Northern Intellectual Property Rights Standard for the South?*

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May, 1999

Abstract

We build a theoretical North-South model to analyze intellectual property rights (IPR) protection. By comparing the optimal IPR protection of the South (the less developed world) and that of the North (the more developed world), we show that the former is weaker than the latter. We also find that it is globally optimal that the South adopts an IPR standard that is more stringent than its own individually optimal one, but less stringent than that of the North. Furthermore, it can be shown that under certain conditions, the world is worse off if the South is forced to adopt the Northern standard than if the South is allowed to adopt its own standard, or even not protect at all. Therefore, Northern IPR standard should not be forced upon the South.

Keywords: Intellectual property rights, innovation, imitation, North-South, TRIPS Agreement. JEL Classification Number: F1, O31, O34.

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* We would like to thank Amy Glass, Earl Grinols and Ping Wang for helpful comments. We also benefit from presentation at City University of Hong Kong and the Midwest International Economics Conference held at Purdue University (1999).
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1 Introduction

In the Uruguay Round of the General Agreement on Tariffs and Trade, the participating countries agreed to adopt a set of universal minimum standards of intellectual property rights (IPR) protection. This agreement is called the Agreement on Trade-Related Aspects of Intellectual Property Rights (the TRIPS Agreement).\(^1\) It basically supplements the World Intellectual Property Organization Conventions on intellectual property, with substantive obligations and disciplines within the World Trade Organization. According to many observers (e.g., Reichman, 1995), most of the terms of the agreement are backward-looking, based on the prevailing standards in developed countries (the North) at the time of the negotiation. Consequently, developing countries (the South) would have to substantially strengthen their legal protection of IPR.\(^2\) Because of this, it is interpreted that the agreement forces the South to adopt the then prevailing Northern IPR standard.

The TRIPS Agreement can be subject to questions. For example, is the South doing too little to protect IPR (from the Southern and global welfare point of view)? What are the welfare consequences, for the South, the North and the World, of strengthening IPR protection in the South? From the global welfare point of view, does the South protect too much if it adopts Northern IPR standard? Answers to these questions would help address some other important issues. If it is globally optimal for the South to adopt the Northern IPR standard, then the world would be better off if there is a quid pro quo between the two regions: the South adopts the Northern IPR standard and the North allows its market to be more accessible by Southern goods. However, if the Northern IPR standard is so stringent that applying it to the South leads to a decline of global welfare, then the grounds for forcing the South to adopt the Northern IPR standard are much weakened. This paper deals with the above questions and issues directly.

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\(^1\)See UNCTAD (1997) and Maskus (1998) for more about the TRIPS and related issues.

\(^2\)For example, the agreement stipulates patent length of twenty years for the pharmaceutical industry, whereas a country like India only protects pharmaceutical patents for seven years, with compulsory licensing during the protection period.
To achieve this end, based on the stylized facts with minor modifications, we build a North-South model with trade, innovation and imitation. The model has the following assumptions: the South has lower innovative capability than the North, the South does not protect IPR at all before the TRIPS, and the TRIPS forces the South to adopt the IPR standard that the North has adopted before the TRIPS. With this model, we derive a number of results. First, as long as the Southern market is not too small compared to the Northern market and the South’s innovative capability is not too low, the South has incentives to protect IPR. However, its individually optimal IPR protection is not as strong as that of the North. Second, given that the North is committed to its pre-TRIPS standard, it is globally optimal for the South to adopt an IPR standard below the Northern standard. Lastly, under certain conditions (for example, when the Southern market is much smaller than the Northern market), global welfare will be lower if the South is forced to adopt the Northern standard than if the South does not protect IPR at all. Therefore, Northern IPR standard should not be forced upon the South.

Policy implications can be drawn from the present analysis. Although the South has very low capability of innovation, it should have incentives to protect IPR if its market is sufficiently large. We also argue for increasing Southern IPR protection beyond its individually optimal level for the sake of global welfare, since the losses to the South from doing that can be more than compensated by the gains accrued to the North. It suggests that the North should help the South in some other areas so that the South will be willing to strengthen its IPR protection. However, the global welfare reaches the maximum when the South protects IPR at a certain level which is between the South’s individually optimal standard and the Northern standard. Therefore, it may very well be the best for the North to strike a compromise with the South rather than forcing the South to adopt the Northern IPR standard.

There have been various efforts to study both theoretically and empirically the effects of IPR protection on innovation, trade, foreign direct investment and economic growth.\(^3\) As much as we are aware of, however, this paper is among the first to assume that both the North and the

\(^3\)See Mansfield (1986), Maskus and Penubarti (1995), Gould and Gruben (1996), Horowitz and Lai (1996), and Lai (1998). For example, Lai (1998) analyzes how the global rate of technological progress is affected by IPR protection in the South, if the North specializes in innovation and the South specializes in imitation, as in a product cycle model. Since stronger IPR protection in the South can increase the rate of innovation, there is a tradeoff between the dynamic gains and static losses from strengthening IPR protection in the South.
South have innovative capabilities and consider optimal degrees of IPR protection for the North, the South and the world as a whole. There are some other studies in the literature that are related to the present one in one way or another. Both Chin and Grossman (1990) and Deardorff (1992) examine welfare effects of extending IPR protection from the North to the South. They find, as we do, that many results depend on the size of the Southern market. However, there are two notable differences between our paper and those two. First, they assume that the South does not have innovative ability. Second, they examine only the case where the South has either full or no IPR protection. In contrast, we are able to identify the optimal degrees of IPR protection in the North and the South. Diwan and Rodrik (1991) also consider various degrees of IPR protection in the North and the South. Interestingly, they find that to maximize the global welfare which is the equally weighted sum of the Northern and Southern welfare, the rates of patent protection in the two regions must be identical. They derive this result using a model different from ours. Specifically, they emphasize the taste difference between the two regions and assume no innovation from the South. Helpman (1993) has a general equilibrium North-South model, in which the North does the innovation and the South does the imitation, to study both IPR and trade protection. He finds that tightening IPR protection in the South hurts the South and may or may not benefit the North. But we think this result needs to be reconsidered if we take into account the South’s innovative ability. We examine this issue in our partial equilibrium model, which is able to include a more detailed microeconomic analysis of firm and government behaviors.

The organization of the paper is as follows. Section 2 lays out the basic features of the model and derives the optimal IPR protection standard in the North before the TRIPS. Given that

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4Recently, Glass (1999) considers the case where the South acquires the ability to innovate via imitation. But she has a focus different from the present paper. As for the optimal degrees of IPR protection in the North and the South, Richardson and Gaisford (1996) use graphic analysis to show that the South will lose by moving to a common world standard, which resembles the Northern standard. However, they do not consider Southern innovation and global welfare.

