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# Protection of Basic Research and R&D Incentives in an International Setting*

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We look at cumulative innovations and the protection of basic research which does not carry stand-alone commercial value in an international setting. Due to the complementarily of the innovations, we find that for some parameter range, technology leading countries do not always prefer the strongest protection standard. Similarly, technology lagging countries do not always prefer the weakest protection standard. Thus intellectual property rights may be an instrument to soften R&D competition in the development stage and may be used to coordinate R&D efforts. Our model suggests that there may be less disputes on intellectual property right standards among countries in industries characterised by sequential innovations.
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## 1. Introduction

We analyse countries' incentives to enforce intellectual property rights by considering a patent race model consisting of a research stage (R) and a development stage (D). To emphasise the problem of complementarity and insufficient appropriation, we assume that the R stage output is necessary for the D stage, but it does not carry any stand-alone commercial value. The strength of IPR protection is measured by the share of profit granted to the inventor which completes the R stage. We assume that there is spill-over of the research output, and firms can engage in D stage research as long as one firm has successfully completed R stage in the first period[1]. When IPR protection is weak, the R stage technology is easily imitated and the first inventor gets a small share of the profit. A high IPR standard makes imitation difficult, and the inventor which owns the R stage research output is rewarded with a large share of profit.

In this paper, we look at the IPR regime in the international setting with one inventor being foreign. Both symmetric countries and asymmetric countries are analysed. For asymmetric country analysis, we study the case that after the R stage, inventors' positions are asymmetric with one technology leader and one technology follower[2]. The analysis of asymmetric countries complements the literature on the North versus South debate on intellectual property rights. For symmetric countries, we look at the optimal IPR regime in the beginning of the R stage when the two countries have the same R&D capacity.

We argue that IPR protection may serve as a mechanism for international R&D coordination. With the research output in the R and D stages being complements, stronger IP protection may serve as the device to soften competition in the innovation market. One interesting feature of this model is that with IPR protection, the technology leader gets some share of the follower's profit if the latter completes the patent race. Therefore, the success of the rival does not necessarily harm the firm and depending on the parameter values, an inventor may wish to encourage or deter the rival's R&D investment.

For the asymmetric country case with

the focus on the D stage research incentives, our result indicates that it is not necessarily the case that the technology follower always wants the IPR protection level to be as week as possible. Stronger IPR protection can be used as an instrument to soften the D stage competition. In particular, for industries with high research costs and high probability of success in the D stage, the follower may prefer to grant more IPR protection and encourage the leader not to invest in the D stage. Therefore, for the North-South IPR protection debate, the South may benefit from strengthening IPR protection in innovations where its application is costly to implement but the likelihood of success is high.

On the other hand, setting a very strong IPR protection may not always be advantageous to the leader either. When the likelihood of discovery and the research cost in the D stage are small, the leader may wish to set a weaker IPR protection and encourage the follower to invest in the D stage to increase the chance of making a discovery. In these industries, developed countries may benefit by lowering the IPR standard.

When research incentives in both stages are taken into consideration, we show that for some parameter ranges, symmetric countries may choose asymmetric levels of IPR protection in equilibrium. Harmonisation of IPR protection across countries may not be welfare enhancing. In general, the optimal level of IPR protection for the basic research is higher if the R stage innovation is costly or if the probability of success is low, and the optimal protection is lower if the D stage innovation is costly or if the D stage discovery rate is low. In the global setting where countries can offer different IPR protection, the first mover's optimal IPR protection decreases in that of the second mover's. Firms invest in R&D in each stage simultaneously with focus on pure strategy equilibria. With sequential move, there is typically a first mover advantage. For most parameter ranges, the first mover sets a lower protection level compared with the second mover.

The layout of the paper is as follows. Section two presents a brief reviews of the related literature. Section three introduces the model set up. We then analyse the game starting with the D stage, followed by the analysis of the whole game starting from the beginning of the R stage. Finally, Section 6 concludes. Proofs of results and some selected simulation tables are presented in the appendix.

## 2. Related Literature

Our paper relates to several streams of literature. First, it looks at a nation's optimal protection for basic research and how the policy should be adjusted after taking into consideration of the global environment. This is related to the analysis on TRIPs. A few important issues in this literature include: if there is a coordination problem in setting IPR policies; if the policy can correct the externality generated by innovation; what the incentive compatible policy would be for the South; what the global welfare maximising policy would be; whether or not there is welfare gain by harmonising IPR protection among nations. Most papers in this literature employ a multi-sector trade model while we have a strategic patent race framework. The policy instrument that we study in this paper is the share of profit granted to the basic technology. This is the focus of sequential innovation literature and research joint venture (RJV) literature. But the focus of the literature consider a innovation problem within a country.

### 2.1 Trade related aspects of intellectual property rights (TRIPs)

The TRIPs agreements were included in

the GATT Uruguay Round negotiation with enforcement and dispute appeal mechanisms and specify the minimum standard for IPR protection for member countries. While most economists agree that liberalisation on trade and services is in general welfare enhancing for all member countries, the welfare effects of TRIPs is more controversial. See Maskus (2000) for a review of how national differences give rise to different IP policies and how IP policies affect trading relationships and foreign direct investment. The argument for strengthening IPR in developing countries is to correct for the externality created by the inventors in developed countries. Due to the asymmetry in R&D capacity, it is difficult to argue for a case when the South can generate enough dynamic gain to offset the static loss. This line of argument suggests that TRIPs represent welfare redistribution among countries, with developed countries, the USA in particular, being the main beneficiary. It is not always the case that global welfare increases after the IPR harmonisation.

In a two-country analysis, Deardorff (1992) shows that extending IPR protection raises welfare for the inventing country while the welfare to the other country may fall and it is never optimal to extend the patent protection to the entire world. Helpman (1993) uses a dynamic general equilibrium model and concludes that less developed countries (LCDs) necessarily lose from tighter IPRs while developed countries may gain or lose. When the rate of imitation is slow, a tightening of IPRs hurts both regions. When the rate of imitation is high, developed countries gain while LCDs lose from strengthening IPRs. These papers assume that only the North has the research capacity and do not consider the simultaneous choice of IPR protection levels by trading partners. Glass and Saggi (2002) showed that a strengthening of IPR protection in the South would reduce the rate of innovation. Lai (1998) finds that the effects of strengthening IPRs depend on the channels of technology transfer from the North to the South. Most studies at best reach ambiguous welfare conclusion for TRIPs.

