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PATENTS, APPROPRIATE TECHNOLOGY, AND NORTH-SOUTH TRADE

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ABSTRACT

We consider the differential incentives of the North and the South to provide patent protection to innovating firms in the North. The two regions are assumed to have a different distribution of preferences over the range of exploitable technologies. Due to the scarcity of R&D resources, the two regions are in potential competition with each other to encourage the development of technologies most suited to their needs. This provides a motive for the South to provide patent protection even when it constitutes a small share of the world market and hence has strong free riding incentives otherwise. A benevolent global planner will set equal rates of patent protection only when it weights the welfare of the two regions equally. We find that the comparative statics of the Nash equilibrium exhibit considerable ambiguity. Numerical simulations in the benchmark case yield the following results: (i) when the technological preferences of the two countries become more similar, the level of patent protection provided by the South is reduced; (ii) when the relative market size of the South is increased, the South enhances its patent protection. In both cases, the level of Northern patents is relatively insensitive.

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I. Introduction

One of the contentious North-South issues under discussion in the current round of GATT negotiations concerns the protection of intellectual property rights (IPRs). The U.S., European Community, and Japan are in broad agreement that the international trading system provides inadequate protection to IPRs, and have put forth a number of proposals to tighten restrictions; poorer countries, whose practices would be most immediately affected, oppose these proposals on the grounds that they would increase the profits of monopolistic foreign firms at the expense of domestic consumers.

Under the present regime, IPRs are largely beyond the scope of the GATT, and fall under the jurisdiction of the World Intellectual Property Organization (WIPO), a U.N. agency. It is WIPO that oversees the existing international agreements on IPRs such as the Paris Convention (on patents) and the Berne Convention (on copyrights). The Paris Convention requires member states, under the national treatment principle, to apply identical criteria to foreign and domestic firms, but does not prescribe specific levels of patent protection. Most of the ninety-eight members of the Convention are in fact developing countries. But the developed countries argue that the prevailing practices in the South leave much to be desired. Among complaints voiced by the former are: selective sectoral coverage in national legislation; inadequate remedies and sanctions in case of infringement of IPRs; procedural and administrative difficulties impeding access to courts; and arbitrariness and discrimination in the application of domestic statutes. Developing countries like Brazil and India in turn stress the possible exacerbation of monopolistic practices by Northern firms if patent protection were to become more stringent. Therefore, they resist GATT involvement in IPRs, and prefer to use WIPO, which lacks enforcement power, as the forum for discussion of such issues.[1]

The basic economic issue that underlies the conflict of interest is easy to see.[2] Most patented products or processes that make it to Southern markets are developed in the North. The North would therefore profit from tighter patent procedures in the South, as this would protect Northern firms against imitators in their export markets. According to the U.S. International Trade Commission, U.S. firms lose around $8 billion annually from patent and copyright infringements (cited in Baldwin, 1988). But by the same token, the South would like to pay as little as possible for these innovations, which is what lax patent protection achieves. To be sure, this in turn reduces the incentives of Northern firms to invest in R&D. As long as the South is a small part of the world market, however, the adverse effects of its policies on global innovative activity are also small, and free riding on the North makes eminently good sense. As a recent paper by Chin and Grossman (1988) demonstrates, it may be in the South's interest to provide no patent protection whatsoever.

In this paper we analyze this conflict of interest by bringing into consideration another feature of some importance. This new feature consists of the possibility that the North and South may have differing technological needs: the North would like to develop drugs against cancer and heart disease, whereas the South benefits more from drugs against tropical diseases; labor is cheap in the South but expensive in the North, so the North's labor-saving innovations are less useful in the South. When R&D resources that can be

1. This discussion is drawn from various GATT sources. See also Baldwin (1988), Benko (1988), Hamilton and Whalley (1988), pp. 28-29, and Kelly et al. (1988), p. 39.

2. For an early statement of the issues, see Penrose (1951), especially chaps. VII and X.

deployed in support of these innovations are limited, choices have to be made as to which areas will receive greater emphasis. Now Southern patents may have a role to play in promoting the development of technologies appropriate to the South that would not have been developed in the absence of these patents.[3] This incentive now competes against the free-riding motive. As we shall see, one implication is that a benevolent global planner who puts a greater weight on the South's welfare than on the North's would no longer necessarily prefer lower patent protection in the South. Another implication of the potential competition for suitable technologies is that increased patent protection in the South need not always be good for the North.

The only other formal model devoted to IPRs in the North-South context that we are aware of is the one by Chin and Grossman (1988). These authors consider the competition between two firms, one each form the North and South. The Northern firm can invest in process innovation, which the Southern firm can copy costlessly when the South provides no patent protection. Our framework differs from theirs in a number of respects. We allow for a continuum of potential technologies, with a different distribution of preferences over them in the two regions. This framework can be interpreted in terms of product, as well as process, innovation. Second, our model has free entry into the R&D sector, rather than duopolistic competition between two firms. Third, we allow gradations of patent protection, which is more

3. This point was recognized early on by Vernon (1957, p. 12): "... there is a case to be made that inventors in the industrialized areas of the world may need some special incentive to concentrate their talents on products of special utility to the underdeveloped areas." The only empirical study on LDC patents appears to be the one by Deolalikar and Roller (1989), which analyzes the relationship between patenting and total factor productivity for Indian firms.

general than the simple binary choice (protection or no protection) analyzed by Chin and Grossman. Finally, we assume that the Northern and Southern markets are segmented, due to differential patent-law application in the two regions. All of these features appear to be desirable ones. Their cost is that, unlike Chin and Grossman, we do not get into the details of the strategic interactions between Northern and Southern firms competing in oligopolistic markets.

II. Preliminaries

We allow for an unlimited spectrum of potential technologies, indexed by the continuous variable $\theta \in (-\infty, \infty)$. The range of discovered technologies, characterized by a lower bound $\underline{\theta}$ and an upper bound $\overline{\theta}$, is endogenous and denoted by $[\underline{\theta}, \overline{\theta}]$. We limit the analysis to uninterrupted ranges (i.e. no "holes" are allowed in the range).

Consumers are differentiated by taste, with each having a preferred variety of technology.[4] Consumers can therefore also be indexed by their preferred θ. To keep things simple, we assume each consumer gets utility of 1 if his prefered technology is available, and 0 otherwise. Letting $u(\theta)$ stand for the utility of consumer with preferred technology θ, we have:

$$(1)\quad u(\theta) = \begin{cases} 1 & \text{if } \underline{\theta} \leq \theta \leq \overline{\theta}, \\ 0 & \text{otherwise.} \end{cases}$$

Northern consumers are distributed according to the continuous distribution

4. The use of the term "consumer" here is perfectly general, and applies equally well to producers who are downstream users of technology. If we interpret the set of technologies as pertaining to a particular economic activity, θ could measure the required capital-labor ratio, the level of skilled labor needed, the expected life of the equipment, and so forth. Or, θ could simply index different products.

function $B(\theta)$ with support $(-\infty, \infty)$. Aggregate consumer welfare in the North can then be written as a function of the range of discovered technologies:

$$(2)\quad U^n(\underline{\theta}, \overline{\theta}) = \int_{-\infty}^{\infty} u(\theta)B(\theta)d\theta = \int_{\underline{\theta}}^{\overline{\theta}} B(\theta)d\theta,$$

where we have used (1). For the moment, nothing specific need be assumed about the shape of B(.). But it will help to think of B(.) as a single-peaked, symmetric distribution such as the normal.