5In particular, Deardorff (1992) shows that the global welfare will be reduced if the Northern IPR standard is extended to a very large part of the South. In a related study, Yang (1998) argues that because of the free-ride problem existing among the Southern countries, the Southern IPR protection is too weak.

6Using models with North-South trade, innovation and imitation, the present paper emphasizes the difference of IPR protection between the North and the South, while Qiu (1999) has a focus on comparing the Northern tariff and Southern tariff.

7Taylor (1993) has an interesting study on how Northern firms respond to the lax IPR protection in the South by creating market-made protection, i.e., technology masquing.
the North is committed to that level of IPR protection, we evaluate the individually optimal IPR protection of the South. Section 3 analyzes the properties of the optimal Southern IPR protection standard, and compares it with the Northern standard. Section 4 examines the effect of Southern IPR protection on global welfare. The properties of the globally optimal Southern protection are also analyzed. Section 5 summarizes the findings.

2 The Model and Analysis

There are two regions in the world, the North and the South. There are also two distinct regimes, with regime 1 representing the pre-TRIPS era and regime 2 the post-TRIPS era. To put things in sharper contrast, we assume that the North has high innovative capability while the South has much lower innovative capability. Moreover, we assume that there is no IPR protection in the South while the North establishes its IPR standard in regime 1 taking into account only the innovative capability of the North (i.e. ignoring the innovative capability of the South). In regime 2, the South is forced to adopt the IPR standard that the North has committed to in regime 1. This, we interpret, is what is stipulated in the TRIPS Agreement. To evaluate the TRIPS Agreement, we also consider the case in which the South sets its IPR protection freely in regime 2 given the North has committed to its own standard.

2.1 Regime 1 (pre-TRIPS): Optimal IPR Protection in the North

Consider one or many industries with very high potential for product innovation. Assume that any newly invented product will become obsolete after $T$ periods. At the beginning of this regime, the Northern government sets its IPR protection standard based on the knowledge that the South has negligible innovative capability and does not protect IPR. Although IPR is a very comprehensive concept, we use patent protection to represent IPR protection. Specifically, the Northern government sets patent length $T_n$, meaning that before $T_n$ (periods), imitated products are prohibited from being sold in the region. Then all potential Northern innovators

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8We do not attempt to explain why the South does not protect IPR in Regime 1, but simply take it as a given fact. The assumption is basically consistent with the facts at the time the TRIPS Agreement was signed.

9$T$ can be regarded as the length of the product cycle — after $T$ periods, all previously developed products are completed replaced by better products.
decide whether to make their individual R&D investments, and if they do, new products will be developed.\footnote{We can also interpret $T_n/T$ as the degree of IPR protection. When $T_n = T$, there is full protection of IPR; when $T_n = 0$, there is no protection.} We call the innovator of product $i$ "Northern firm $i$". Given $T_n$, let $M$ be the number of new products introduced to the market. Although the number of products are finite, we assume that they are continuous in our mathematical derivation for easier handling. When the IPR protection expires, all products will be imitated and the imitation cost is assumed to be zero. Assume that there are $N_n$ identical consumers in the North and the representative consumer's utility in period $t$ is:

$$u_n(t) = \int_0^M x_{nn}(i)^\alpha di + y_n, \quad 0 < \alpha < 1,$$

where $x_{nn}(i)$ is the quantity of the new product $i$ consumed by the representative consumer ($x_{nn}(i) = 0$ if product $i$ is not invented or there is no consumption of it), and $y_n$ is the traditional product with the price being normalized to one. Each consumer maximizes her utility subject to budget constraint $I_n \geq \int_0^M p_{nn}(i)x_{nn}(i)di + y_n$ where $p_{nn}(i)$ is the price of product $i$ and the expenditure $I_n$ is exogenously given. For notation simplicity, define $\epsilon \equiv 1/(1 - \alpha)$ and $A = (1 - \alpha)\alpha^{(1+\alpha)\epsilon}$. Then, the derived demand function by the representative consumer is

$$x_{nn}(i) = \left[\frac{p_{nn}(i)}{\alpha}\right]^{-\epsilon}.$$}

Thus, the aggregate demand for product $i$ in the North is

$$X_{nn}(i) = N_n\left[\frac{p_{nn}(i)}{\alpha}\right]^{-\epsilon}.$$}

For simplicity, assume that the marginal cost of production is constant and equal to one for all products. Then, Northern firm $i$'s operational profit (i.e., profit not including innovation costs) is $\pi_{nn}(i) = [p_{nn}(i) - 1]X_{nn}(i)$. Under the IPR protection, firm $i$ is a monopolist in product $i$. As a result, in every period $t \leq T_n$,

$$p_{nn}(i) = \frac{1}{\alpha}, \quad X_{nn}(i) = N_n\alpha^{2\epsilon}, \quad \pi_{nn}(i) = N_nA.$$}

In every period $t > T_n$, because of imitation, prices are driven down to the production cost and so

$$p_{nn}(i) = 1, \quad X_{nn}(i) = N_n\alpha^{\epsilon}, \quad \pi_{nn}(i) = 0.$$
As a result, the representative consumer’s utility is
\[ u_n(t) = M(1 - \alpha)\alpha^{2\alpha\epsilon} + I_n, \quad \text{for } t \leq T_n; \]
\[ u_n(t) = M(1 - \alpha)\alpha^{\alpha\epsilon} + I_n, \quad \text{for } t > T_n. \]

We now turn to firms’ profits. Assume the innovation costs of different products are different. Because of diminishing returns to innovation (sometimes called the ‘fishing out’ problem), the marginal cost of innovation increases with the number of developed products. We index goods in ascending order of the innovation costs, i.e. a good with a lower index \( i \) has a lower innovation cost than a good with a higher \( i \). It is assumed that the innovation cost of product \( i \) is \( i^{1/b} \) where \( 0 < b < 1 \).\(^{11}\) To simplify the analysis, we assume that there is no discount of the future.\(^{12}\) Then, firm \( i \)'s total profit is
\[ \Pi_n(i) = \int_0^{T_n} \pi_m(i)dt - i^b = N_nT_nA - i^b. \]

The cut-off firm, \( M \), is defined as the one that earns zero profit, i.e., \( \Pi_n(M) = 0 \). This leads to
\[ M = (N_nT_nA)^b. \]

Thus, all products with \( i \leq M \) are invented and
\[ \frac{\partial M}{\partial b} = M\ln(N_nT_nA) > 0, \]
as long as \( N_nT_nA > 1 \), which is assumed. Moreover,
\[ \frac{\partial M}{\partial T_n} = \frac{bM}{T_n} > 0, \quad \frac{\partial^2 M}{\partial T_n^2} = \frac{b(b - 1)M}{T_n^2} < 0. \]

The welfare function of the North, denoted by \( W_n(T_n) \) or \( w_n(T_n, M) \), is defined as the sum of consumer utility and producer profits, which is given as
\[ W_n(T_n) = w_n(T_n, M) = N_n \int_0^{T_n} u_n(t)dt + N_n \int_{T_n}^{T} u_n(t)dt + \int_0^{M} \Pi_n(i)di \]
\[ = N_nT_nM(1 - \alpha)\alpha^{2\alpha\epsilon} + N_n(T - T_n)M(1 - \alpha)\alpha^{\alpha\epsilon} + N_nTI_n + MN_nT_nA - \frac{b}{1 + b}M^{1/b}. \]

\(^{11}\)We could instead use a more general cost function such as \( a + \gamma i^{1/b} \) where \( \gamma > 0 \); or more generally, \( f(i) \), where \( f(0) \geq 0, f'(i) > 0 \). But our results will not be altered qualitatively.