Some papers argue that while developing countries lose in TRIPS agreements, they can be compensated in the accompanying trade liberalisation. Therefore, it is necessary to bundle the property right negotiation with trade negotiation. Lai and Qiu (2003) build a multi-sector North-South trade model where both regions have the capacity to conduct research and analyse international IPR protection. They conclude that the North has a higher protection standard than the South in the non-cooperative equilibrium and it is globally optimal to strengthen the protection standard in the South to the Northern level. To provide adequate participation incentive for South, they suggest that the North should liberalise its traditional goods market. Lai and Qiu (2004) look at the issue slightly differently and suggest that the North can use tariffs to supplement inadequate IPR protection. The conclusion is that trade liberalisation is more important in the South than in the North. Grossman and Lai (2003) modify Lai and Qiu (2003) to include resource constraint in the two sectors. They consider the world economy with ongoing innovation in two countries that are different in market size and innovative capacities. They show that in general the North would prefer a stronger IPR regime and harmonisation of patent policies is neither necessary nor sufficient for global efficiency. Furthermore, harmonisation of patent policies benefits the North and quite possibly harms the South.

More recently legal scholars have questioned validity of harmonization based on necessity of the system to be dependent on factors such as industrial structure and innovation policy, which are country specific both in the context of multilateral agreements such as TRIPS (Reichman and Dreyfuss (2007), Suzuki (2008a)) and as part of bilateral trade agreements (Suzuki (2008b)) which are becoming more common. There is also view that patents should be more technology specific (Burke and Lemeley (2002)), which does not bar international harmonization per se but questions harmonization.

Aoki and Prusa (1993) analyse the effects of national treatment and discriminatory IPR protection for foreign inventors. They conclude that discriminatory protection may not increase domestic R&D. They analyse the home market and do not consider the foreign government's reaction. Žigić (2000) uses a strategic trade policy framework and analyses a game in which the competition occurs in the North market. The South can choose the degree of IPRs protection while the North can choose the tariff level. He finds that since a tariff can be used as a compensation for weaker IPRs in the South, the optimal tariff is higher than in the simple duopoly model without innovation. The South does not innovate in his model and relaxing IPR protection increases welfare for the South if it remains active in the market[3]. Ishikawa (2007) and Horiuchi and Ishikawa (2009) consider the interplay between tariff setting and technology transfer. They concluded that an increase in tariff may foster technology transfer due to the usual tariff jumping effect. However, a decrease in tariff may also increase technology transfer for entry deterrence purpose. Ghosh and Ishikawa (mimeo) finds that the South may be willing to offer IPR protection while facing the trade off between Northern competition and FDI. Ishikawa and Houriuchi (forthcoming) looks at FDI in a vertically related industry.

Sato (2001) analyses a similar situation to what we consider. Two monopolistic firms in two countries, a technological leader and a technological late-comer, engage in R&D to produce similar products and compete in a third market. In the model, only the technology leader can engage in the basic research and the technology laggard imports the basic technology, Both firms then compete in R&D for the applied technology. Sato constructs the conditions under which the technology laggard without a comparative advantage in the applied technology can win the race. However, in the paper, firms can choose the level of technology spill-over as well as the level of cost sharing in the basic research stage, and the two variables are not correlated. Suzawa (2002) argues that with some dependence between these two variables, the paradox Sato presented would not emerge.

Poyago-Theotoky and Teerasuwannajak (forthcoming) also reach the conclusion that the country with higher research capacity does not always prefer perfect patent protection. Countries in their model differ in terms of research capacities. They do not look at strategic setting of protection levels between the countries and only analyse the polar cases of complete or zero research spillovers.

## 2. 2 RVJ and multi-stage R&D competition

In our model, the share of profit paid to the technology owner of the basic research impacts on firms' research incentives. It is similar to mechanisms used for profit sharing in RJVs. However, in a two country analysis, two countries do not have to agree upon a common share. We review some literature on RJVs and multi-stage R&D competition in this section.

Aghion and Tirole (1994) and Green and Scotchmer (1995) analyse multi-stage patent races with R&D knowledge-selling arrangements and study how the profit should be divided between two inventors. In their settings, each inventor is only capable of doing one stage of research. Therefore, the basic research owner does not face the trade-off of more competition in the D stage. Our model assumes that both inventors can conduct research in both stages.

Denicolo (2002) analyses the optimal degree of forward patent protection for the first invention. He shows that strong protection is less preferred if the first innovation is more valuable or if the likelihood of making a discovery is high. Intuitively, when the inventor can extract sufficient rent without patent protection, strong forward protection is not necessary. We also show that the optimal share granted to the first invention is larger when the R stage research is costly or the likelihood of success is low. However, two countries may select quite different levels of IPR protection in equilibrium. We show that there is first mover advantage when the patent race game features sequential move. Aoki and Nagaoka (2009) extend Denicolo's model and consider the patentability of the intermediate technology. In their paper, they consider trade secrecy as an alternative to patent. The patentability of the intermediate technology can be interpreted in the similar fashion as the level of IPR protection in this paper. Both Denicolo and Aoki & Nagaoka assume constant returns to scale for innovation in their models. Having more firms in the patent race will not increase the return from innovation. Therefore, the inventor always prefers to be the only one pursuing the D stage research if it has completed the R stage. In our framework, having more firms participating in the D stage increases the probability that the discovery will be made. For sufficiently strong IPR protection, a firm might prefer that the rival does not drop out in the patent race[4)].

Some aspect of our modelling approach is close to Bloch and Markowitz (1996). The focus of their paper is on the optimal disclosure delay and the optimal policy is the one which minimises the expected discovery time of the innovation. They model a discrete version of Grossman and Shapiro (1987) and assume fixed cost R&D investment and constant discovery probability. Unlike the conclusion of Bloch and Markowitz and Grossman and Shapiro and many other papers in the patent race literature (for examples Fudenberg *et al.* (1983) and Harris and Vickers (1987)), the technology leader in our model does not always have higher incentive to invest compared with the follower. The level of IPR protection plays an important role for the leader in deciding whether or not to enter the D stage race. All of the above papers consider the case of domestic inventors.

## 3. Model Setup

The model is a two-stage R&D race game. The first stage represents the research (R) stage and the second stage is the development (D) stage. We assume that the first stage output carries no stand-alone commercial value and inventors only realise profit after the completion of the D stage[5)]. There are two inventors, $A$ and $B$, residing in countries $A$ and $B$ respectively, racing each other in this innovation game. Inventors move sequentially in each stage and we focus on pure strategy equilibrium.