Consumers in the South are parameterized in same manner, except that we assume the distribution function for Southern consumers is centered on a mean to the right of that of the North. Further, the mass of Southern customers is a fraction γ of those in North ($\gamma<1$), with γ measuring the relative market share of the two regions. This allows us to write the distribution function $B_s(\theta)$ for the South as a simple transformation of that of the North.

$$B^s(\theta) = \gamma B(\theta - S).$$

Aggregate consumer welfare in the South is then given by

$$(3)\quad U^s(\underline{\theta}, \overline{\theta}) = \gamma\int_{\underline{\theta}}^{\overline{\theta}} B(\theta - S)d\theta.$$

We assume that all innovations take place in the North. This is not terribly restrictive provided that the North has a sufficiently strong comparative advantage in research and development or that the South can appropriately discriminate between domestic and foreign firms in the application of its patent laws. As both of these are realistic features of the current regime, we can concentrate on the decisions of Northern firms alone. We assume that there is an infinite supply of potential innovating firms, with each existing firm identified by the technology it has developed. There is a fixed cost c required to develop each technology; marginal costs of production will not play an interesting role for innovating firms, so we will ignore them. These fixed costs are treated parametrically by the firms, even though an expansion of the range $[\underline{\theta}, \overline{\theta}]$ tends to drive c up as the costs of resources used in the innovation process are bid up. So we will write $c = c(\overline{\theta} - \underline{\theta})$, with $c'>0$ and $c''>0$. This "congestion" effect acts like an externality, and will play an important role in the analysis. Its purpose is to capture the reality that the resources used in R&D are not in perfectly elastic supply.

Consider the pricing strategy of a firm which has developed and patented a certain technology. If patent protection were perfect, the firm could capture the entire consumer surplus by charging a price of unity (technically, unity minus epsilon). Since patent protection never provides for full monopoly,[5] it is preferable to work with a model in which the firm can capture only a fraction of consumer surplus and has to charge a price lower than unity. A simple way to link the patent laws to the pricing behavior of firms is as follows. Suppose the innovator faces a large fringe of potential imitators in the North, each of which can mimic the former by incurring unit costs of $\alpha<1$ and no fixed costs. The parameter α can be thought of in part as capturing the (expected) unit costs incurred by imitators if they are brought to court and successfully prosecuted. In this sense, α parameterizes the restrictiveness of the prevailing patent laws in the North, with higher α

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5. In practice, even full patent rights are likely to confer only limited protection against imitators and fail to internalize R&D spillovers. See Dasgupta (1988) and Jaffe (1986).

associated with more complete patent protection. The analogous role in the South is played by the parameter β. Since the innovator's marginal costs are assumed zero (or, less restrictively, lower than the imitators), he will always have the incentive to charge the limit-prices $\alpha \in [0, 1)$ and $\beta \in [0, 1)$ in the the two regions, respectively.[6] Hence the market equilibrium is similar to that with contestable markets: for each technology in the produced range, the incumbent firm (the innovator) charges the price which equals the unit cost of potential entrants. The costs of potential imitators are in turn determined by the restrictiveness of prevailing patent laws.

Total Northern profits can then be written as:

$$(4) \quad \Pi(\underline{\theta}, \overline{\theta}) = \int_{\underline{\theta}}^{\overline{\theta}} [\alpha B(\theta) + \beta\gamma B(\theta - S)] d\theta - [\overline{\theta} - \underline{\theta}] c(.).$$

We assume that entry into <u>new</u> technologies, as opposed to already developed ones, is free. Firms enter until revenues just cover fixed costs. This allows us to determine the range of existing technologies by imposing the following zero-profit conditions.

$$(5) \quad \alpha B(\underline{\theta}) + \beta\gamma B(\underline{\theta} - S) - c(\overline{\theta} - \underline{\theta}) = 0,$$

$$(6) \quad \alpha B(\overline{\theta}) + \beta\gamma B(\overline{\theta} - S) - c(\overline{\theta} - \underline{\theta}) = 0,$$

which must hold at the edges of the range (see Figure 1). Provided $B(\theta)$ is single-peaked and not truncated, (5) and (6) together determine the range $[\underline{\theta}$,

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6. Notice the implication that firms can charge different prices in different regions. This requires that Southern imitators not be able to market their output in the North. The justification is that patent restrictions apply to all sales within a region, irrespective of whether they originate from home or foreign firms. This is consistent with the Paris Convention. Further, in the U.S., importation of a product that uses a domestically-patented <u>process</u> is forbidden.

$\overline{\theta}$] of technologies which firms will find in their interest to develop. We assume that S or γ are small enough to ensure that the range of profitable technologies is indeed a continuous one. Notice that as long as $\beta>0$, the presence of the South allows the North to exploit a wider range of technologies, as fixed costs can be spread on a larger base. For the same reason, Northern firms will always market their products in the South, even if the degree of patent protection there is substantially lower than in their home market.

Social welfare in the North is the sum of consumer benefits and profits, and can be stated as a function of the range of discovered technologies:

$$(7) \quad W^n(\underline{\theta}, \overline{\theta}) = \int_{\underline{\theta}}^{\overline{\theta}} [B(\theta) + \beta\gamma B(\theta - S)]d\theta - [\overline{\theta} - \underline{\theta}]c(.).$$

The corresponding expression for the South is:

$$(8) \quad W^s(\underline{\theta}, \overline{\theta}) = \int_{\underline{\theta}}^{\overline{\theta}} (1-\beta)B_s(\theta)d\theta = \gamma\int_{\underline{\theta}}^{\overline{\theta}} (1-\beta)B(\theta - S)d\theta.$$

Note that $\beta\gamma\int B(\theta - S)d\theta$ represents the transfer of profits from the South to the North and is therefore subtracted from Southern welfare.

III. Comparative Statics for the Range of Technologies

The policy instruments in this model are α and β, which parameterize the degree of patent protection provided in the two regions. They affect the levels of welfare in the North and South through their influence on the range of innovations, and, in the case of β, through the magnitude of the profit transfers from the South to the North. We start by analyzing the response of

$\underline{\theta}$ and $\bar{\theta}$ to changes in exogenous parameters.

We first note that equations (5) and (6) yield a relationship between marginal benefits in the two regions:

$$(9) \quad [B(\underline{\theta}) - B(\bar{\theta})] = \gamma(\beta/\alpha)[B(\bar{\theta}\text{-}S) - B(\underline{\theta}\text{-}S)].$$

The expressions in the square brackets capture the difference between marginal consumer benefits at the edges of the range for the two regions. Suppose that the South did not exist ($\gamma=0$), that it did not provide any patent protection ($\beta=0$), or that its tastes were identical to the North's ($S=0$). Then (9) would require equality between $B(\underline{\theta})$ and $B(\bar{\theta})$. This equates the marginal consumer benefits (in the North) at each end of the range. When the South enters the picture, however, this equality need no longer hold; as we shall see, the range of produced innovations becomes skewed away from Northern tastes and towards Southern tastes. The larger is the Southern market (γ), the taste differential (S), and the relative level of Southern patent protection (β/α), the more pronounced this becomes.

As a final preliminary, a note is warranted regarding the sign of the partial derivative of the benefit function B(.), as this plays an important role in the following analysis. With a symmetric, single-peaked distribution function, $B'(\theta)$ is positive or negative depending on which side of the mean θ lies. We will henceforth assume that $\bar{\theta}$ and ($\bar{\theta}$-S) will always lie to the right, and $\underline{\theta}$ and ($\underline{\theta}$-S) always to the left, of the mean of $B(\theta)$.[7] This ensures that

$$B'(\bar{\theta}) < 0, \quad B'(\bar{\theta}\text{-}S) < 0, \quad B'(\underline{\theta}) > 0, \quad B'(\underline{\theta}\text{-}S) > 0.$$

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7. This is in fact too restrictive for the results to be discussed below to hold. A weaker condition will generally suffice.

An interpretation of these conditions in economic terms is that the marginal benefit from innovations _falls_ as the range of innovations becomes broader. They will always hold for a distribution like the normal one, provided S is not too large.

