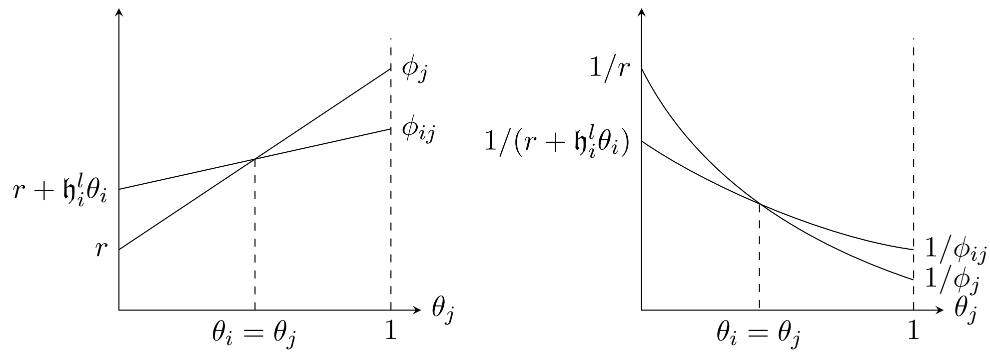
Part 1: Consider the case $s_i^* > s_j$. The sign of $\mathrm{d}s_i^*/\mathrm{d}s_j$ is identical to the sign of $\partial G_a(s_i, s_j)/\partial s_j$. The latter is determined by

$$\frac{\partial G_a(\cdot)}{\partial s_j} = f[s_j]\left[2\bar{\pi}^L\theta_i \frac{\mathfrak{h}_i^l \mathfrak{h}_i^w}{\phi_j^2} + s_i\left(\frac{\mathfrak{h}_i^l + \mathfrak{h}_i^w}{\phi_j^2} - \frac{\mathfrak{h}_i^w}{\phi_{ij}^2}\right)\right]. \tag{10}$$

To verify that the second summand within the bracket term is positive, Figure 6 and the notion that it is the derivative of $s_i(1/\phi_j - 1/\phi_{ij})$ with respect to s_j is useful.

For any given θ_i, functions ϕ_j and ϕ_{ij} are linear in θ_j as illustrated in Figure 6(a). Both functions intersect at $\theta_i = \theta_j$; and only values of θ_j to the right of the intersection point are relevant for case 2. Consequently, the functions $1/\phi_j$ and $1/\phi_{ij}$ necessarily have the functional forms as indicated in Figure 6(b). It is easy to see that the $|\partial\phi_j^{-1}/\partial\theta_j| > |\partial\phi_{ij}^{-1}/\partial\theta_j|$. Keeping in mind that $\mathrm{d}\theta_j/\mathrm{d}s_j < 0$, it follows that the derivative of $s_i(1/\phi_j - 1/\phi_{ij})$ with respect to s_j is positive. Although the optimal NOS s_i will change in response to variations in the foreign NOS s_j, the functional forms remain identical so that the sign of the derivative does not change. Hence, the first and the second summand of the bracket term in equation (10) are positive and the optimal NOS is and increasing function of the foreign NOS for the case of $s_i \geq s_j$.

Part 2: follows analogous steps.



(a) (b)

Figure 6: The functional form of ϕ

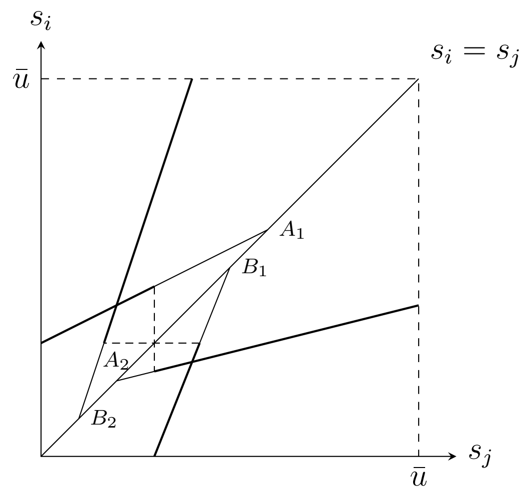


Figure 7: NOSs for an industrialised and developing country

Part 3: Let $\underline{s}_j$ and $\overline{s}_j$ be defined as in the proof to Proposition 1. According to Lemma 4.3, W_i^0 has decreasing differences across the point $s_i = s_j$ so that $s_i^a(s_j) > s_i^b(s_j)$ for all $s_j \in [\underline{s}_j, \overline{s}_j]$. Another consequence of Lemma 4.3 is that the jump point $\tilde{s}_j$ cannot attain the boundary values of $\underline{s}_j$ and $\overline{s}_j$ and the result immediately follows. □

Proposition 3. To prove the claim, it is demonstrated that point A_1 moves down while A_2 moves up, B_2 approaches zero and B_1 moves below A_2 as $\mathfrak{h}_j^w$ approaches zero in Figure 7.