An inventor's R&D progress is illustrated by its position in the R&D race, $s_i \in \{0, 1, 2\}$. Position $s_i=0$ indicates that inventor $i$ is at the starting point of the R&D race, $s_i=1$ means that inventor $i$ has finished the R stage, and $s_i=2$ indicates that inventor $i$ has completed the D stage. We analyse the cases for both asymmetric and symmetric inventors. For asymmetric inventors, we analse the subgame when the R stage competition is concluded and firms' positions are $\{0, 1\}$. For symmetric inventor case, we analyse firms' behaviour after the R stage competition when the positions are $\{1, 1\}$ and firms' behaviour from the beginning of the R stage with positions $\{0, 0\}$[6)].

Table 1. D Stage Normal Form for the Global Setting When $(s_A, s_B) = (1, 1)$

| $A \backslash B$ | I | NI |
|---|---|---|
| I | $2p_D(\pi_M - p_D(\pi_M - \pi_D)) - c_D$, $2p_D(\pi_M - p_D(\pi_M - \pi_D)) - c_D$ | $2p_D\pi_M - c_D$, 0 |
| NI | $0, 2p_D\pi_M - c_D$ | 0, 0 |

There is complete information in this game. In the beginning of the first stage, standing at position 0, firms invest in the R stage. In the beginning of the second stage, knowing its own and the rival's research outcome in the R stage, firms invest again in the D stage. We assume that it is not possible to finish both stages in the second period. There is spill-over once the R stage is concluded. The inventor which failed in the first stage research can engage in the D stage if the rival has the R stage research output.

In the R stage, an inventor decides whether or not to incur the investment cost $c_R$. If it invests, it completes the R stage with probability $p_R$. Otherwise, it stays at position zero. The R&D technology for the D stage is defined in the same fashion with the fixed cost being $c_D$ and the probability of success being $p_D$.

When an inventor is successful in the R stage research and is the only one to make the D stage discovery, it gets the monopoly profit $\pi_M$. When both inventors complete the R stage and both get to position 2 in the end of the second stage, they each gets the duopoly profit $\pi_D$. We assume $\pi_M \geq 2\pi_D$. When the R and D stage discoveries are made by different inventors, they share the profit. Let $\lambda, \lambda \in [0, 1]$, denote the share of profit granted to the R stage technology. For example, if one inventor completes the R stage while the other completes the D stage, the former gets $\lambda\pi_M$ and the latter gets $(1-\lambda)\pi_M$. If both firms compete the D stage while only one firm came up with the R stage discovery, the one with the basic research gets $(1+\lambda)\pi_D$ while the other one gets $(1-\lambda)\pi_D$. The variable $\lambda$ thus measures the degree of IPR protection for basic research. $\lambda=0$ corresponds to the case of free imitation. $\lambda=1$ corresponds to extreme protection of the basic research output and the inventor which fails in the first period research would drop out from D stage competition. For the two country analysis, we assume national treatment for the foreign inventor and the same degree of protection is offered to both the domestic and foreign firms[7]. The game finishes after two periods, whether or not inventors have reached the finishing line.

The timing is that countries set $\lambda$ sequentially first, and then firms compete in R stage followed by investments in D stage. The game is solved backwards to obtain the subgame perfect Nash equilibrium.

Each country takes into consideration both profit in the domestic market and profit in the foreign market. Countries can set different $\lambda_s$. Strategic interaction between countries matter. For example, if one country provides a high $\lambda$, the other one may be able to free ride on it for stimulating research incentives and set a low $\lambda$.

## 4. D Stage Equilibrium

We discuss two subgames here: symmetric positions after the R stage game with $(s_A, s_B) = (1, 1)$ and asymmetric positions after the R stage game with $(s_A, s_B) = (0, 1)$. The case $(s_A, s_B) = (0, 0)$ is trivial and the following discussion only focuses on the case where at least one firm has made the R stage discovery after the first period. The case $(s_A, s_B) = (1, 0)$ is symmetric to $(s_A, s_B) = (0, 1)$ except for the areas where the first mover advantage is important.

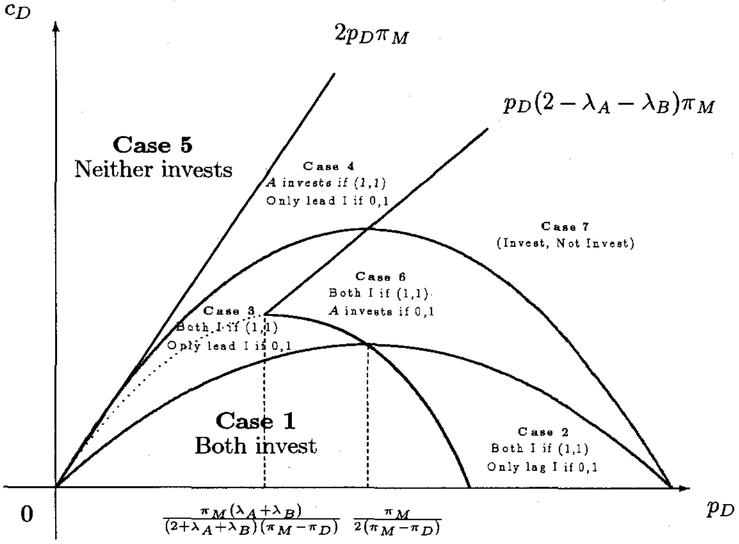
For positions $(s_A, s_B) = (1, 1)$, the normal form representation is given in Table 1.

The normal form has Battle of the Sexes structure (if it were simultaneous moves). If the cost is very small, $c_D \leq 2p_D(\pi_M - p_D(\pi_M - \pi_D))$, then investing is a dominant strategy (Case 1-4 regions in Figure 1). If the cost is

**Table 2. D stage normal form for the global market when $(s_A, s_B) = (0, 1)$**

| $A \backslash B$ | I | NI |
|---|---|---|
| I | $p_D(2-\lambda_A-\lambda_B)(\pi_M-p_D(\pi_M-\pi_D))-c_D$, $p_D(2+\lambda_A+\lambda_B)(\pi_M-p_D(\pi_M-\pi_D))-c_D$ | $p_D\pi_M(2-\lambda_A-\lambda_B)-c_D$, $p_D(\lambda_A+\lambda_B)\pi_M$ |
| NI | $0, 2p_D\pi_M-c_D$ | $0, 0$ |

**Figure 1. Equilibrium in the D Stage When the Global Market is Considered.**




very large, $c_D \geq 2p_D\pi_M$, then not investing in dominant (Cases 5 region in Figure 1). For intermediate levels, a firm invests if the rival does not invest. $B$'s subgame perfect strategy is to not invest if $A$ invests, and invest if $A$ does not. First mover $A$ invests since this yields positive profit.