(i) _Effects of Increased Northern Patent Protection_. We differentiate (5)-(6) totally to perform comparative-statics analysis. Let the determinant of the system be denoted by $\Delta < 0$ (see the appendix). Then the effect of changes in α on the boundaries of the range of innovations can be determined as follows:

$$(10)\quad d\underline{\theta}/d\alpha = \underset{(-)}{(1/\Delta)}\{\underset{(-)}{-B(\underline{\theta})}[\underset{(-)}{\alpha B'(\overline{\theta}) + \beta\gamma B'(\overline{\theta}-S)}] + \underset{(0/+)}{[B(\underline{\theta}) - B(\overline{\theta})]}c'\} < 0.$$

As discussed above, $B'(\overline{\theta})$ and $B'(\overline{\theta}-S)$ are both _negative_. Moreover, we will see that $[B(\underline{\theta}) - B(\overline{\theta})] \geq 0$ (i.e. the range will be generally skewed to the right). These ensure that an increase in patent protection in the North will unambiguously reduce the lower bound, increasing the number of innovations on the left of the distribution. These are the innovations which are not greatly valued in the South.

Some ambiguity exists, however, with the upper bound:

$$(11)\quad d\overline{\theta}/d\alpha = \underset{(-)}{(1/\Delta)}\{\underset{(-)}{-B(\overline{\theta})}[\underset{(+)}{\alpha B'(\underline{\theta}) + \beta\gamma B'(\underline{\theta}-S)}] + \underset{(0/+)}{[B(\underline{\theta}) - B(\overline{\theta})]}c'\},$$

which is _positive_ only if $[B(\underline{\theta}) - B(\overline{\theta})]c'$ is not too large. The interpretation is as follows. If the range of innovations is already too skewed to the right (i.e. towards Southern tastes) so that $[B(\underline{\theta}) - B(\overline{\theta})] \gg 0$, an increase in Northern patent protection may well lead to some of the innovations that are relatively more suitable to the South to drop out. This possibility is due to the crowding-out of existing products as the expansion of the range of innovative activity increases costs incurred by all incumbents. When this does not happen, an increase in α will generate more innovation on the upper end of the range as well.

Further, combining expressions (10) and (11), it can be seen that the overall range of innovations unambiguously expands as α increases:

$$(12)\quad d\bar{\theta}/d\alpha - d\underline{\theta}/d\alpha$$
$$= (1/\Delta)\{B(\bar{\theta})[\alpha B'(\underline{\theta}) + \beta\gamma B'(\underline{\theta}\text{-}S)] - B(\underline{\theta})[\alpha B'(\bar{\theta}) + \beta\gamma B'(\bar{\theta}\text{-}S)]\} > 0.$$

Therefore, patent protection in the North will increase innovative activity, but may do so at the expense of some products which are particularly suited to Southern requirements.

(ii) Effects of Increased Southern Patent Protection. The effects of patent protection in the South are similar to those discussed above, except that they get moderated by the parameter γ. Hence, an increase in β unambiguously increases the innovations that are more appropriate to Southern needs (i.e. those on the right of the distribution):

$$(13)\quad d\bar{\theta}/d\beta = (\gamma/\Delta)\{-B(\bar{\theta}\text{-}S)[\alpha B'(\underline{\theta}) + \beta\gamma B'(\underline{\theta}\text{-}S)] + [B(\underline{\theta}\text{-}S) - B(\bar{\theta}\text{-}S)]c'\} > 0$$

The ambiguity now exists with respect to innovations near the lower end of the range:

$$(14)\quad d\underline{\theta}/d\beta = (\gamma/\Delta)\{-B(\underline{\theta}\text{-}S)[\alpha B'(\bar{\theta}) + \beta\gamma B'(\bar{\theta}\text{-}S)] + [B(\underline{\theta}\text{-}S) - B(\bar{\theta}\text{-}S)]c'\}$$

which can be positive if the (negative) term $[B(\underline{\theta}\text{-}S) - B(\bar{\theta}\text{-}S)]c'$ is sufficiently large in absolute value. Notice that $[B(\underline{\theta}\text{-}S) - B(\bar{\theta}\text{-}S)]$ is the difference between Southern marginal consumer benefits at the two ends of the innovation range. . The likelihood that increased patent protection in the South will lead to some of the products favored in the North to drop out increases with: (i) the degree to which existing innovations mirror Northern requirements; (ii) the diffferences in tastes between the two regions; and (iii) the magnitude of the cost increase as the range broadens.

Once again, irrespective of whether some innovations drop out, the range itself must broaden:

(15) $d\bar{\theta}/d\beta - d\underline{\theta}/d\beta$

$$= (\gamma/\Delta)\{B(\bar{\theta}-S)[\alpha B'(\underline{\theta}) + \beta\gamma B'(\underline{\theta}-S)] - B(\underline{\theta}-S)[\alpha B'(\bar{\theta}) + \beta\gamma B'(\bar{\theta}-S)]\} > 0,$$

but the presence of the South skews the range to the right relative to the mean of the $B(\theta)$ distribution.

(iii) Effects of Change in Relative Market Sizes. As far as the range of innovations is concerned, the relative market-size parameter γ enters the model in much the same way that β does: an increase in γ, just as an increase in β, raises the weight placed by Northern firms on Southern tastes. Therefore, the comparative-statics results are much the same. The range of innovations broadens unambiguously ($d\bar{\theta}/d\gamma - d\underline{\theta}/d\gamma > 0$), and more of the potential innovations particularly suited to Southern tastes are developed ($d\bar{\theta}/d\gamma > 0$). Some of the innovations at the other end may drop out if the term $\beta[B(\underline{\theta}-S) - B(\bar{\theta}-S)]c'$ is sufficiently negative.

(iv) Effects of Change in Tastes. Taste differences between the two regions are captured here by the parameter S; the larger is S, the greater the taste difference. We would expect that as S increases, the range of innovations becomes progressively more skewed away from Northern tastes. This is indeed the case, as both the lower and upper bound of the range unambiguously move to the right (i.e., $d\underline{\theta}/dS > 0$ and $d\bar{\theta}/dS > 0$). Further, one can show that when $\gamma\beta<\alpha$, we must have $d\underline{\theta}/dS < 1$ and $d\bar{\theta}/dS < 1$.

What about the number of innovations, or the size of the range? The comparative-statics yield:

$$(16)\quad d\overline{\theta}/dS - d\underline{\theta}/dS = (\alpha\beta\gamma/\Delta)[\underset{(-)}{B'(\underline{\theta})}\underset{(-)}{B'(\overline{\theta}-S)} - B'(\overline{\theta})\underset{(-)}{B'(\underline{\theta}-S)}],$$

whose sign looks ambiguous at first sight. With a symmetric distribution, however, more can be said. Remember that the range of innovations $[\underline{\theta}, \overline{\theta}]$ will generally be skewed to the right relative to the mean of $B(\theta)$ (due to the South's influence). This allows us to gauge the relative slopes along the distribution as follows: $|B'(\underline{\theta})| > |B'(\overline{\theta})|$ and $|B'(\overline{\theta}-S)| > |B'(\underline{\theta}-S)|$. Therefore the first term in the square brackets dominates and the sign of the expression must be <u>positive</u>. An increase in taste differences between the North and South <u>widens</u> the range of innovations that are developed.

To conclude this section, there is reason to think that there will be both cooperative and non-cooperative elements in any North-South bargain over patent protection. To some extent, patent protection in the North and South are substitutes for each other, as either increases the incentive of Northern firms to engage in innovative activity. The closer is γ to unity, the greater impact Southern patent protection has on the profitability of Northern innovation. But Northern and Southern patents are <u>imperfect</u> substitutes for each other. Everything else being the same, both regions would prefer to have the range of innovations be as congruent with their tastes and requirements as possible. Southern patent protection, for example, not only increases the range of innovations, but also skews it away from Northern preferences. As we shall see, this may provide a rationale for the South to provide protection even when the incentives to free ride on Northern patents are strong.