\(^{12}\)Our results will not be affected qualitatively even if the future is discounted.
The Northern government’s objective is to maximize the Northern welfare by choosing $T_n$. Assuming interior solution, the first order condition for optimal $T_n$ is

$$\frac{dW_n}{dT_n} = \frac{\partial w_n}{\partial T_n} + \frac{\partial w_n}{\partial M} \frac{\partial M}{\partial T_n} = 0.$$ 

Note that

$$\frac{\partial w_n}{\partial T_n} = -N_n M [1 - (1 + \alpha)\alpha^\alpha] (1 - \alpha)\alpha^\alpha < 0.$$ 

This is the marginal effect of lengthening IPR protection for existing products. It is the sum of consumer losses and producer gains, which adds up to a deadweight loss. This is the social marginal cost of IPR protection, denoted by $MC \equiv |\partial w_n/\partial T_n|$. The magnitude of $MC$ increases as $T_n$ increases:

$$\frac{\partial MC}{\partial T_n} = N_n \frac{\partial M}{\partial T_n} [1 - (1 + \alpha)\alpha^\alpha] (1 - \alpha)\alpha^\alpha > 0.$$ 

On the other hand, lengthening IPR protection encourages more innovations, which enlarges product variety and so raises consumer welfare. This is the social marginal benefit (MB) of increasing $T_n$:

$$MB \equiv \frac{\partial w_n}{\partial M} \frac{\partial M}{\partial T_n} = N_n [T - T_n (1 - \alpha^\alpha)](1 - \alpha)\alpha^\alpha \frac{\partial M}{\partial T_n} > 0.$$ 

It is easy to check that the MB decreases as $T_n$ increases.

(FIGURE 1 IS ABOUT HERE)

The optimal IPR protection in the North, denoted by $T_n^\ast$, is chosen such that $MC = MB$, as in Figure 1.\(^{13}\) With the above analysis, the first order condition reduces to\(^{14}\)

$$T_n [1 - (1 + \alpha)\alpha^\alpha] = [T - T_n (1 - \alpha^\alpha)] b, \quad (1)$$

where

$LHS = \frac{MC}{N_n MT_n^{-1} A(1 - \alpha)\alpha^\alpha}, \quad RHS = \frac{MB}{N_n MT_n^{-1} A(1 - \alpha)\alpha^\alpha}.$

Solving equation (1) gives the optimal protection:

$$T_n^\ast = \frac{bT}{1 - (1 + \alpha + b)\alpha^\alpha + b}. \quad (2)$$

\(^{13}\)It can be shown that $\partial^2 MC/\partial T_n^2 < 0$ and $\partial^2 MB/\partial T_n^2 > 0$.

\(^{14}\)The second order condition is automatically satisfied as it can be easily checked that $d^2 W_n/dT_n^2 < 0$. 


To ensure an interior solution, we need to impose some constraints on the parameters. Using (2), a necessary and sufficient condition for $T_n^* > 0$ is $1 + b - (1 + \alpha + b)\alpha^\alpha > 0$, which is automatically satisfied, and the necessary and sufficient condition for $T_n < T$ is:

**Constraint 1:** \[ 1 - (1 + \alpha + b)\alpha^\alpha > 0. \]

This latter condition requires that $b$ is not too big. When $b$ increases, both MC and MB are higher. But if $b$ is too big, a small increase in the IPR protection will induce a lot of innovations, i.e., MB becomes much higher. It makes it worthwhile for the North to continue raising protection until $T$. Graphically, in Figure 1, both the MC and MB curves shift up but the MB curves shifts up more. For a sufficiently large $b$, the MB curve will intersect the MC curve at $T_n \geq T$. We now have our first result:

**Proposition 1:** Under Constraint 1, the optimal length of IPR protection in the North is as given in (2), which is less than $T$. A decrease in the cost of innovation across all firms warrants stronger IPR protection, i.e., $\partial T_n^*/\partial b > 0$. Moreover, $\partial T_n^*/\partial T > 0$. That is, an increase in the length of the product cycle raises the optimal length of IPR protection.

**PROOF:** Straightforward from (2). □

To see these results, first, recall that both the MC and MB curves shift upwards as $b$ increases. However, the MB-to-MC ratio increases as $b$ increases, indicating that the impact of $b$ on MB is larger than the impact on MC. Therefore, $T_n^*$ increases. Second, an increase in $T$ increases MB without affecting MC. Therefore, $T_n^*$ increases with $T$.

### 2.2 Regime 2 (post-TRIPS): Optimal IPR Protection in the South

In this regime, the South is required to adopt the Northern standard, that is, $T_s = T_n^*$ is forced upon the South, where $T_s$ is the patent length in the South. However, in this subsection, we first ignore the constraint $T_s = T_n^*$ to evaluate the individually optimal IPR standard of the South given that $T_n = T_n^*$, which is part of the TRIPS Agreement.

Let us consider only the case of “national treatment” as stipulated in the TRIPS Agreement of the Uruguay Round. That is, all products in the same market are protected for the same periods regardless of their origins. Given $T_n^*$ and $T_s$, let $M_n$ and $M_s$ be the numbers of new products introduced in the North and the South, respectively. While products $i$ and $j$ ($i \neq j$), produced in the North or the South, are different products, we should also treat product $i$
innovated by the North and product $i$ innovated by the South as different products. Suppose there are $N_s$ identical consumers in the South. With trade in new products, the Southern representative consumer’s utility in period $t$ is:

$$u_s(t) = \int_0^{M_s} x_{ss}(i)\alpha di + \int_0^{M_n} x_{ns}(i)\alpha di + y_s, \quad 0 < \alpha < 1,$$

where $x_{ss}(i)$ is the amount of Southern product $i$ consumed by this consumer in the Southern market, $x_{ns}(i)$ is the amount of Northern product $i$ consumed by this consumer in the Southern market, and $y_s$ is the traditional good with price equaling to one. Let $p_{ss}$ and $p_{ns}$ be the prices of the corresponding products in the Southern market. The consumer maximizes her utility subject to budget constraint $I_s \geq \int_0^{M_s} p_{ss}(i)x_{ss}(i)di + \int_0^{M_n} p_{ns}(i)x_{ns}(i)di + y_s$. The derived demand is

$$x_{ss}(i) = \left[\frac{p_{ss}(i)}{\alpha}\right]^{-\epsilon} \text{ and } x_{ns}(i) = \left[\frac{p_{ns}(i)}{\alpha}\right]^{-\epsilon}.$$