For positions $(s_A, s_B) = (0, 1)$, the payoff matrix is listed below in Table 2.

Again, if $c_D$ is small, then investing is the dominant strategy (Case 1). If the cost is large, then not investing is dominant (Case 5). The intermediate range has three parts. If $A$ invests, $B$ invests if $c_D \leq p_D[2\pi M-(2+\lambda_A+\lambda_B)p_D(\pi_M-\pi_D)]$. If $A$ does not invest, $B$ invests if $c_D \leq 2p_D\pi_M$. When $B$ invests, $A$ invests if $c_D \leq p_D(2-\lambda_A-\lambda_B)(\pi_M-p_D(\pi_M-\pi_D))$. When $B$ does not invest, $A$ invests if $c_D \leq p_D(2-\lambda_A-\lambda_B)\pi_M$. When the positions are $(s_A, s_B) = (1, 0)$, the payoffs are reversed while $A$ is still the first mover.

Checking the boundary values:

$$p_D[2\pi_M-(2+\lambda_A+\lambda_B)p_D(\pi_M-\pi_D)] \geq p_D\pi_M(2-\lambda_A-\lambda_B)$$

if

$$p_D \leq \frac{1}{\left(\frac{2}{(\lambda_A+\lambda_B)}+1\right)}\left(\frac{\pi_M}{(\pi_M-\pi_D)}\right).$$

And

$$p_D[2\pi_M-(2+\lambda_A+\lambda_B)p_D(\pi_M-\pi_D)] \geq p_D(2-\lambda_A-\lambda_B)(\pi_M-p_D(\pi_M-\pi_D))$$

if

$$p_D \leq \frac{\pi_M}{2(\pi_M-\pi_D)}.$$

The D stage equilibrium is depicted in $(p_D, c_D)$ space in Figure 1. We can see that in cases 4, 6, and 7, the first mover advantage matters and $A$ invests.

## 4.1 Optimal Protection Level in the D Stage for Asymmetric Countries

In this section, we present the optimal protection level for the R stage research output if the countries were to maximise the domestic firm's global profits. Note that each country's chosen policy only affect firm's profit in the given country.

**Lemma 1** *Given positions $(s_A, s_B) = (0, 1)$, for $c_D \leq (2-\lambda_A-\lambda_B)p_D\pi_M$ and $c_D \leq (2-\lambda_A-\lambda_B)p_D\pi_M$, $A$'s best response is to set $\lambda_A = \frac{p_D(2\pi_M-p_D(\pi_M-\pi_D)(2+\lambda_B))-c_D}{p_D^2(\pi_M-\pi_D)}$. $\lambda_A$ decreases in $\lambda_B$. $B$'s best response is to set $\lambda_B = 1$.*

**Proof.** See the Appendix. ■

**Proposition 1**

For $c_D \geq \frac{2\pi_M p_D(\pi_M-2p_D(\pi_M-\pi_D))}{\pi_M-p_D(\pi_M-\pi_D)}$,

Table 3. R stage normal form for the global market setting.

| $A\backslash B$ | I | NI |
|---|---|---|
| I | $p_R(p_r\pi_{11}+(1-p_R)\pi_{10})+(1-p_R)p_r\pi_{01}-c_R$, $p_R(p_R\pi_{11}+(1-p_R)\pi_{01})+(1-p_R)p_R\pi_{10}-c_R$ | $p_R\pi_{10}-c_R$, $p_R\pi_{10}$ |
| NI | $p_R\pi_{01}$, $p_R\pi_{01}-c_R$ | 0, 0 |

$$\lambda_A=\frac{p_D(2\pi_M-3p_D(\pi_M-\pi_D))-c_D}{p_D^2(\pi_M-\pi_D)} \text{ and } \lambda_B=1$$

*is an equilibrium.*

**Proof.** Solve for the intersection point of the best responses given in Lemma 1 and substitute the solution for the $c_D$ condition. ■

**Lemma 2** *Given positions* $(s_A, s_B)=(0,1)$, *for* $c_D \leq 2p_D(\pi_M-2p_D(\pi_M-\pi_D))$, *the best responses are* $\lambda_A=0$ *and* $\lambda_B=2-\lambda_A-\dfrac{c_D}{p_D(\pi_M-p_D(\pi_M-\pi_D))}$.

**Proof.** See the Appendix. ■

**Proposition 2** *Given positions* $(s_A, s_B)=(0,1)$, *for* $c_D \geq p_D(\pi_M-p_D(\pi_M-\pi_D))$ *and* $c_D \leq 2p_D(\pi_M-2p_D(\pi_M-\pi_D))$, $\lambda_A=0$ *and* $\lambda_B=2-\dfrac{c_D}{p_D(\pi_M-p_D(\pi_M-\pi_D))}$ *is an equilibrium.*

**Proof.** Solve for the intersection point and parameter range given in Lemma 2 and add the condition to ensure that $\lambda_B \in [0,1]$. ■

## 5. R stage equilibrium

We present the normal form game for the R stage in Table 3.

We analyse the R stage game according to the cases listed in Figure 1. The analysis here is used for simulation in the next section.

**Case 1** Inventors, payoffs are symmetric.

$$\begin{aligned}\pi_A[\mathrm{I,I}] &= \pi_B[\mathrm{I,I}]\\ &= 2p_Rp_D(2-p_R)(\pi_M-p_D(\pi_M-\pi_D))\\ &\quad -p_Rc_D(2-p_R)-c_R;\end{aligned}$$

$$\begin{aligned}\pi_A[\mathrm{I,NI}] &= \pi_B[\mathrm{NI,I}]\\ &= p_R((2+\lambda_A+\lambda_B)p_D(\pi_M\\ &\quad -p_D(\pi M-\pi_D))-c_D)\\ &\quad -c_R;\end{aligned}$$

$$\begin{aligned}\pi_A[\mathrm{NI,I}] &= \pi_B[\mathrm{I,NI}]\\ &= p_R\pi_{01}\\ &= p_R(p_D(2-\lambda_A-\lambda_B)(\pi_M\\ &\quad -p_D(\pi_M-\pi_D))-c_D);\end{aligned}$$