In the rest of the paper, the comparative-statics results developed here will play an important role. We draw attention in particular to the significance of the ambiguity in the signs of $d\overline{\theta}/d\alpha$ and $d\underline{\theta}/d\beta$. A sufficient condition for the reaction curves of the two regions to slope down in a Nash equilibrium will be that $d\bar{\theta}/d\alpha > 0$ and $d\underline{\theta}/d\beta < 0$. We will treat this as the benchmark. But when $d\bar{\theta}/d\alpha < 0$ and/or $d\underline{\theta}/d\beta > 0$, increased patent protection in one region leads to the elimination of innovations that are more highly favored in the other region compared to the those that are being stimulated. In such circumstances, one or both of the reaction curves can slope up and much of the conventional wisdom be reversed.

Since many of the analytical expressions we derive below are of ambiguous sign, we will fortify our discussion of the channels at work with a set of numerical simulations. Our simulations assume that consumer preferences in the North are distributed according to the standard normal distribution, and that the cost function is given by $c(\bar{\theta}-\underline{\theta}) = [\exp(\bar{\theta}-\underline{\theta})]/2000$. In our central case, $S = 1.2$ and $\gamma = 0.3$. That is, Southern tastes are assumed to be centered 1.2 standard deviations away from the mean of Northern tastes, and the South is taken to represent a market 30 percent as big as the North. (These values ensure that the reaction functions are both negatively sloped around the Nash equilibrium.) We will also refer to an alternative case with more extreme taste differences, where $S = 2$ and $\gamma = 0.12$, in which the Northern reaction function will be positively sloped.

IV. Welfare Analysis

Suppose a benevolent global dictator were to assign patent rights to the two regions in accordance with a conventional social welfare function. Would she impose equal rates of patent protection?

To begin with, let the global welfare function (W) be written as an equally-weighted sum of welfare in the two regions:

$$(17)\quad W(\underline{\theta}, \bar{\theta}) = \int_{\underline{\theta}}^{\bar{\theta}} [B(\theta) + \beta\gamma B(\theta - S)]d\theta - [\bar{\theta} - \underline{\theta}]c(.) + \int_{\underline{\theta}}^{\bar{\theta}} \gamma(1-\beta)B(\theta - S)d\theta$$

$$= \int_{\underline{\theta}}^{\bar{\theta}} B(\theta)d\theta + \int_{\underline{\theta}}^{\bar{\theta}} \gamma B(\theta - S)d\theta - [\bar{\theta} - \underline{\theta}]c(.).$$

Since we have two independent instruments, α and β, to control two targets, $\underline{\theta}$ and $\bar{\theta}$, we might as well assume that we can exercise direct control over the range of innovations. The first-order conditions with respect to $\underline{\theta}$ and $\bar{\theta}$, respectively, are:

$$(18)\quad B(\underline{\theta}) + \gamma B(\underline{\theta} - S) - c - [\bar{\theta} - \underline{\theta}]c' = 0,$$

$$(19)\quad B(\bar{\theta}) + \gamma B(\bar{\theta} - S) - c - [\bar{\theta} - \underline{\theta}]c' = 0,$$

Setting (18) and (19) equal to each other yields:

$$(20)\quad [B(\underline{\theta}) - B(\bar{\theta})]/[B(\bar{\theta} - S) - B(\underline{\theta} - S)] = \gamma.$$

Hence the smaller is γ, the less off-center is the range of innovations relative to Northern tastes. Putting (20) together with equation (9), we are left with the equality $\gamma = \gamma(\beta/\alpha)$, which requires $\alpha = \beta$. Therefore, when the global welfare function is strictly utilitarian, global optimality does indeed require <u>equal</u> levels of patent protection in the two regions. Note that this holds irrespective of the sizes or tastes of the two regions.

The explanation is as follows. Since we are maximizing total benefits in the North and the South, the relative size of the South, γ, also represents the relative weight we place on its welfare. But firms weight the two regions according to their relative profitability, which is captured by the ratio $\gamma(\beta/\alpha)$. Firm behavior coincides with social optimality only when $\alpha = \beta$.

We can say more about the properties of the optimal levels of patent protection. Substituting for c(.) from (5) and (6), we can rewrite equations

(18) and (19) as follows:

$$(18') \quad (1-\alpha)B(\underline{\theta}) + (1-\beta)\gamma B(\underline{\theta}-S) = [\overline{\theta}-\underline{\theta}]c'$$

$$(19') \quad (1-\alpha)B(\overline{\theta}) + (1-\beta)\gamma B(\overline{\theta}-S) = [\overline{\theta}-\underline{\theta}]c'.$$

When costs are not increasing in the range of innovations ($c'=0$), the right-hand side is zero, implying $\alpha = \beta = 1$. With constant costs, there are no distortions in the market, and firms should be allowed to capture the entire consumer surplus. Patent protection is complete. But when congestion effects are present ($c'>0$), firms confer a negative externality on each other. Each additional firm that enters drives up the costs of incumbents, so that if patent protection were complete, there would be too many firms. In this case, since the right-hand side of (18') and (19') is positive, social optimality requires $\alpha = \beta < 1$. Patent protection will be incomplete.

This is, of course, a rather different story from that commonly given as to why governments provide less than full patent protection. The usual explanation has to do with reducing the monopoly power of firms to which protection has been granted and enabling innovations to be readily diffused after a fixed number of years. But, formally, these explanations can be reconciled with the present framework. We could presume for example that, due to technological spillovers, the research costs of each firm are a decreasing function of the quantity of publicly available technology. As α and β increase, patents become more restrictive and fewer technologies remain in the public domain. Therefore, costs of all firms possibly increase.[8] This is

8. More specifically, two effects can be identified as α and β are raised. The first, which argues in favor of patents, is that more research is undertaken. The second, which argues against patents, is that less of it becomes available to all firms and costs are not sufficiently reduced. When patent protection is nearly complete, a small decrease can have second-order effects in terms of the first, but first-order effects in terms of the second.

quite similar to the effect that operates in the present model.

Now suppose that the global dictator is egalitarian, and that she values the poor South's welfare more than the North's. How would this change the relationship between the optimal α and β?

Let the relative weight attached to the South's welfare be denoted ϕ, with $\phi>1$. Global welfare can now be written as

$$(21)\quad W(\underline{\theta}, \overline{\theta}) = \int_{\underline{\theta}}^{\overline{\theta}} [B(\theta) + \beta\gamma B(\theta - S)]d\theta - [\overline{\theta} - \underline{\theta}]c(.) + \phi\int_{\underline{\theta}}^{\overline{\theta}} \gamma(1-\beta)B(\theta - S)d\theta$$

$$= \int_{\underline{\theta}}^{\overline{\theta}} B(\theta)d\theta + \Phi\int_{\underline{\theta}}^{\overline{\theta}} \gamma B(\theta - S)d\theta - [\overline{\theta} - \underline{\theta}]c(.),$$

where $\Phi = [\phi - (\phi-1)\beta]$. Note that $\Phi > 1$ as long as $\beta < 1$. Therefore the only difference with the earlier objective function is that now the <u>gross</u> benefits of the South--gross in the sense that profit transfers to the North are not included--receives a weight larger than one (Φ). The analogue of (20) now is

$$(20')\quad [B(\underline{\theta}) - B(\overline{\theta})]/[B(\overline{\theta}-S) - B(\underline{\theta}-S)]$$
$$= \gamma\Phi - [\gamma(1-\alpha)(\mu + \nu)\int B(\theta - S)d\theta]\ [B(\overline{\theta}-S) - B(\underline{\theta}-S)]^{-1},$$

where $\mu = d\beta/d\overline{\theta} > 0$ and $\nu = d\beta/d\underline{\theta} > 0$ (see the appendix). Notice that since $\overline{\theta}$ and $\underline{\theta}$ are now treated directly as policy variables, the two derivatives μ and ν refer to the implied changes in β needed to bring about the desired adjustments in the boundaries. (They are <u>total</u> derivatives, as α is being endogenously adjusted as well.) Putting this together with (9) and simplifying, we get:

(22) $\beta = \alpha\Omega$, with

This would call for incomplete patent protection.