Hence, the aggregate demand for Southern product $i$ in the Southern market and that for Northern product $i$ are, respectively,

$$X_{ss}(i) = N_s\left[\frac{p_{ss}(i)}{\alpha}\right]^{-\epsilon} \text{ and } X_{ns}(i) = N_s\left[\frac{p_{ns}(i)}{\alpha}\right]^{-\epsilon}.$$

As in the North, assume for simplicity that the constant marginal cost of production is equal to one for all Southern products. Thus, Southern firm $i$’s operational profit from the South’s market is $\pi_{ss}(i) = [p_{ss}(i) - 1]X_{ss}(i)$, and Northern firm $i$’s operational profit from export to the Southern market is $\pi_{ns}(i) = [p_{ns}(i) - 1]X_{ns}(i)$. Under the IPR protection in the South, each firm is a monopolist in its product market. As a result, for $t \leq T_s$,

$$p_{ss}(i) = p_{ns}(i) = 1, \quad X_{ss}(i) = X_{ns}(i) = N_s\alpha^2, \quad \pi_{ss}(i) = \pi_{ns}(i) = N_s\alpha.$$

For $t > T_s$, imitation takes place in the South and therefore there is no demand for imports. However, products previously innovated by the North and now imitated by the South are still traded in the Southern market. As a result, for $t > T_s$,

$$p_{ss}(i) = p_{ns}(i) = 1, \quad X_{ss}(i) = X_{ns}(i) = N_s\alpha^\epsilon, \quad \pi_{ss}(i) = \pi_{ns}(i) = 0.$$

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15 We assume free trade in order to focus on IPR policy. Qiu (1999) considers tariff but treats IPR policy as given.

16 In general, labor cost is lower in the South than that in the North while innovation cost is higher in the South than that in the North. However, we emphasize the North-South difference in innovation costs here.
Therefore, the representative consumer’s utility at time $t$ is:

$$u_s(t) = (M_s + M_n)(1 - \alpha)\alpha^{2\alpha^c} + I_s, \quad \text{for } t \leq T_s;$$

$$u_s(t) = (M_s + M_n)(1 - \alpha)\alpha^{\alpha^c} + I_s, \quad \text{for } t > T_s.$$

We shall skip the analysis of the Northern market, which is similar to that of the Southern market. Note that Southern firm $i$’s profit derived from exporting to the Northern market is $\pi_{sn}(i) = N_nA$, for $t \leq T_n^s$, and zero for $t > T_n^s$. In the South, assume that the innovation cost of product $i$ is $i^{1/c}$ where $0 < c < 1$. Southern firm $i$ sells its product to both the Southern market and the Northern market. Thus, its total profit is

$$\Pi_s(i) = \int_0^{T_s} \pi_{ss}(i)dt + \int_{T_s}^{T_n^*} \pi_{sn}(i)dt - i^\frac{1}{c} = (N_sT_s + N_nT_n^*)A - i^\frac{1}{c}.$$

Similarly, the total profit of Northern firm $i$, is

$$\Pi_n(i) = \int_0^{T_n^*} \pi_{nn}(i)dt + \int_{T_n^*}^{T_s} \pi_{ns}(i)dt - i^\frac{1}{b} = (N_sT_s + N_nT_n^*)A - i^\frac{1}{b}.$$

The cut-off firm in the North, $M_n$, and that in the South, $M_s$, are defined as the ones that earn zero profit, i.e., $\Pi_n(M_n) = 0$ and $\Pi_s(M_s) = 0$, respectively. This leads to

$$M_n = \mu^b \quad \text{and} \quad M_s = \mu^c \quad \text{where} \quad \mu \equiv (N_sT_s + N_nT_n^*)A.$$

Thus,

$$\frac{\partial M_n}{\partial b} = \mu^b \ln(\mu) > 0, \quad \frac{\partial M_s}{\partial c} = \mu^c \ln(\mu) > 0,$$

since $\mu > 1$. Moreover,

$$\frac{\partial M_n}{\partial T_s} = N_s b \mu^{b-1} A > 0, \quad \frac{\partial^2 M_n}{\partial T_s^2} = N_s^2 b (b - 1) \mu^{b-2} A^2 < 0,$$

$$\frac{\partial M_s}{\partial T_s} = N_s c \mu^{c-1} A > 0, \quad \frac{\partial^2 M_s}{\partial T_s^2} = N_s^2 c (c - 1) \mu^{c-2} A^2 < 0.$$

The welfare of the South, denoted by $W_s(T_s)$ or $w_s(T_s, M_s, M_n)$, is defined and given as

$$W_s(T_s) = w_s(T_s, M_s, M_n) = N_s \int_0^{T_s} u_s(t)dt + N_s \int_{T_s}^{T} u_s(t)dt + \int_0^{M_s} \Pi_s(i)di$$

$$= N_sT_s[(M_s + M_n)(1 - \alpha)\alpha^{2\alpha^c} + N_s(T - T_s)[(M_n + M_s)(1 - \alpha)\alpha^{\alpha^c} + N_sTI_s].$$
+M_s(N_sT_s + N_nT_n)A - \frac{c}{1 + c} M_s^{1+c}.

The Southern government’s objective is to maximize the Southern welfare by choosing $T_s$. Assuming interior solution, the first order condition for optimal $T_s$ is

$$\frac{dW_s}{dT_s} = \frac{\partial w_s}{\partial T_s} + \frac{\partial w_s}{\partial M_s} \frac{\partial M_s}{\partial T_s} + \frac{\partial w_s}{\partial M_n} \frac{\partial M_n}{\partial T_s} = 0.$$  

Note that

$$\frac{\partial w_s}{\partial T_s} = -N_s\{M_s[1 - (1 + \alpha)\alpha^{\alpha_e}] + M_n(1 - \alpha^{\alpha_e})\}(1 - \alpha)\alpha^{\alpha_e} < 0.$$  

The social marginal cost (i.e. the deadweight loss) of IPR protection in the South, denoted by $MC = |\partial w_s/\partial T_s|$, increases with $T_s$:

$$\frac{\partial MC}{\partial T_s} = N_s\{\frac{\partial M_s}{\partial T_s}[1 - (1 + \alpha)\alpha^{\alpha_e}] + \frac{\partial M_n}{\partial T_s}[1 - \alpha^{\alpha_e}]\}(1 - \alpha)\alpha^{\alpha_e} > 0.$$  

On the other hand, using the zero profit condition for firm $M_s$ and firm $M_n$, respectively, we have

$$\frac{\partial w_s}{\partial M_s} \frac{\partial M_s}{\partial T_s} = N_s[T - T_s(1 - \alpha^{\alpha_e})](1 - \alpha)\alpha^{\alpha_e} \frac{\partial M_s}{\partial T_s} > 0,$$

$$\frac{\partial w_s}{\partial M_n} \frac{\partial M_n}{\partial T_s} = N_s[T - T_s[1 - \alpha^{\alpha_e}]\](1 - \alpha)\alpha^{\alpha_e} \frac{\partial M_n}{\partial T_s} > 0,$$

the sum of which captures the social marginal benefit (MB) from raising $T_s$. It is easy to check that the marginal benefit is decreasing in $T_s$.