**Case 2** Inventors, payoffs are symmetric in this case.

$$\begin{aligned}\pi_A[\mathrm{I,I}] &= \pi_B[\mathrm{I,I}]\\ &= 2p_Rp_D(\pi_M-p_Rp_D(\pi_M-\pi_D))-p_Rc_D\\ &\quad -c_R;\end{aligned}$$

$$\begin{aligned}\pi_A[\mathrm{I,NI}] &= \pi_B[\mathrm{NI,I}]\\ &= p_R\pi_{10}-c_R\\ &= (\lambda_A+\lambda_B)p_Rp_D\pi_M-c_R;\end{aligned}$$

$$\begin{aligned}\pi_A[\mathrm{NI,I}] &= \pi_B[\mathrm{I,NI}]\\ &= p_R\pi_{01}\\ &= p_R[p_D(2-\lambda_A-\lambda_B)\pi_M-c_D];\end{aligned}$$

**Case 3** Inventors, payoffs are symmetric in this case.

$$\begin{aligned}\pi_A[\mathrm{I,I}] &= \pi_B[\mathrm{I,I}]\\ &= 2p_Rp_D(\pi_M-p_Rp_D(\pi_M-\pi_D))-p_Rc_D\\ &\quad -c_R;\end{aligned}$$

$$\begin{aligned}\pi_A[\mathrm{I,NI}] &= \pi_B[\mathrm{NI,I}]\\ &= p_R(2p_D\pi_M-c_D)-c_R;\end{aligned}$$

$$\begin{aligned}\pi_A[\mathrm{NI,I}] &= \pi_B[\mathrm{I,NI}] = \pi_A[\mathrm{NI,NI}]\\ &= \pi_B[\mathrm{NI,NI}] = 0.\end{aligned}$$

**Case 4** Inventor $A$:

$$\pi_A[\mathrm{I,I}] = p_R(2p_D\pi_M-c_D)-c_R;$$
$$\pi_A[\mathrm{I,NI}] = p_R(2p_D\pi_M-c_D)-c_R;$$
$$\pi_A[\mathrm{NI,I}] = 0.$$

Inventor $B$:

$$\pi_B[\mathrm{I,I}] = p_R(1-p_R)(2p_D\pi_M-c_D)-c_R;$$
$$\pi_B[\mathrm{I,NI}] = 0;$$
$$\pi_B[\mathrm{NI,I}] = p_R(2p_D\pi_M-c_D)-c_R;$$

**Case 5** In this case, the research cost in the D stage is prohibitively high such that no inventors carry out research in the D stage. The equilibrium in the R stage is (NI, NI).

**Case 6** For inventor $A$ :

$$\pi_A[\mathrm{I,I}] = p_R p_D(4\pi_M - 2p_R\pi_M - 2p_R p_D(\pi_M - \pi_D) - (1-p_R)(\lambda_A+\lambda_B)\pi_M) - 2p_R c_D + p_R^2 c_D - c_R;$$

$$\pi_A[\mathrm{I,NI}] = p_R\pi_{10} - c_R = p_R(2p_D\pi_M - c_D) - c_R;$$

$$\pi_A[\mathrm{NI,I}] = p_R\pi_{01} = p_R(p_D(2-\lambda_A-\lambda_B)\pi_M - c_D);$$

For inventor $B$ :

$$\pi_B[\mathrm{I,I}] = p_R^2(2p_D(\pi_M - p_D(\pi_M-\pi_D)) - c_D) + (1-p_R)p_R((\lambda_A+\lambda_B)p_D\pi_M) - c_R;$$

$$\pi_B[\mathrm{I,NI}] = 0;$$

$$\pi_B[\mathrm{NI,I}] = p_R((\lambda_A+\lambda_B)p_D\pi_M) - c_R;$$

**Case 7** For inventor $A$ :

$$\pi_A[\mathrm{I,I}] = \pi_M p_R p_D(4 - 2p_R - (\lambda_A+\lambda_B)(1-p_R)) - p_R c_D(2-p_R) - c_R;$$

$$\pi_A[\mathrm{I,NI}] = p_R(2p_D\pi_M - c_D) - c_R;$$

$$\pi_A[\mathrm{NI,I}] = p_R(p_D(2-\lambda_A-\lambda_B)\pi_M - c_D);$$

For inventor $B$ :

$$\pi_B[\mathrm{I,I}] = (\lambda_A+\lambda_B)(1-p_R)p_R p_D\pi_M - c_R;$$

$$\pi_B[\mathrm{I,NI}] = \pi_B[\mathrm{NI,NI}] = 0;$$

$$\pi_B[\mathrm{NI,I}] = (\lambda_A+\lambda_B)p_R p_D\pi_M - c_R;$$

### 5.1 Protection levels and profits with symmetric Countries

We carry out the analysis at the beginning of the R stage for symmetric countries by numerical simulation. Selected simulation tables are reported in the Appendix.

**Remark 1** *When $p_R$ is small, in equilibrium, $\lambda_B > \lambda_A$. This equilibrium also gives the highest global welfare. Note that global welfare remains the same if we decreases $\lambda_B$ to $\lambda_A$. However, global welfare decreases if $\lambda_A$ is raised to be the same as $\lambda_B$.*

We conclude that, when two countries have different IPR protection levels, harmonisation may not be desirable. Even if the countries wish to harmonise the IPR protection level, moving towards the weaker protection level may be more beneficial than strengthening the common protection level towards the standard set by the country with stronger IPR.

**Remark 2** *When $c_R$ and $c_D$ are both high, in equilibrium, $\lambda_B$ is high and $\lambda_A$ is low. A's best response is not monotonic in $\lambda_B$. When $\lambda_B$ is low, optimal $\lambda_A$ is intermediate. As $\lambda_B$ increases, $\lambda_A$ decreases initially and then increases when $\lambda_B$ gets very large. The optimal $\lambda_B$ is weakly decreasing in $\lambda_A$. Countries. non-cooperative equilibrium also gives the highest global welfare. Harmonisation is not necessarily welfare enhancing.*

**Remark 3** *When $p_D$ is small, in equilibrium, $\lambda_B > \lambda_A$. Given a $\lambda_B$, A always prefers a low $\lambda_A$. The optimal $\lambda_B$ decreases in $\lambda_A$. When $p_D$ is very large, there exists an equilibrium where $\lambda_A$ and $\lambda_B$ are both large with $\lambda_A > \lambda_B$. The optimal $\lambda_A$ is weakly increasing in $\lambda_B$. The optimal $\lambda_B$ is weakly decreasing in $\lambda_A$.*

**Remark 4** *For some parameter ranges, in equilibrium, each inventor specialises in one stage of R and D. The optimal $\lambda_A$ decreases in $\lambda_B$. The optimal $\lambda_B$ decreases in $\lambda_A$ initially and when $\lambda_A$ gets very large, B prefers setting a large $\lambda_B$ as well. The simulation results for this example is given in Table 4 in the Appendix.*

## 6. Conclusions

We have analysed inventors.investment incentives when the patent race consists of two complementary stages. When we only focus on the D stage competition and take inventors' initial positions as given, our result indicates that when $p_D$ and $c_D$ are large, the follower may prefer setting a higher $\lambda$ and encourage the leader not to invest in the D stage. Therefore, for the North-South IPR protection debate, if the development of a new product requires a research stage and a development stage, the South may benefit by strengthening IPR protection in innovations where its application is costly to implement but the likelihood of success is high. On the other hand, when $p_D$ and $c_D$ are small, the leader may wish to set a lower $\lambda$ and encourage the follower to invest in the D stage to increase the chance of making a discovery. In these industries, developed countries may benefit by lowering the IPR protection.