$$\Omega = \underset{(+)}{[1+\alpha(\phi-1)]^{-1}}\{\phi + \underset{(-)}{(1-\phi)}\underset{(+)}{(\mu + \nu)}\underset{(+)}{\int B(\theta-S)d\theta}\ \underset{(+)}{[B(\bar{\theta}-S) - B(\underline{\theta}-S)]^{-1}}\}.$$

Notice that $\phi > 1+\alpha(\phi-1)$, so that the effect of the first term in the curly brackets (i.e. ϕ) is to <u>raise</u> β relative to α. This comes from the desire to skew the innovation range towards Southern tastes. But as β increases, so do profit transfers to the North, and this effect is captured by the long second term in the curly brackets, which is negative and subtracts from ϕ. Whether Ω on the whole is bigger or smaller than unity cannot be determined a priori. But the closer are Southern preferences to Northern ones, the greater the likelihood that Ω will be less than one, and that β will fall short of α. This can be seen from (22): $[B(\bar{\theta}-S) - B(\underline{\theta}-S)]$ becomes smaller (and hence its inverse larger) as S goes to zero (see [9]).[9] As Northern and Southern preferences become more alike, then, the free-riding motive of the South exerts a growing influence. But when Southern preferences for technology differ substantially from those of the North, the globally optimal β could well exceed α.

While the theoretical possibilities are unconstrained, numerical simulations with the specifications described above yield the result that as ϕ is increased, the optimal level of Northern protection consistently rises while Southern protection falls. These results are diplayed in Table 1. With sufficiently large ϕ, the global planner would allow the South to have a complete free ride.

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9. There is of course nothing here that would stop β from turning negative. A planner who values the South's welfare sufficiently will in this case try to enrich that region by engineering reverse profit transfers from the North, while raising α to offset the adverse incentives on Northern R&D. It may be natural to think of β as being bound below by 0.

Therefore, when the global planner places more weight on the welfare of the South, there is no longer any reason to equate α and β. But, unlike what may have been expected, there is no general reason to let the South provide lower levels of patent protection either. The planner has to trade off the free-riding benefits to the South against the losses arising from reduced levels of investment in technologies that are particularly appropriate to poor countries.

V. The Nash Equilibrium

In the enviroment described above, patent protection in each block affects welfare in the other block. The questions we pose next are: What sort of patent laws emerge in the North and in the South if each region reacts to the other region's patent laws by optimizing over the level of patent protection in its own market? How is this equilibrium affected by the size and the taste preferences of the South? And how does it compare with the Pareto-optimal patent protection administered by a benevolent dictator? To answer these questions, we first develop the players' reaction functions under the assumption of Nash behavior.

(i) The Northern reaction function. The Northern planner choses α to maximize social welfare (7), taking β as given. Optimally, the marginal cost of protection is set equal to the marginal benefit. We differentiate (7) with respect to α, rearrange using (5) and (6) and set equal to zero:

$$(23)\quad W^n_\alpha = (1-\alpha)[B(\overline{\theta})\overline{\theta}_\alpha - B(\underline{\theta})\underline{\theta}_\alpha] - c'[\overline{\theta}-\underline{\theta}][\overline{\theta}_\alpha-\underline{\theta}_\alpha] = 0,$$

where we have introduced the following notation: $\overline{\theta}_\alpha = d\overline{\theta}/d\alpha$, $\underline{\theta}_\alpha = d\underline{\theta}/d\alpha$, etc. The second term of (23) represents the positive marginal cost of increased protection, an expression that is proportional to the size of the innovation range $[\overline{\theta}-\underline{\theta}]$ and to the positive effect of α on the range $[\overline{\theta}_\alpha-\underline{\theta}_\alpha]$.

The first term represents the net marginal benefit that accrues on both sides of the range, and it is only $(1-\alpha)$ times the marginal consumer surplus (the term in brackets) because a proportion α of the increase in consumer surplus is dissipated in research costs by the marginal innovating firms. (Remember that zero-profit conditions hold at the edges of the range.) The marginal gain in consumer surplus due to an expansion of the range of innovations is composed of two effects: the lower range necessarily expands (to the left) after an increase in α, thus increasing welfare. The upper range generally also expands (to the right) as firms can spread their cost on a larger base. But, as discussed in section III, because costs increase with the range of innovations, it is possible that the upper range retracts (to the left).

Let α^* stand for the North's optimal patent. When costs are not rising $(c'=0)$, (23) is always positive for $\alpha<1$, implying that $\alpha^*=1$. This would be the case where there are no congestion effects in R&D. But with costs increasing with the range of research activity, $\alpha^*<1$ since at $\alpha=1$, the expression in (23) is negative. Moreover, when $\beta=0$, α^* is strictly positive, since at $\alpha=0$, $\underline{\theta}=\overline{\theta}$ and the second term of (23) is zero while the first is positive.

How does the North react to an increase in protection in the South? In general, but not always, the North will <u>reduce</u> protection in response, due to two considerations: (i) at the margin the positive effect of Northern protection on own welfare is attenuated, and (ii) research costs are increased as a result of higher β. The ambiguity noted above with respect to the signs of $\overline{\theta}_\alpha$ and $\underline{\theta}_\beta$, however, imply that effect (i) does not always obtain, such that a decrease in α is sometimes <u>un</u>desirable. To see that, apply the implicit function theorem to (23) to get:

$$(24) \quad d\alpha^*/d\beta = - W^n_{\alpha\beta} \; / \; W^n_{\alpha\alpha}$$

where the denominator $W^n_{\alpha\alpha}$ is negative by the second order condition. Hence, the slope of the reaction function in (24) has the same sign as the numerator $W^n_{\alpha\beta}$. In order to evaluate the sign of $W^n_{\alpha\beta}$, we drop the terms corresponding to second derivatives of $\underline{\theta}$ and $\overline{\theta}$,[10] on the assumption that these are likely to be of second-order importance. $W^n_{\alpha\beta}$ is then given by:

$$(25)\quad W^n_{\alpha\beta} = (1-\alpha)[B'(\overline{\theta})\overline{\theta}_\alpha\overline{\theta}_\beta - B'(\underline{\theta})\underline{\theta}_\alpha\underline{\theta}_\beta] - [c'+c''(\overline{\theta}-\underline{\theta})][\overline{\theta}_\alpha-\underline{\theta}_\alpha][\overline{\theta}_\beta-\underline{\theta}_\beta]$$

where the first term captures effect (i) and the second captures effect (ii) mentioned above. Expression (25) is negative in general, and positive only when $\overline{\theta}_\alpha$ is negative and large and/or $\underline{\theta}_\beta$ is positive and large.

The interpretation is as follows. In general, as the range of innovations widens, the marginal benefit of innovation drops on both sides of the range, discouraging protection. In this case, both this effect and the rising R&D costs contribute to a lessening of Northern protection. But when tastes are very different and α and β are far apart, increased Southern protection <u>can</u> enhance marginal benefits of an increase in α. This can occur in two types of situations: when $\underline{\theta}_\beta>0$ and large, an increase in β shifts the range away from Northern preferences and increased Northern protection can increase marginal revenue by recapturing the valuable technologies that would be lost otherwise. And when $\overline{\theta}_\alpha<0$ and large enough, a reduction in α hurts the North by leading to the substitution of too many less valuable innovations on the upper side of the range. In these cases, the positive effect on marginal revenue can overtake the negative effect on marginal costs and it is possible that an increase in β will be met with an increase in α^* as the North attempts

10. In other words we assume $\underline{\theta}_{\alpha\alpha} = \underline{\theta}_{\alpha\beta} = \overline{\theta}_{\alpha\alpha} = \overline{\theta}_{\alpha\beta} = 0$. This is somewhat analogous to the assumption of linear demand curves in standard oligopoly theory. We maintain this assumption throughout the paper.

to shift the range of technologies away from Southern preferences.

The more general case is clearest when North-South tastes coincide (i.e S=0). In this case, it is possible to show (see the appendix) that the Northern reaction function becomes linear in Southern protection and that it is unambiguously downard sloping. In particular, we get:

(26) $d\alpha^*/d\beta = -1/\gamma < 0$ (at S=0).