We can draw a figure, which is similar to Figure 1, to show that at the optimal Southern IPR protection, $T_s^*$, the MC curve and the MB curve intersect. Mathematically, $T_s^*$ is determined by the first-order condition, which is reduced to

$$\mu^c[1 - (1 + \alpha)\alpha^{\alpha_e}] + \mu^b(1 - \alpha^{\alpha_e}) = N_s A[T - T_s(1 - \alpha^{\alpha_e})](\epsilon \mu^{c-1} + b \mu^{b-1}), \quad (3)$$

where

$$\text{LHS} = \frac{MC}{N_s(1 - \alpha)\alpha^{\alpha_e}}, \quad \text{RHS} = \frac{MB}{N_s(1 - \alpha)\alpha^{\alpha_e}}.$$  

First, we check the constraints on the parameters. Using (3), we show that with Constraint 1 in place, a sufficient condition for $T_s^* \leq T$ is

**Constraint 2:** \( 1 - (1 + \alpha + c)\alpha^{\alpha_e} > 0. \)

\footnote{The second order condition is automatically satisfied as it can be easily checked that $d^2W_s/dT_s^2 < 0$.}
It requires that $c$ is small. The reason is similar to that for Constraint 1.

Again, by setting $T_s = 0$ in (3) and imposing LHS $< \text{RHS}$, we obtain a sufficient condition for $T_s^* > 0$:

$$N_n T_n^* [1 - (1 + \alpha)\alpha^{\alpha\epsilon}] - N_s T c < 0 \quad \text{and} \quad N_n T_n^* (1 - \alpha^{\alpha\epsilon}) - N_s T b < 0.$$  

Using (2), the above condition reduces to, respectively, $N_s b [1 - (1 + \alpha)\alpha^{\alpha\epsilon}] / [1 - (1 + \alpha + b)\alpha^{\alpha\epsilon} + b]$ and $N_n (1 - \alpha^{\alpha\epsilon}) < N_s [1 - (1 + \alpha + b)\alpha^{\alpha\epsilon} + b]$. Thus, to have $T_s^* > 0$, we need

**Constraint 3:**

$$\frac{N_s}{N_n} > \max \left\{ \frac{b[1 - (1 + \alpha)\alpha^{\alpha\epsilon}]}{c[1 - (1 + \alpha + b)\alpha^{\alpha\epsilon} + b]}, \frac{1 - \alpha^{\alpha\epsilon}}{1 - (1 + \alpha + b)\alpha^{\alpha\epsilon} + b} \right\}.$$  

We summarize the above analysis in Proposition 2 below.

**Proposition 2:** It is optimal for the South to protect IPR as long as the Southern market is sufficiently large compared with the Northern market.

Conversely, we can also show that if $N_s$ is very small relative to $N_n$ and $c$ is very small relative to $b$, then the optimal Southern IPR protection is a corner solution: $T_s^* = 0$.

We have shown that, unlike the South, the North finds it always optimal (in regime 1) to protect IPR even if $N_n$ is very small. This difference arises from the different opportunity of trade. We will discuss the impact of international trade on the optimal Southern IPR protection in the next section.

### 3 Analysis of the Optimal IPR Standards

In the preceding section, we have derived the conditions which determine the optimal Southern IPR protection given that $T_n = T_n^*$. In this section, we examine some properties of this optimal Southern protection and compare the Southern protection with its Northern counterpart in regime 1. First, we explore how $T_s^*$ depends on the Northern IPR protection. To do this, we replace $T_n^*$ in (3) by $T_n$ that can take any value from 0 to $T$. Then, we have

**Lemma 1:** Suppose $0 < T_s^* < T$. Then, an increase in $T_n$ leads to a strict decrease in $T_s^*$, i.e., $\partial T_s^*/\partial T_n < 0$.  

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PROOF: From (3), it is obvious that $\partial \text{LHS}/\partial T_s > 0$, $\partial \text{LHS}/\partial T_n > 0$, $\partial \text{RHS}/\partial T_s < 0$, and $\partial \text{RHS}/\partial T_n < 0$. Therefore, an increase in $T_n$ must be accompanied by a decrease in $T_s$ to restore equality of the LHS and RHS. \(\square\)

Therefore, stronger protection in the North makes it optimal for the South to protect less. The main reason for the substitution effect of Northern protection for Southern protection is that as $T_n$ increases, the product variety is enlarged due to more incentive to innovate, and so the MC curve of the Southern protection shifts up. This calls for a reduction of protection in the South, $T_s$. On the other hand, the MB curve of the Southern protection shifts down when consumers have obtained larger product variety, due to the decreasing effect of variety on marginal benefit. This also calls for lowering IPR protection in the South.

Next, we examine the implications of market size for optimal IPR protection.

**Proposition 3 :** The optimal IPR protection in the South is stronger if the Southern market becomes larger, or the Northern market becomes smaller. Mathematically, $\partial T_s^n/\partial N_s > 0$ and $\partial T_s^n/\partial N_n < 0$.

PROOF: See Appendix A. \(\square\)

It is interesting to understand why the two market sizes have the opposite impacts on the optimal Southern IPR protection. The intuition behind $\partial T_s^n/\partial N_n < 0$ is the same as that behind $\partial T_s^n/\partial T_n < 0$, which is given above: a larger Northern market results in larger product variety, which increases the MC of protection and lowers the MB of protection. While a larger Southern market also leads to larger product variety, which therefore requires lowering the Southern IPR protection, more consumers in the South benefit from raising Southern IPR protection, increasing the MB of protection. This latter effect dominates the former one.

Finally, we obtain the last result of this section.

**Proposition 4 :** $T_s^n < T_n^n$. That is, it is individually optimal for the South to protect IPR less than the North does.