When research incentives in both stages are taken into account, we show that for some parameter ranges, even symmetric countries choose asymmetric levels of IPR protection in equilibrium. Furthermore, harmonisation of IPR protection across countries may not be welfare enhancing. In general, the optimal $\lambda$ decreases in $p_R$ and $c_D$ and increases in $c_R$ and $p_D$. In the global setting where countries can choose different $\lambda_s$, the first mover's optimal $\lambda$ decreases in that of the second mover's.

We have assumed sequential move for the two-stage R&D game. The result indicates that the sequence of moves is important and there is a first mover advantage. It would be beneficial for countries to try to invest in the patent race early. For most parameter ranges, the first mover sets a lower $\lambda$ compared with the second mover. For some parameter ranges, it is optimal to select a $\lambda$ and make each inventor specialise in one stage of research.

Our analysis can be extended in many ways. The first one is that for an international setting, trade in goods can work as a complement or substitute for trade in knowledge. The inclusion of tradeable goods would make the analysis more comprehensive and would also make it comparable the international trade literature.

Secondly, for the two country analysis when research incentives are included, we assume that countries have the same innovative capacity. That is, firms share the same technology parameters. It could be extended to consider asymmetric countries with different $p_R$ and $p_D$. We can analyse the equilibrium when one country has absolute advantage in carrying out research in both stages and the case that neither of them enjoys absolute advantage. Our conjecture is that if countries are asymmetric, there should be more gains from trade in technology and it would emphasise the need for international research cooperation. It may be more likely that countries would specialise in R and D.

Finally, in the model, it is assumed that it is not possible to catch up and come up with the R stage technology in the second period. If the catching up behaviour is possible, the parameter for this leapfrogging probability would affect the equilibrium in this two stage R&D race.

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**Notes**

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1) The channels through which spill-overs take place are documented in several studies (Mansfield (1985), Mansfield *et al.* (1981), Levin *et al.* (1987), and Neven and Siotis (1996)).

2) Asymmetry refers to asymmetric positions, not asymmetric research capacities. A firm is a technology leader if in the end of the R stage race, it has made discovery for R stage research output while the rival has not.

3) That is, if the North does not set a prohibitive tariff.

4) As will be made more clear later, to convince the firm which does not have the R stage research output to remain in the race, the share of profit granted to the basic research cannot be too high.

5) This assumption simplifies the analysis and emphasises the first inventor's incentive to encourage research in the D stage. The results carry through even if the intermediate technology has some standalone value as long as the completion of the D stage adds significant value to the R stage invention.

6) The situation that firms are asymmetric in terms of different innovative capacity is not modelled.

7) National treatment is required in TRIPs. This

assumption is also employed in Lai and Qiu (2003) and Grossman and Lai (2003).

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## 7. Appendix

### 7.1 Proofs of results

**Proof.** of Lemma 1: $\pi_A((\mathrm{I}, \mathrm{NI})|s_A=0, s_B=1)>\pi_A((\mathrm{I}, \mathrm{I})|s_A=0, s_B=1)$. When $A$ invests, it always prefers that $B$ does not invest. To make $B$ not to invest, we need $\pi_B((\mathrm{I}, \mathrm{NI})|s_A=0, s_B=1)>\pi_B((\mathrm{I}, \mathrm{I})|s_A=0, s_B=1)$. Or

$$\lambda_A \geq \frac{p_D(2\pi_M-p_D(\pi_M-\pi_D)(2+\lambda_B))-c_D}{p_D^2(\pi_M-\pi_D)}.$$

Note that

$$\frac{p_D(2\pi_M-p_D(\pi_M-\pi_D)(2+\lambda_B))-c_D}{p_D^2(\pi_M-\pi_D)} \leq 1.$$

if $c_D \geq p_D(2\pi_M-p_D(2+\lambda_B)(\pi_M-\pi_D))$. $\pi_A((\mathrm{I}, \mathrm{NI})|s_A=0, s_B=1)>\pi_A((\mathrm{NI}, \mathrm{NI})|s_A=0, s_B=1)$ and $A$ invests when $B$ does not invest if $c_D(2-\lambda_A-\lambda_B)p_D\pi_M$. When the two conditions are satisfied simultaneously, the equilibrium is that $A$ invests with the best response $\lambda_A=\frac{p_D(2\pi_M-p_D(\pi_M-\pi_D)(2+\lambda_B))-c_D}{p_D^2(\pi_M-\pi_D)}$. $B$'s best response is $\lambda_B=1$. ■

**Proof.** of Lemma 2: When $B$ does not invest, it always prefers that $A$ invests. When $B$ invests, it prefers that $A$ invests if $\lambda_B \geq \frac{2\pi_M}{(\pi_M-p_D(\pi_M-\pi_D))}-(2+\lambda_A)$. This is the minimum $\lambda$ required for $B$'s incentive constraint.

When $B$ invests, $A$ prefers investing if $2-\lambda_A-\frac{c_D}{p_D(\pi_M-p_D(\pi_M-\pi_D))} \geq \lambda_B$. This is the upper bound for $\lambda_B$ given that $A$'s incentive constraint must be satisfied.

$$2-\lambda_A-\frac{c_D}{p_D(\pi_M-p_D(\pi_M-\pi_D))} \geq \frac{2\pi_M}{(\pi_M-p_D(\pi_M-\pi_D))}-(2+\lambda_A)$$

if $c_D \leq 2p_D(\pi_M-2p_D(\pi_M-\pi_D))$. $B$ prefers investing when $A$ invests if

$$c_D \leq p_D(2\pi_M-p_D(2+\lambda_A+\lambda_B)(\pi_M-\pi_D)).$$

This is always satis. ed if $c_D \leq 2p_D(\pi_M-2p_D(\pi_M-\pi_D))$. Therefore, for $c_D \leq p_D(2\pi_M-4p_D(\pi_M-\pi_D))$, $B$'s best response is $\lambda_B=2-\lambda_A-\frac{c_D}{p_D(\pi_M-p_D(\pi_M-\pi_D))}$.