Points A_1 and A_2 are defined by $\overline{s}_j := \{s_j \in [0, \bar{u}] : \overline{G}_j := \bar{\pi}^L\theta_j(2\mathfrak{h}_i^l + \mathfrak{h}_i^W) - s_j\phi_j = 0\}$ and $\underline{s}_j := \{s_j \in [0, \bar{u}] : \underline{G}_i := \bar{\pi}^L\theta_j\mathfrak{h}_i^w - s_j\phi_j = 0\}$ respectively. By symmetry, B_1 and B_2 are defined by $\overline{s}_i := \{s_i \in [0, \bar{u}] : \overline{G}_i := \bar{\pi}^L\theta_i(2\mathfrak{h}_j^l + \mathfrak{h}_j^W) - s_i\phi_i = 0\}$ and $\underline{s}_i := \{s_i \in [0, \bar{u}] : \underline{G}_i := \bar{\pi}^L\theta_i\mathfrak{h}_j^w - s_i\phi_i = 0\}$. It can easily be verified that

$$\frac{\partial \overline{G}_j}{\partial \mathfrak{h}_j^w} = 2\theta_j(\bar{\pi}^L - s_j) > 0, \frac{\partial \underline{G}_j}{\partial \mathfrak{h}_j^w} = -s_j\theta_j < 0, \frac{\partial \overline{G}_i}{\partial \mathfrak{h}_j^w} = \frac{\partial \underline{G}_i}{\mathfrak{h}_j^w} = \theta(\bar{\pi}^L - s_j) > 0$$

$$\text{so that} \qquad \frac{\partial \overline{s}_j}{\partial \mathfrak{h}_j^w} > 0, \; \frac{\partial \underline{s}_j}{\partial \mathfrak{h}_j^w} < 0, \; \frac{\partial \overline{s}_i}{\partial \mathfrak{h}_j^w} = \frac{\partial \underline{s}_i}{\mathfrak{h}_j^w} > 0.$$

Consequently, as $\mathfrak{h}_j^w$ declines, the points move into the above specified directions. It remains to be demonstrated that B_2 approaches zero and that $\underline{s}_j > \overline{s}_i$ as $\mathfrak{h}_j^w$ becomes small. These fact immediately follow from the definition of $\underline{s}_i$ on the one hand and the definitions of $\underline{s}_j$ and $\overline{s}_i$ on the other hand. □

References

Davis, M. H. D. (1993): *Markov Models and Optimization*, vol. 49 of *Monographs on Statistics and Applied Probability*. Chapman & Hall, London.

Fudenberg, D. and J. Tirole (1993): *Game Theory*. MIT Press, Cambridge (MA).

Hunt, R. M. (1999): “Nonobviousness and the incentive to innovate: An economic analysis of intellectual property reform”. Working Paper No. 99-3, Federal Reserve Bank of Philadelphia.

Hunt, R. M. (2002): “Patentability, industry structure, and innovation”. Federal Reserve Bank of Philadelphia, Working Paper 01-13/R, Philadelphia.

Lee, T. and L. L. Wilde (1980): “Market structure and innovation: A reformulation”. *Quarterly Journal of Economics*, vol. 94, pp. 429–436.

Loury, G. C. (1979): “Market structure and innovation”. *Quarterly Journal of Economics*, vol. 93, pp. 395–410.

Merges, R. P. and J. F. Duffy (2002): *Patent Law and Policy: Cases and Materials*. 3 edn. LexisNexis, Newark.

Reinganum, J. F. (1992): “The timing of innovations: Research, development, and diffusion”. In: R. Schmalensee and R. D. Willig (eds.), “Handbook of Industrial Organization”, vol. 1, chap. 14. North–Holland, Amsterdam et al., pp. 849–908.

Ross, S. M. (1992): *Applied Probability Models with Optimization Applications*. Dover Publications, New York.

Weiss, P. (2004): “International harmonisation of patentable subject matters”. Mimeo.

Weiss, P. (2005a): “Do european computer–related patents increase welfare?” *Rivista di Politica Economia*, vol. XCV, pp. 7–16.

Weiss, P. (2005b): “The optimal non–obviousness standard”. Mimeo.

World Trade Organization (1994): “Uruguay Round Agreements, Annex 1C: Trade–Related Aspects of Intellectual Property Rights (TRIPs)”. URL `http://www.wto.org/english/docs_e/legal_e/27-trips_01_e.htm`.