PROOF: See Appendix B. \(\square\)

It is important to understand why it is optimal for the South to adopt an IPR standard lower than what the North is committed to. There are three reasons: (1) the South has lower innovative capability than the North does; (2) the South does not benefit from the additional profits accrued
to Northern firms as $T_s$ increases; and (3) the South takes into account the committed Northern IPR protection and trade opportunity when evaluating its optimal protection whereas the North neglects the innovative capability of the South. Now we further explain why these three factors give rise to the result of Proposition 4. Recall that the MC-to-MB ratio of the Northern IPR protection is equal to one at $T_n = T_n^*$, and now in regime 2, the MC-to-MB ratio of the Southern IPR protection is equal to one at $T_s = T_s^*$. Thus, $T_s^*$ is smaller than $T_n^*$ if and only if the MC-to-MB ratio of IPR protection by the South is greater than one at $T_s = T_s^*$. The intuition for Proposition 4, therefore, comes from the fact that, when the South protects as much as the North, it finds that the marginal cost of protection is greater than the marginal benefit. So, it is optimal for the South to lower its IPR protection below that of the North. Suppose now that $T_s = T_n^*$. First, there is the fact that $b > c$ gives the South less incentive to protect IPR, since the MC-to-MB ratio increases as $b$ decreases. Second, because the South does not benefit from the increased profits of Northern firms as $T_s$ increases, the MC for the South increases further. However, when $T_n^*$ is set in regime 1, the Northern government takes into account profits accrued to all innovators since the South does not innovate or its innovation is negligible. Third, the fact that the South takes into account the committed Northern protection and trade opportunity results in a higher MC-to-MB ratio. To see why, suppose for the sake of discussion that $b = c$, $N_s = N_n$, and the South can capture the increased profits of Northern firms resulting from increased $T_s$. Then the autarky IPR protection of the South should be the same as that of the North. However, the South takes into account international trade, which enables the South to consume Northern products. Therefore, compared with autarky, the product variety available to Southern consumers has been expanded. Moreover, the Southern firms can sell their products to the North and thus there are more Southern innovations compared with autarky. Because MC increases with variety, the MC of the Southern protection is more than double of that under autarky. On the other hand, since MB decreases with variety, the MB of Southern protection is less than double of that under autarky. (More generally, when $N_s \neq N_n$, MC increases more than proportionately does MB.) Therefore, there is an increase in the MC-to-MB ratio of the South to above one when $T_s = T_n^*$. 

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4 Southern IPR Standard and Global Welfare

In this section, we evaluate the globally optimal IPR standard of the South given that \( T_n = T_n^* \). We also examine the condition under which the world benefits from increasing Southern IPR standard from \( T_s = 0 \) to \( T_s = T_s^* \).

First, we evaluate the South’s best response given \( T_n = T_n^* \). Based on the analysis of subsection 2.2, the Northern representative consumer’s utility at time \( t \) is

\[
\begin{align*}
  u_n(t) &= (M_s + M_n)(1 - \alpha)\alpha^{2\alpha} + I_n, \quad \text{for } t \leq T_n^*, \\
  u_n(t) &= (M_s + M_n)(1 - \alpha)\alpha^{\alpha} + I_n, \quad \text{for } t > T_n^*.
\end{align*}
\]

Thus, the Northern welfare in regime 2, denoted by \( W_n(T_s) \) or \( w_n(T_s, M_s, M_n) \), is defined and given as

\[
W_n(T_s) = w_n(T_s, M_s, T_n^*, M_n) = N_n \int_0^{T_n^*} u_n(t)dt + N_n \int_{T_n^*}^T u_n(t)dt + \int_0^{M_n} \Pi_n(i)di
\]

\[
= N_n(M_n + M_s)(1 - \alpha)\alpha^{\alpha}[T - T_n^*(1 - \alpha^{\alpha})] + N_n T_l + M_n(N_s T_s + N_n T_n^* A) - \frac{b}{1 + b} M_n^{1+b}.
\]

Recall that \( M_n = \mu^b \) where \( \mu = (N_s T_s + N_n T_n)A \). Therefore, for all \( T_s \),

\[
\frac{\partial W_n}{\partial T_s} = N_n \left( \frac{\partial M_n}{\partial T_s} + \frac{\partial M_s}{\partial T_s} \right)(1 - \alpha)\alpha^{\alpha}[T - T_n^*(1 - \alpha^{\alpha})] + \mu^b \frac{\partial \mu}{\partial T_s} > 0. \tag{4}
\]

Similarly, by assuming that the Northern protection \( T_n \) can also be changed, we can show \( \partial W_n/\partial T_n > 0 \). We immediately obtain the following result.\(^{18}\)

**Lemma 2**: The North (South) always benefits from stronger IPR protection in the South (North), regardless of the current degree of protection in the South and the North, i.e., \( \partial W_n/\partial T_s > 0 \) and \( \partial W_s/\partial T_n > 0 \).

The benefit comes from enlarging product variety in both countries (\( \partial M_n/\partial T_s > 0 \) and \( \partial M_s/\partial T_n > 0 \)) and increasing innovators’ profits (\( \partial \Pi_n(i)/\partial T_s > 0 \) and \( \partial \Pi_s(i)/\partial T_n > 0 \)). As a result of stronger IPR protection in foreign countries, a country’s consumers enjoy more

\(^{18}\)If, however, consumers from the two regions have different tastes on products, it is possible that the North (South) cannot always benefit from stronger IPR protection in the South (North), as shown by Diwan and Rodrik (1991).
foreign product variety, and its firms’ profits also increase. There is, therefore, a positive cross-
border externality of strengthening IPR protection. Since a country’s individually optimal IPR
protection does not take into account this positive externality, IPR is underprotected from the
world’s point of view if countries all adopt their individually optimal IPR standards.

We now turn to considering the impact of increasing South’s IPR protection on global welfare.
By definition, the global welfare is the sum of the two regions’ welfare, \( W(T_s) = W_n(T_s) + W_s(T_s) \).
First, we can easily check that \( W(T_s) \) is concave in \( T_s \), i.e., \( d^2W/dT_s^2 < 0 \), for all \( T_s \). Second,
by (3) and (4), we have,
\[
\frac{dW}{dT_s}|_{T_s=T_s^*} = \frac{dW_n}{dT_s}|_{T_s=T_s^*} + \frac{dW_n}{dT_s}|_{T_s=T_s^*} > 0. \tag{5}
\]
That is, provided that there is no corner solution for \( T_s^* \), by slightly raising the Southern IPR
protection from its individually optimal level, \( T_s^* \), the global welfare increases. This is due to the
positive externality of IPR protection indicated by Lemma 2. This result supports the argument
of raising Southern IPR protection. The question is how far the Southern IPR protection should
be raised in order to achieve the global welfare optimum.