(ii) The Southern reaction function. Similarly, we can derive the first-order condition for the Southern planner and the reaction function with respect to Northern protection. The problem is quite similar to the Northern problem, with the difference that the cost of increased protection is an increased transfer to foreigners rather than an increased cost of research. Differentiating (8) with respect to β and setting to zero, we have (assuming an interior solution for β):

$$(27)\quad W^s_\beta = \gamma(1-\beta)[B(\bar{\theta}-S)\bar{\theta}_\beta - B(\underline{\theta}-S)\underline{\theta}_\beta] - \gamma\int_{\underline{\theta}}^{\bar{\theta}} B(\theta-S)d\theta = 0$$

The second term represents the marginal cost of increased protection in terms of higher payments to the innovating foreign firms. If there were no offsetting positive effect to Southern patent protection, β^* would of course be optimally set to its lowest possible level as the South would simply free ride on Northern innovations. However, there are in general gains associated with protection and they are represented by the first term in equation (27). An increase in β increases the range of innovations and tilts it towards Southern tastes.[11] Note that the first term gets smaller with β, since only

11. The degree to which it does that depends, of course, in part on the relative size of the Southern market, γ (see section III).

$(1-\beta)$ of the consumer surplus is captured by the South. In particular, the marginal benefit of protection is zero at $\beta=1$ and therefore, β^* is necessarily smaller than 1. Finally, note that β^* can be zero in general but that it is certainly positive when $\alpha=0$. (This is because $W^s_\beta > 0$, when $\alpha = \beta = 0$.)

The slope of the Southern reaction function is given by:

$$(28) \quad d\beta^*/d\alpha = - W^s_{\alpha\beta} \,/\, W^s_{\beta\beta}$$

which--because the denominator is negative--has the same sign as the numerator. Ignoring again the second order terms in $\underline{\theta}$ and $\overline{\theta}$, $W^s_{\alpha\beta}$ is given by:

$$(29) \quad W^s_{\alpha\beta} = (1-\beta)[B'(\overline{\theta}-S)\overline{\theta}_\alpha\overline{\theta}_\beta - B'(\underline{\theta}-S)\underline{\theta}_\alpha\underline{\theta}_\beta] - [B(\overline{\theta}-S)\overline{\theta}_\alpha - B(\underline{\theta}-S)\underline{\theta}_\alpha]$$

which is negative when $\overline{\theta}_\alpha>0$ and/or $\underline{\theta}_\beta<0$. However, (29) could be positive and it might be in the interests of the the South to react to stiffer Northern protection by increasing its own protection. This would occur when: (i) increased Northern protection shifts the range of innovations sufficiently away from Southern tastes ($\overline{\theta}_\alpha<0$ and large); and when (ii) at the margin, a reduction in Southern protection would add on too many innovations on the less-valuable lower end of the range ($\underline{\theta}_\beta>0$ and large). Both situations are more likely to occur when North-South preferences are quite different. Again it is possible to show that with similar tastes (S=0):

$$(30) \quad d\beta^*/d\alpha = - \gamma < 0 \quad (\text{at } S=0).$$

(See the appendix.)

(iii) <u>Comparative statics</u>. When the Nash game described above is played, several types of equilibria may emerge, with both reaction functions sloping down, one of the reaction functions sloping up, or even both reaction functions sloping up. Here we will focus on small changes around equilibria in which both reaction functions slope down, presumably the case that best describes the current situation. Even in this case, however, a range of different comparative statics results are possible.

(iiia) The effect of taste differences. When North-South preferences get closer, both regions react by altering their levels of protection. There are several effects at play here and the global effect of a change in tastes cannot be completely determined. In order to describe the channels through which relative preferences affect the final outcome, use the implicit function theorem on (23) and (27) to get:

(31) $\partial\alpha^*/\partial S = - W^n_{\alpha S} / W^n_{\alpha\alpha}$,

(32) $\partial\beta^*/\partial S = - W^s_{\beta S} / W^s_{\beta\beta}$.

These determine the direction of shifts in the respective reaction functions. In both eqations, the expressions have the same sign as their numerators since the denominators are negative when the second-order conditions of the maximization problems are satisfied. The numerators are respectively given by:

(33) $W^n_{\alpha S} = (1-\alpha)[B'(\overline{\theta})\overline{\theta}_\alpha\overline{\theta}_S - B'(\underline{\theta})\underline{\theta}_\alpha\underline{\theta}_S] - [c'+c''(\overline{\theta}-\underline{\theta})][\overline{\theta}_\alpha-\underline{\theta}_\alpha][\overline{\theta}_S-\underline{\theta}_S]$

(34) $W^s_{\beta S} = \gamma(1-\beta)[B'(\overline{\theta}-S)(\overline{\theta}_S-1)\overline{\theta}_\beta - B'(\underline{\theta}-S)(\underline{\theta}_S-1)\underline{\theta}_\beta]$

$- \gamma[B(\overline{\theta}-S)\overline{\theta}_S - B(\underline{\theta}-S)\underline{\theta}_S - \int B'(\theta-S)d\theta]$.

Let us first consider the effects of taste differences on Southern optimal protection. As North-South preferences get closer (i.e. S decreases), the South is affected through two channels, both of which generally discourage patent protection. (i) First, for a given level of protection, what must be paid to the foreign innovators increases as S decreases. This marginal cost effect is captured by the second term in (34): since protection becomes in a sense more expensive, there are incentives to decrease it. In effect, as the South becomes more similar to the North, its tax base becomes larger because the existing technologies--which are biased towards Northern tastes--now produce a higher consumer surplus.[12] (ii) Second, the marginal benefit of innovations at the ends of the range generally decrease. This is captured by the positive sign of the first term in (34). To see why, first remember that the range of innovations gets smaller, and that it shifts to the left by less than the shift in Southern preferences because the reduction in research costs associated with the smaller range forces the marginal firms (at the ends of the range) to service thinner markets. As a result, marginal welfare gets smaller at $\overline{\theta}$, and higher at $\underline{\theta}$. Since in general the first effect dominates, the Southern reaction function will tend to shift to the left as S is reduced.

As tastes get closer, the North is also affected through two channels. (i) First, the range of innovations necessarily shrinks, reducing the fixed cost of innovation for all technologies. This effect--captured by the second term in (33)--encourages the North to increase innovation in its most prefered technologies and this is achieved with higher protection. (ii) The other effect--represented by the first term in brackets--captures the change in marginal welfare at the ends of the innovation range, and on net exerts a depressing effect on domestic patent protection: the lower end of the range

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12. To illustrate that, imagine that India and Brazil have similar rates of patent protection, but that Brazilian technological needs are closer to those of the North than is the case for India. Then the above considerations state that, given Northern influences on the existing range of technologies, a representative consumer in Brazil would have a larger consumer surplus and would be paying larger royalties to foreign firms.

widens ($\underline{\theta}$ decreases) allowing the North to capture new technologies that are less valuable at the margin. This reduces the need for patent protection as, in effect, the marginal productivity of protection falls. On the other hand, the upper end of the range retracts, increasing the marginal benefits at $\overline{\theta}$.[13] This effect tends to encourage increased protection, but it is in general smaller than the depressing effect at the lower end of the innovation range (unless $\overline{\theta}_S$ is much larger than $\underline{\theta}_S$). In sum, both the marginal cost and the marginal benefit of protection are reduced and the reaction of the North will depend on the relative importance of these effects.

Figure 2 illustrates the possible outcomes when S <u>increases</u>.[14] As North-South preferences get further apart, the Southern reaction function shifts up while the Northern reaction function can either increase or decrease. The new equilibrium is either at a point like B or C, with higher β but ambiguous results in the North, or at a point like D with higher α but lower β. The only general conclusion that can be drawn when both reaction functions are downward sloping is that at least one of the two regions must increase its protection when S gets larger. (Conversely, either α or β must fall when S gets smaller.) In our simulations we find that β is generally increased while α is fairly insensitive (decreasing slightly at first, but then increasing) as S becomes larger (see Table 2). Table 2 also diplays the possibility that the South may choose <u>higher</u> levels of protection than the North if the taste differences become pronounced enough (and the Northern reaction function becomes positively sloped).