For $A$, when both firms invest, $\pi_A$ decreases in $\lambda_A$ and it always prefers setting $\lambda_A=0$. ■

### 7.2 Simulation tables

**Table 4. Simulation results for $p_R=0.5$, $c_R=1$, $p_D=0.85$, $c_D=1$, $M=3$, and $\pi_D=1$.**

$p_R=0.1$, $c_R=c_D=1$, $p_D=0.5$, $\pi_M=10$, $\pi_D=4$:

| $\lambda_B$ | $\lambda_A$ | R Stage Eqm | D Stage Eqm | $\pi_A$ | $\pi_B$ | $\pi_A+\pi_B$ |
|---|---|---|---|---|---|---|
| 0.5 | 0.7 | NI, I | I, I | 0.18 | 0.02 | 0.2 |
| 0.5 | 0.9 | I, I | I, I | 0.14 | 0.14 | 0.28 |
| 0.7 | 0.5 | NI, I | I, I | 0.18 | 0.02 | 0.2 |
| 0.7 | 0.7 | I, I | I, I | 0.14 | 0.14 | 0.28 |
| 0.7 | 0.9 | I, I | I, I | 0.14 | 0.14 | 0.28 |
| 0.9 | **0.5** | **I, I** | **I, I** | **0.14** | **0.14** | **0.28** |
| 0.9 | **0.7** | **I, I** | **I, I** | **0.14** | **0.14** | **0.28** |
| 0.9 | 0.9 | NI, NI | Case 3 | 0 | 0 | 0 |

$p_R=0.5$, $c_R=3$, $c_D=1$, $p_D=0.5$, $\pi_M=10$, $D=4$:

| $\lambda_B$ | $\lambda_A$ | R Stage Eqm | D Stage Eqm | $\pi_A$ | $\pi_B$ | $\pi_A+\pi_B$ |
|---|---|---|---|---|---|---|
| 0.1 | 0.1 | NI, I | I, I | 2.65 | 0.35 | 3 |
| 0.1 | 0.2 | NI, I | I, I | 2.475 | 0.525 | 3 |
| 0.1 | 0.3 | NI, I | I, I | 2.3 | 0.7 | 3 |
| 0.1 | 0.5 | NI, I | I, I | 1.95 | 1.05 | 3 |
| 0.1 | 0.7 | NI, I | I, I | 1.6 | 1.4 | 3 |
| 0.1 | 0.9 | I, I | I, I | 1.5 | 1.5 | 3 |
| 0.5 | 0.1 | NI, I | I, I | 1.95 | 1.05 | 3 |
| 0.5 | 0.2 | NI, I | I, I | 1.775 | 1.225 | 3 |
| 0.5 | 0.3 | NI, I | I, I | 1.6 | 1.4 | 3 |
| 0.5 | 0.5 | NI, I | I, I | 1.25 | 0.75 | 2 |
| 0.5 | 0.7 | I, I | I, I | 1.5 | 1.5 | 3 |
| 0.5 | 0.9 | I, I | I, I | 1.5 | 1.5 | 3 |
| 0.7 | 0.1 | NI, I | I, I | 1.6 | 1.4 | 3 |
| 0.7 | 0.2 | I, I | I, I | 1.5 | 1.5 | 3 |
| 0.7 | 0.9 | I, I | I, I | 1.5 | 1.5 | 3 |
| 0.9 | **0.1** | **I, I** | I, I | **1.5** | **1.5** | **3** |
| 0.9 | **0.2** | **I, I** | **I, I** | **1.5** | **1.5** | **3** |
| 0.9 | **0.3** | **I, I** | **I, I** | **1.5** | **1.5** | **3** |
| 0.9 | **0.5** | **I, I** | **I, I** | **1.5** | **1.5** | **3** |
| 0.9 | **0.7** | **I, I** | **I, I** | **1.5** | **1.5** | **3** |
| 0.9 | 0.9 | I, NI | Case 3 | 0.75 | 0.75 | 1.5 |

$p_R=0.5$, $c_R=3$, $c_D=3$, $p_D=0.5$, $\pi_M=10$, $\pi_D=4$:

| $\lambda_B$ | $\lambda_A$ | R Stage Eqm | D Stage Eqm | $\pi_A$ | $\pi_B$ | $\pi_A+\pi_B$ |
|---|---|---|---|---|---|---|
| 0.1 | 0.5 | NI, I | I, I | 0.95 | 0.05 | 1 |
| 0.1 | 0.7 | NI, I | I, I | 0.6 | 0.4 | 1 |
| 0.1 | 0.9 | I, NI | I, I | 0.75 | 0.25 | 1 |
| 0.5 | 0.1 | NI, I | I, I | 0.95 | 0.05 | 1 |
| 0.5 | 0.2 | NI, I | I, I | 0.775 | 0.225 | 1 |
| 0.5 | 0.3 | NI, I | I, I | 0.6 | 0.4 | 1 |
| 0.5 | 0.5 | I, NI | I, I | 0.75 | 0.25 | 1 |
| 0.5 | 0.7 | I, NI | Case 3 | 0.5 | 0 | 0.5 |
| 0.7 | 0.1 | NI, I | I, I | 0.6 | 0.4 | 1 |
| 0.7 | 0.2 | I, NI | I, I | 0.575 | 0.425 | 1 |
| 0.7 | 0.3 | I, NI | I, I | 0.75 | 0.25 | 1 |
| 0.7 | 0.5 | I, NI | Case 3 | 0.5 | 0 | 0.5 |
| 0.9 | 0.1 | I, NI | I, I | 0.75 | 0.25 | 1 |
| 0.9 | 0.2 | I, NI | I, I | 0.925 | 0.075 | 1 |
| 0.9 | 0.9 | I, NI | Case 3 | 0.5 | 0 | 0.5 |