Differentiating \( W(T_s) \) with respect to \( T_s \) gives
\[
\frac{dW}{dT_s} = -(1 - \alpha)\alpha^{ \alpha ^{\cdot}} N_s \mu^c (1 + \alpha) \alpha ^{\cdot} + \mu (1 - \alpha ^{\alpha ^{\cdot}}) + A(1 - \alpha)\alpha^{ \alpha ^{\cdot}} N_s \mu^c (1 - \alpha ^{\alpha ^{\cdot}}) + \mu (1 - \alpha ^{\alpha ^{\cdot}}) + N_s A \mu^b. \tag{6}
\]
If \( dW/dT_s \geq 0 \) at \( T_s = T_n^* \), then raising the Southern standard to the Northern standard
will increase global welfare. Otherwise, the global welfare is maximized by allowing \( T_s < T_n^* \).
We show in Proposition 5 below that the former case never occurs. Let \( T_s^w \equiv \text{argmax } W \), the
Southern IPR protection which maximizes the global welfare.

**Proposition 5**: The global welfare is maximized when the IPR protection in the South is at
a level below that of the North. Mathematically,
\[
\frac{dW}{dT_s} \bigg|_{T_s=T_n^*} < 0, \text{ which, together with (5), implies } T_s^* < T_s^w < T_n^*.
\]

**Proof**: See Appendix C. □
Refer to Figure 2. It is obvious that we just need to explain the inequality $T^w_s < T^*_n$. Recall from Proposition 1 that $T^*_n$ is the optimal IPR protection for the North and it is chosen when the North assumes there is no trade in the new products with the South. When the IPR protection is chosen in a closed economy, there is no underprotection since there is no externality in IPR protection. The globally optimal IPR protection should internalize any cross-border externality arising from a country’s IPR protection, just as the choice of $T^*_n$ internalizes all the externalities within a closed economy. Notice also that $T^*_n$ does not depend on the market size. Therefore, if $b = c$, the optimal global IPR protection should be equal to $T^*_n$. On the other hand, $T^*_n$ increases with $b$ (by Proposition 1). This implies that $T^w_s < T^*_n$ since $b > c$. In other words, given $T_n = T^*_n$, the value of $T_s$ that maximizes global welfare is less than $T^*_n$ because the innovative ability of the South is lower than that of the North.

While it is globally optimal for the South to adopt a lower IPR standard than the North, the globally optimal Southern IPR standard gets higher as the South gets larger. This is proved in Proposition 6 below.

**Proposition 6:** The Southern IPR protection that maximizes global welfare is an increasing function of the size of the Southern market. Mathematically, we have $\partial T^w_s / \partial N_s > 0$.

**PROOF:** See Appendix D. □

The Southern market size may affect the globally optimal IPR protection in many ways, but the following is the most important one. We have now understood that the reason for $T^w_s > T^*_s$ is that the former ($T^w_s$) takes into account the positive cross-border externality of the Southern IPR protection, but the latter ($T^*_s$) does not. As $N_s$ increases, there is a higher demand for goods from the Southern market as well as a greater Southern-developed product variety, and therefore the magnitude of the positive externality of Southern IPR protection is greater. This calls for an increase in Southern IPR protection to internalize the externality.

Thus, the global welfare is not maximized by forcing the South to adopt the Northern standard. To emphasize this point, we show that under certain plausible conditions, the global welfare is higher at $T_s = 0$ (allowing the South not to protect at all) than at $T_s = T^*_n$. Furthermore,
the global welfare may even reach its maximum at $T_s = 0$. We now explore these possibilities. We do this by numerical simulation using Mathematica. The conclusion is summarized below:

**Proposition 7**: (Numerical result) When the Southern market is sufficiently smaller and the Southern innovative capability is sufficiently lower than those of the North, global welfare is lower when the South is forced to adopt the Northern IPR standard than when the South is allowed to have no IPR protection at all.

For example, when $\alpha = 0.5, b = 0.3, c = 0.1, T = 20$ and $N_n = 100$, we find that $W(T_s = 0) > W(T_s = T_{n}^{*})$ when $N_s < 32$. Moreover, when $\alpha = 0.5, b = 0.3, T = 20, N_n = 100$ and $N_s = 20$, we find that $W(T_s = 0) > W(T_s = T_{n}^{*})$ when $c < 0.2$. See Figures 3, 4 and 5A. In Figure 5B, $T_n^w = 0$. In such a situation, the argument for forcing the South to adopt the IPR standard of the North is much weakened.

(FIGURES 3-5 ARE ABOUT HERE)

5 Summary and Conclusion

As far as we are aware of, our paper is one of the first on IPR protection that assume that all countries have the capability to innovate and that there is an optimal degree of IPR protection for each country/region. We also assume that the South does not protect IPR at all before the TRIPS Agreement was signed. We interpret the TRIPS Agreement as one that commits the world to the prevailing IPR standard of the North at the time the agreement was signed. Many interesting results are obtained. Some of them agree with the findings in the literature, but a richer set of results are obtained. A summary of our findings is given below.

As long as the Southern market is sufficiently large compared with the Northern market, it is optimal for the South to protect IPR.

There is a positive cross-border externality in strengthening a country’s IPR protection under free trade. Therefore, when it is individually optimal for the South to protect IPR at all, it is globally optimal for the South to increase its IPR protection above its individually optimal level, at least to a certain extent. This contrasts with the result in Chin and Grossman (1990). Our result suggests that it would be mutually beneficial to both regions for the South to improve its
existing level of protection, at least up to a certain point, provided that the North compensates
the South sufficiently so as to leave the latter at least as well-off as before.

Although it might be globally optimal for the South to increase its IPR protection above its
individually optimal level, it is globally optimal for the South to adopt a weaker IPR standard
than that of the North. The main reason is that the South has lower capability to innovate
than the North does. Interestingly, this means that even for products for which the South has
a much larger market than the North does, it is still globally optimal for the South to adopt a
IPR standard lower than that of the North. This contrasts with what is obtained in Diwan and

Under certain conditions (for example, when the Southern market is much smaller than the
Northern market and the innovative capability of the South is much lower than that of the
North), global welfare will be lower if the South is forced to adopt the Northern standard than
if the South is allowed to have no IPR protection at all.

As the South gets larger, it is individually optimal for it to strengthen IPR protection.
(Therefore, as China’s market for patented goods grows, it should have more incentive to
strengthen IPR protection.) Whereas Chin and Grossman (1990) find that it is optimal for
the South to protect IPR when its market is sufficiently large, we find that it is optimal for the
South to strengthen the protection when its market becomes larger; but the Southern incentive
to protect IPR can never be as strong as the Northern incentive.

As the Southern market gets larger, it is also globally optimal for the South to strengthen
its IPR protection. This result is somewhat consistent with Deardorff (1992), who finds that
when the fraction of the world that is weak in IPR protection is large, it is globally optimal
to extend the strong IPR protection to more of these countries. What was not addressed by
Deardorff (1992), but has been addressed by us, is that the globally optimal level of protection
in the South would never be as high as the Northern standard as long as the South has lower
innovative capability than the North does.