(iiib) <u>Changes in relative market size</u>. A change in the relative size of

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13. Note that this effect goes the other way when $\overline{\theta}_\alpha < 0$.

14. This is drawn for the stable case where the South's reaction function is more steeply sloped than the North's.

the Southern market also has ambiguous effects on the equilibrium strategies when both reaction functions slope down. It is easy to verify that in that case

$$\partial\alpha^*/\partial\gamma = - W^n_{\alpha\gamma} / W^n_{\alpha\alpha} = - \beta W^n_{\alpha\beta} / \gamma W^n_{\alpha\alpha} < 0,$$

$$\begin{aligned}\partial\beta^*/\partial\gamma &= - W^s_{\beta\gamma}/W^s_{\beta\beta} \\ &= \beta\{(1-\beta)[B'(\underline{\theta}-S)\underline{\theta}_\beta{}^2 - B'(\overline{\theta}-S)\overline{\theta}_\beta{}^2] + [B(\underline{\theta}-S)\underline{\theta}_\beta - B(\overline{\theta}-S)\overline{\theta}_\beta]\}/W^s_{\beta\beta} < 0\end{aligned}$$

In words, the reactions functions of both regions shift back when γ increases. Hence, the level of patent protection must decline in at least one of the two regions. This implies that, somewhat paradoxically, an increase in the size of the South can lead to reduced protection in <u>both</u> the North and the South. From the North's perspective, as the Southern market enlarges, the range of innovation widens beyond the most desirable level and it may make sense to reduce (costly) protection. But the South may have been expected to always increase β, as the costs of free riding now apparently become larger. This is not so because an increase in γ also increases the benefits of free riding, as the profit transfers at the margin increase commensurately--see the South's first-order condition (27). Moreover, since γ and β are substitutes for each other in determining the technology range, it may be rational for the South to use the extra leverage provided by the increase in its market size to reduce profit transfers to the North (via a reduction in β).

Table 3 shows some simulation outcomes for the benchmark case. These are generally in line with conventional wisdom. As γ is reduced, the South progressively reduces β, and eventually stops protection altogether.

(iv) <u>The inefficiency of the Nash equilibrium</u>. We end by demonstrating that the Nash equilibrium is inefficient from the global standpoint. This is natural, given the spillovers involved. Protection in any one region profits the other region (when reaction functions are downward sloping). Since neither side takes into account these spillovers, there is likely to be too little innovation. However, other possible effects go the other way: in particular, with α and β different enough, wasteful competition sets in, and may lead to too much protection in both blocks.

To illustrate the effects at work, we evaluate the marginal (equally-weighted) welfare of our benevolent global dictator at the Nash equilibrium. Differentiating (17) with respect to α and then β, we have:

$$(35)\quad W_\beta = [B(\overline{\theta}) + \gamma B(\overline{\theta}-S) - c - (\overline{\theta}-\underline{\theta})c']\overline{\theta}_\beta + [-B(\underline{\theta}) - \gamma B(\underline{\theta}-S) + c + (\overline{\theta}-\underline{\theta})c']\underline{\theta}_\beta,$$

$$(36)\quad W_\alpha = [B(\overline{\theta}) + \gamma B(\overline{\theta}-S) - c - (\overline{\theta}-\underline{\theta})c']\overline{\theta}_\alpha + [-B(\underline{\theta}) - \gamma B(\underline{\theta}-S) + c + (\overline{\theta}-\underline{\theta})c']\underline{\theta}_\alpha.$$

To evaluate (36) at the Nash equilibrium, we plug in (23). Then, provided that $\overline{\theta}_\alpha > 0$ (which is a sufficient but not necessary condition), the resulting expression can be shown to be positive for all $\beta<1$, including β^* of the Nash equilibrium:

$$(37)\quad W_\alpha = [\alpha B(\overline{\theta}) + \gamma B(\overline{\theta}-S) - c]\overline{\theta}_\alpha - [\alpha B(\underline{\theta}) + \gamma B(\underline{\theta}-S) - c]\underline{\theta}_\alpha.$$

The expressions in the square brackets are positive from the zero-profit conditions (5)-(6). Thus, the North is generally underpatented from a world welfare point of view. The reason for that is simply that the Northern decision makers do not take into account the positive externality that innovations produce in the South. Note that when $\beta=1$, (37) is equal to zero (using [5] and [6]). Only in this limiting case is the Northern patent optimal from a global point of view.

But it may be possible for the North to be overpatented. This can occur when $\overline{\theta}_\alpha<0$ and large. In this case, there is wasteful competition in protection as the North would be trying to shift the range of innovations towards its most preferred technologies.

The analysis is quite similar for the South. To evaluate (35) at the Nash equilibrium, plug in (23) and (27), and rearrange to get:

$$(38)\quad W_\beta = (1-\alpha)[B(\overline{\theta})\overline{\theta}_\alpha - B(\underline{\theta})\underline{\theta}_\alpha][(\overline{\theta}_\beta/\overline{\theta}_\alpha) - (\underline{\theta}_\beta/\underline{\theta}_\alpha)] + \gamma\int B(\theta-S)d\theta.$$

which is generally positive (when $\overline{\theta}_\beta>0$ and $\underline{\theta}_\alpha<0$). Thus, in general, the South is underprotected because it ignores the positive effect of protection on Northern welfare. In particular, it is easy to verify that at S=0 (38) is unambiguously positive. However it is once again possible that the South will be overprotected when $\overline{\theta}_\beta>0$ and/or $\underline{\theta}_\alpha<0$.

VI. Concluding Remarks

While the model analyzed here is quite simple, it leads to a rich array of comparative-statics results, some of which may appear counter-intuitive at first sight. This is largely due to our emphasis on the dimension of technological choice: some of the usual free-riding considerations have to be qualified when we take into account the possibility that patent laws in the two regions affect not only the quantity of innovation, but also its quality. This becomes important when the two regions have differing technological needs. On the other hand, when the two regions are identical in preferences, the usual conclusions can be recovered.

The analysis leads to several results, some of which can be listed as follows. First, an increase in patent protection in any of the two regions leads to an increase in innovative activity, as well as a greater fit between the available technologies and the preferences of the patenting region. By implication, this skews the technology range away from the needs of the other region. Second, while a strictly utilitarian global welfare function would assign identical rates of patent protection to the North and South, placing greater weight on the welfare of the South necessitates differential treatment. But it is not clear *a priori* whether the South ought to have a lower or higher level of protection than the North. Third, when patent rules are set in an uncoordinated manner, it is possible that a narrowing of the gap between the technological preferences of the two regions will lead to lower rates of patent protection in both the North and the South. Similarly, an increase in the relative market size of the South can lead to a reduction in patent protection in both regions.

Theoretical possibilities aside, our numerical simulations yield results in the benchmark case that are generally in line with intuition. In particular, we find that: (i) a benevolent global planner which places greater weight on the South's welfare would require a higher level of patent protection in the North; (ii) in an uncoordinated equilibrium, a reduction in taste differences between the two regions would reduce patent protection in the South; and (iii) an increase in the relative market size of the South, again in the absence of coordination, would increase Southern patents. In the latter two cases, we find Northern patents to be generally insensitive to the changes mentioned.