$p_R=0.5$, $c_R=1$, $c_D=1$, $p_D=0.1$, $\pi_M=15$, $\pi_D=7$:

| $\lambda_B$ | $\lambda_A$ | R Stage Eqm | D Stage Eqm | $\pi_A$ | $\pi_B$ | $\pi_A+\pi_B$ |
|---|---|---|---|---|---|---|
| 0.1 | 0.1 | NI, I | I, I | 0.778 | 0.062 | 0.84 |
| 0.1 | 0.5 | NI, I | I, I | 0.494 | 0.346 | 0.84 |
| 0.1 | 0.6 | NI, I | I, I | 0.423 | 0.417 | 0.84 |
| 0.1 | 0.7 | I, I | I, I | 0.38 | 0.38 | 0.76 |
| 0.1 | 0.9 | I, I | I, I | 0.38 | 0.38 | 0.76 |
| 0.5 | 0.1 | NI, I | I, I | 0.494 | 0.346 | 0.84 |
| 0.5 | 0.2 | NI, I | I, I | 0.423 | 0.417 | 0.84 |
| 0.5 | 0.3 | I, I | I, I | 0.38 | 0.38 | 0.76 |
| 0.7 | **0.1** | **I, I** | **I, I** | **0.38** | **0.38** | **0.76** |
| 0.7 | **0.5** | **I, I** | **I, I** | **0.38** | **0.38** | **0.76** |
| 0.7 | 0.7 | NI, NI | Case 3 | 0 | 0 | 0 |
| $\lambda_B=0.9$ | 0.1 | I, I | I, I | 0.38 | 0.38 | 0.76 |
| 0.9 | 0.5 | NI, NI | Case 3 | 0 | 0 | 0 |

$p_R=0.5$, $c_R=c_D=1$, $p_D=0.9$, $\pi_M=10$, $\pi_D=4$:

| $\lambda_B$ | $\lambda_A$ | R Stage Eqm | D Stage Eqm | $\pi_A$ | $\pi_B$ | $\pi_A+\pi_B$ |
|---|---|---|---|---|---|---|
| 0.1 | 0.1 | I, I | I, I | 4.34 | 4.34 | 8.68 |
| 0.1 | 0.9 | I, I | I, I | 4.34 | 4.34 | 8.68 |
| $\lambda_B=0.5$ | 0.9 | I, I | I, I | 4.34 | 4.34 | 8.68 |
| 0.7 | 0.7 | I, I | I, I | 4.34 | 4.34 | 8.68 |
| 0.7 | **0.9** | **I, I** | **Case 2** | **5.07** | **5.07** | **10.14** |
| 0.9 | 0.5 | I, I | I, I | 4.34 | 4.34 | 8.68 |
| 0.9 | 0.7 | I, I | Case 2 | 5.07 | 5.07 | 10.14 |
| 0.9 | 0.9 | I, I | Case 6 | 5.27 | 4.87 | 10.14 |

| | $\lambda_A$ | R Stage Eqm | D Stage Eqm | $\pi_A$ | $\pi_B$ | $\pi_A+\pi_B$ |
|---|---|---|---|---|---|---|
| $\lambda_B=0.1$ | 0.6 | NI, NI | I, I | 0 | 0 | 0 |
| | 0.7 | NI, I | I, I | 0.163 | 0.047 | 0.21 |
| | 0.9 | NI, I | Case 2 | 0.775 | 0.275 | 1.05 |
| $\lambda_B=0.5$ | 0.1 | NI, NI | I, I | 0 | 0 | 0 |
| | 0.3 | NI, I | I, I | 0.163 | 0.047 | 0.21 |
| | 0.4 | NI, I | Case 2 | 0.9025 | 0.1475 | 1.05 |
| | 0.5 | NI, I | Case 2 | 0.775 | 0.275 | 1.05 |
| | 0.6 | I, I | Case 6 | 0.6512 | 0.0038 | 0.655 |
| | 0.7 | I, I | Case 6 | 0.5875 | 0.0675 | 0.655 |
| | 0.9 | I, I | Case 6 | 0.3962 | 0.195 | 0.5912 |
| $\lambda_B=0.6$ | 0.1 | NI, NI | I, I | 0 | 0 | 0 |
| | 0.3 | NI, I | Case 2 | 0.9025 | 0.1475 | 1.05 |
| | 0.4 | NI, I | Case 2 | 0.775 | 0.275 | 1.05 |
| | 0.5 | I, I | Case 6 | 0.6512 | 0.0038 | 0.655 |
| | 0.6 | I, I | Case 6 | 0.5875 | 0.0675 | 0.655 |
| | 0.7 | I, I | Case 6 | 0.5237 | 0.1312 | 0.6549 |
| | 0.9 | I, I | Case 6 | 0.3962 | 0.2588 | 0.655 |
| $\lambda_B=0.7$ | 0.1 | NI, I | I, I | 0.163 | 0.047 | 0.21 |
| | 0.3 | NI, I | Case 2 | 0.775 | 0.275 | 1.05 |
| | 0.4 | I, I | Case 6 | 0.6512 | 0.0038 | 0.655 |
| | 0.5 | I, I | Case 6 | 0.5875 | 0.0675 | 0.655 |
| | 0.6 | I, I | Case 6 | 0.5237 | 0.1312 | 0.6549 |
| | 0.7 | I, I | Case 6 | 0.46 | 0.195 | 0.655 |
| | 0.9 | I, I | Case 6 | 0.3325 | 0.3225 | 0.655 |
| $\lambda_B=0.8$ | 0.1 | NI, I | Case 2 | 0.9025 | 0.1475 | 1.05 |
| | **0.3** | **I, I** | **Case 6** | **0.6512** | **0.0038** | **0.655** |
| | 0.4 | I, I | Case 6 | 0.5875 | 0.0675 | 0.655 |
| | 0.5 | I, I | Case 6 | 0.5237 | 0.1313 | 0.655 |
| | 0.6 | I, I | Case 6 | 0.46 | 0.265 | 0.725 |
| | 0.7 | I, I | Case 6 | 0.3962 | 0.2588 | 0.655 |
| | 0.9 | I, I | Case 3 | 0.3275 | 0.3275 | 0.655 |
| $\lambda_B=0.9$ | **0.1** | **NI, I** | **Case 2** | **0.775** | **0.275** | **1.05** |
| | 0.3 | I, I | Case 6 | 0.5875 | 0.0675 | 0.655 |
| | 0.4 | I, I | Case 6 | 0.5237 | 0.1313 | 0.655 |
| | 0.5 | I, I | Case 6 | 0.3962 | 0.195 | 0.5912 |
| | 0.6 | I, I | Case 6 | 0.3962 | 0.2588 | 0.655 |
| | 0.7 | I, I | Case 6 | 0.3325 | 0.3225 | 0.655 |
| | 0.9 | I, I | Case 3 | 0.3275 | 0.3275 | 0.655 |