For future extension, we can modify the existing model to a dynamic one, with the length of
the product cycle and the rate of technological change endogenized through learning-by-doing
or research and development. In that case, Northern as well as Southern IPR protection would
have to take into account their impact on the rate of technological change. Second, we can
consider the interaction among trade policy, FDI policy and IPR policy in a unified model.
Appendix

A Proof of Proposition 3.

Define $P \equiv A[T - T_s(1 - \alpha^{ac})]c$; $Q \equiv [1 - (1 + \alpha)\alpha^{ac}]$; $R \equiv A[T - T_s(1 - \alpha^{ac})]b$ and $S \equiv (1 - \alpha^{ac})$. All of these expressions are independent of $N_s$. Recall that $\mu \equiv N_sT_n + N_nT_n$. Equation (3) can be rewritten as

$$PN_s\mu^{c-1} - Q\mu^c + RN_s\mu^{b-1} - S\mu^b = 0$$

It is straightforward to prove that $\frac{\partial}{\partial N_s}(PN_s\mu^{c-1} - Q\mu^c) > 0$, $\frac{\partial}{\partial N_s}(RN_s\mu^{b-1} - S\mu^b) > 0$, and $\frac{\partial}{\partial T_s}(PN_s\mu^{c-1} - Q\mu^c + RN_s\mu^{b-1} - S\mu^b) < 0$. Therefore, $\frac{\partial T_s^{*}}{\partial N_s} > 0$ from the implicit function theorem.

Similarly, we can prove that $\frac{\partial}{\partial N_n}(PN_s\mu^{c-1} - Q\mu^c) < 0$ and $\frac{\partial}{\partial N_n}(RN_s\mu^{b-1} - S\mu^b) < 0$. Therefore, $\frac{\partial T_s^{*}}{\partial N_n} < 0$.

B Proof of Proposition 4.

The result obviously holds if $T_s^{*} = 0$. Otherwise, the optimal $T_s^{*}$ is determined by equation (3). What we are going to show below is that LHS(3) > RHS(3) when $T_s^{*} = T_n^{*}$, where LHS and RHS correspond to those of (3), respectively. Therefore the optimal $T_s^{*}$ is less than $T_n^{*}$ in order to restore equality of both sides of equation (3).

From (3), we have

$$LHS(3) > (\mu^c + \mu^b)[1 - (1 + \alpha)\alpha^{ac}]$$

(since the increased profits of Northern firms do not increase Southern welfare)

$$> \frac{\mu}{b} \cdot (c\mu^{c-1} + b\mu^{b-1})[1 - (1 + \alpha)\alpha^{ac}] \quad \text{since } b > c$$

$$> \frac{N_s}{N_n} \cdot \left(\frac{m}{b}\right)(c\mu^{c-1} + b\mu^{b-1})[1 - (1 + \alpha)\alpha^{ac}] \quad \text{since } \mu > m, \text{and we impose } T_n^{*} = T_s^{*}$$

$$= [T - T_n^{*}(1 - \alpha^{ac})] AN_n \cdot \frac{N_s}{N_n} \cdot (c\mu^{c-1} + b\mu^{b-1}) \quad \text{from equation (1)}$$

$$= RHS(3).$$

Therefore, LHS(3) > RHS(3) when $T_s^{*} = T_n^{*}$. That is, when the South protects as much as the North, it finds that the marginal cost of protection is greater than the marginal benefit
of protection. So, it is optimal for the South to lower its IPR protection to below that of the North.

C Proof of Proposition 5.

Based on (6), we obtain

$$\frac{dW}{dT_s}|_{T_s = T_n^*} = -(1 - \alpha)\alpha^\alpha N_s(\Phi_4 + \Phi_5),$$

where $$\Phi_4 = [(N_s + N_n)AT_n^*] \{1 - (1 + \alpha)\alpha^\alpha - c[T - T_n^*(1 - \alpha^\alpha)]/T_n^*\},$$ and $$\Phi_5 = [(N_s + N_n)AT_n^*] \{1 - \alpha^\alpha - b[T/T_n^* - (1 - \alpha^\alpha)] - \alpha^\epsilon\}.$$ Substituting $$T_n^*$$, we can easily show $$\Phi_5 = 0$$ and

$$\Phi_4 = [(N_s + N_n)AT_n^*] \{1 - \alpha^\alpha - b[T/T_n^* - (1 - \alpha^\alpha)] - \alpha^\epsilon\}.$$ Substituting $$T_n^*$$, we can easily show $$\Phi_5 = 0$$ and

$$\Phi_4 = [(N_s + N_n)AT_n^*] \{1 - \alpha^\alpha - b[T/T_n^* - (1 - \alpha^\alpha)] - \alpha^\epsilon\}.$$ Substituting $$T_n^*$$, we can easily show $$\Phi_5 = 0$$ and

The result, $$\frac{dW}{dT_s}|_{T_s = T_n^*} < 0$$, follows.

D Proof of Proposition 6.

By definition, $$T_s^w$$ is the solution to the first-order condition $$dW/dT_s = 0$$, where $$dW/dT_s$$ is given in (6). Differentiating this first-order condition with respect to $$N_s$$ and collecting terms will give

$$N_s \Phi_6 \frac{\partial T_s^w}{\partial N_s} = \Phi_7,$$

where $$\Phi_6 = \{c\mu^{c-1}[1 - (1 + \alpha)\alpha^\alpha] + b\mu^{-1}(1 - \alpha^\alpha)\} + AN_s[c(1 - c)\mu^{c-2} + b(1 - b)\mu^{b-2}]\{N_s[T - T_s(1 - \alpha^\alpha)] + N_n[T - T_n^*(1 - \alpha^\alpha)]\} + AN_s[T_s(1 - \alpha^\alpha)]$$, which is positive because $$b\mu^{-1}(1 - \alpha^\alpha) - \alpha^\epsilon b\mu^{-1} > 0$$, and $$\Phi_7 = \{N_s[T - T_s(1 - \alpha^\alpha)] + N_n[T - T_n^*(1 - \alpha^\alpha)]\} \{c\mu^{c-2}[\mu - AN_sT_s(1 - c)] + b\mu^{b-2}[\mu - AN_sT_s(1 - b)]\} + T_s c\mu^{c-1}[N_s[T/T_s - (1 - \alpha^\alpha)] - 1 + (1 + \alpha)\alpha^\alpha] + T_s b\mu^{b-1}[N_s[T/T_s - (1 - \alpha^\alpha)] - 1 + \alpha^\epsilon + \alpha^\alpha],$$ which is positive because all three terms are positive. The result, $$\partial T_s^w/\partial N_s > 0$$, follows.
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