APPENDIX

(a) We start by deriving the comparative statics properties of equations (5) and (6), when the endogenous variables are $\overline{\theta}$ and $\underline{\theta}$. Total differentiation yields:

$$\begin{bmatrix} \alpha B'(\underline{\theta}) + \beta\gamma B'(\underline{\theta}-S) + c' & -c' \\ c' & \alpha B'(\overline{\theta}) + \beta\gamma B'(\overline{\theta}-S) - c' \end{bmatrix} \begin{bmatrix} d\underline{\theta} \\ d\overline{\theta} \end{bmatrix}$$

$$= \begin{bmatrix} -B(\underline{\theta})d\alpha - \gamma B(\underline{\theta}-S)d\beta - \beta B(\underline{\theta}-S)d\gamma + \beta\gamma B'(\underline{\theta}-S)dS \\ -B(\overline{\theta})d\alpha - \gamma B(\overline{\theta}-S)d\beta - \beta B(\overline{\theta}-S)d\gamma + \beta\gamma B'(\overline{\theta}-S)dS \end{bmatrix}$$

The determinant of the system, denoted by Δ, is negative.

(b) Consider next the alternative wherein α and β are treated as endogenous, targeted on specific $\overline{\theta}$ and $\underline{\theta}$. Notice that $d\alpha/d\overline{\theta}$, for example, is not simply the inverse of $d\overline{\theta}/d\alpha$ as different variables are being held constant in each case; in the first case, β is free to vary but $\underline{\theta}$ is parametric; in the latter, $\underline{\theta}$ adjusts endogenously while β is held fixed. The system now looks like:

$$\begin{bmatrix} -B(\underline{\theta}) & -\gamma B(\underline{\theta}-S) \\ -B(\overline{\theta}) & -\gamma B(\overline{\theta}-S) \end{bmatrix} \begin{bmatrix} d\alpha \\ d\beta \end{bmatrix} = \begin{bmatrix} [\alpha B'(\underline{\theta}) + \beta\gamma B'(\underline{\theta}-S) + c']d\underline{\theta} - c'd\overline{\theta} \\ c'd\underline{\theta} + [\alpha B'(\overline{\theta}) + \beta\gamma B'(\overline{\theta}-S) - c']d\overline{\theta} \end{bmatrix}$$

The determinant of the system is positive since $B(\overline{\theta}-S) > B(\overline{\theta})$ and $B(\underline{\theta}) > B(\underline{\theta}-S)$. It can be shown therefore that $(\mu + \nu) = (d\beta/d\overline{\theta} + d\beta/d\underline{\theta})$ is unambiguously positive.

(c) The second-order conditions for the Northern and the Southern maximization problems are respectively:

(A1) $W^n_{\alpha\alpha} = (1-\alpha)[B'(\overline{\theta})\overline{\theta}_\alpha{}^2 - B'(\underline{\theta})\underline{\theta}_\alpha{}^2] - (\overline{\theta}_\alpha - \underline{\theta}_\alpha)[c' + c''(\overline{\theta}-\underline{\theta})] < 0.$

(A2) $W^s_{\beta\beta} = \gamma(1-\beta)[B'(\overline{\theta}-S)\overline{\theta}_\beta{}^2 - B'(\underline{\theta}-S)\underline{\theta}_\beta{}^2] - 2\gamma[B(\overline{\theta}-S)\overline{\theta}_\beta - B(\underline{\theta}-S)\underline{\theta}_\beta],$

which is necessarily negative when $\underline{\theta}_\beta<0$. Otherwise, it is possible that (A2) will be positive, implying that β^* goes to the corner solution $\beta^*=0$.

(d) Using (10), (11), (13) and (14), it is easy to verify that when S=0: $\overline{\theta}_\beta = -\underline{\theta}_\beta$; $\overline{\theta}_\alpha = -\underline{\theta}_\alpha$; $\overline{\theta}_S = -\underline{\theta}_S$; $\gamma\overline{\theta}_\alpha = \overline{\theta}_\beta$; and $B'(\overline{\theta}) = -B'(\underline{\theta})$. Plugging those relationships into (25), (29), (A1) and (A2), (24) reduces to (26), and (28) becomes (30). In general, a Nash equilibrium does not exist in this case, as both reaction functions have the same slope.

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Table 1: Globally Optimal Patent Rates

ϕ	central case[a]: α	β	extreme taste diff[b]: α	β
1.0	0.21	0.21	0.21	0.21
1.5	0.31	0.05	0.28	0.10
5.0	0.78	0.00	0.70	0.00

Notes: [a] $S=1.2$; $\gamma=0.30$. [b] $S=2$; $\gamma=0.12$.

Table 2: Nash Equilibrium Solutions

S	α	β
a. central case[a]:		
0.8	0.22	0.00
1.1	0.22	0.00
1.2	0.21	0.03
1.3	0.20	0.07
1.4	0.20	0.10
1.5	0.20	0.14
1.6	0.21	0.15
b. extreme taste diff[b]:		
1.0	0.22	0.00
1.8	0.23	0.00
2.0	0.20	0.12
2.2	0.20	0.26
2.5	0.23	0.38

Notes: [a] $S=1.2$; $\gamma=0.30$. [b] $S=2$; $\gamma=0.12$.

Table 3: Nash Equilibrium Solutions

γ	α	β
central case[a]:		
0.50	0.20	0.08
0.40	0.20	0.07
0.30	0.21	0.03
0.25	0.21	0.03
0.20	0.21	0.00

Note: [a] S=1.2; γ=0.30.

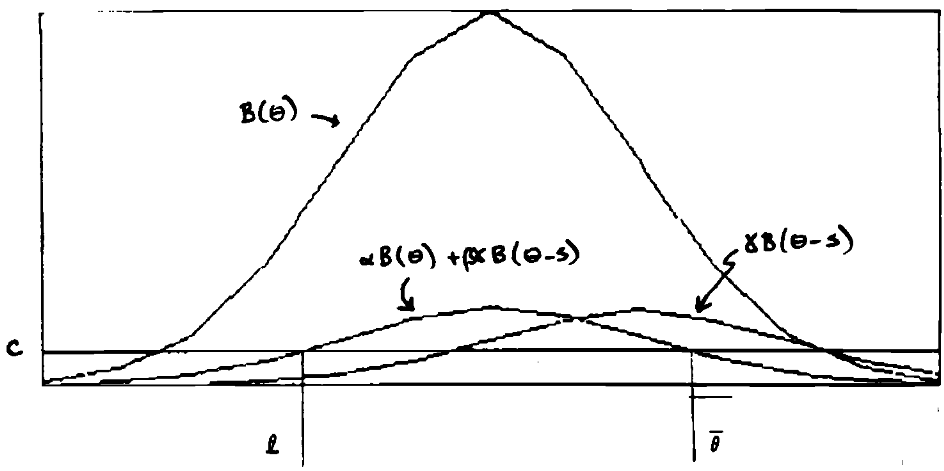

Figure 1

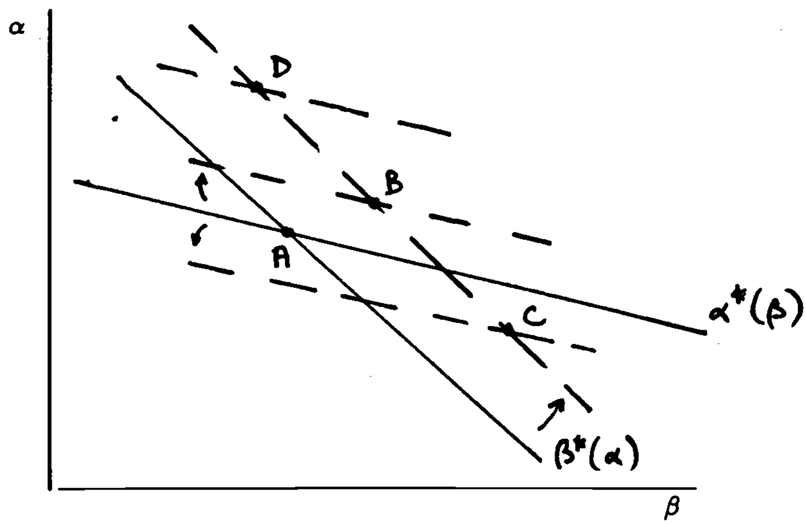

Figure 2