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TRIPS, TRADE, AND GROWTH*

BY M. SCOTT TAYLOR¹

A two country model of endogenous growth is employed to assess the importance of intellectual property rights to trade, growth, and technology transfer. The paper provides theoretical results linking the intellectual property rights regime to trade patterns, aggregate R&D, worldwide growth, and aggregate welfare measures. Failure to provide patent protection for foreign made innovations forces innovators to employ less than the best practice research technologies, reduces aggregate R&D activities worldwide, effectively eliminates technology transfer across countries, and reduces worldwide growth.

1. INTRODUCTION

Economists have for many years recognized the important role intellectual property rights (IPRs) play in facilitating trade. Today the arguments for and against IPRs are still under vigorous debate, particularly in GATT. Discussions on Trade Related Intellectual Property rights (TRIPs) were included in the Uruguay Round because many governments contend that weak or nonexistent patent protection distorts natural trading patterns and reduces the ability of firms to transfer technology abroad. Moreover, nonexistent patent protection may lower the world's R&D by reducing incentives, and thereby diminish worldwide growth. While these contentions may be true, as yet there is little theoretical support for them.

This paper sheds light on this debate by linking the regime for intellectual property protection to trade, growth, and technology transfer in a two country model of endogenous growth. The paper extends the model of Taylor (1993a) to examine how the regime for IPRs protection affects the ability of firms to transfer technologies abroad and go "multinational." Growth is fueled by continual innovation, while trade patterns in both goods and R&D can be determined graphically by employing relative unit labor productivity schedules. The location and scope of R&D activities, the extent of multinational activity, and the worldwide rate of economic growth are all determined endogenously by technologies, factor endowments, and the prevailing regime for intellectual property rights protection.

The existing literature on TRIPs has focused almost exclusively on static, partial

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¹ This paper is a revised version of Chapter Three from my dissertation "Three Essays on the International Diffusion of Technology" at Queen's University (October 1990). I am grateful to R. Harris, J. Brander and two anonymous referees for helpful comments. Financial assistance was provided by the Social Sciences and Humanities Research Council of Canada, the Killam Foundation, and the Centre for International Business Studies at University of British Columbia. The usual disclaimer applies.

equilibrium, North-South models.² Typically researchers have modelled Northern innovators competing with Southern imitators for markets in R&D intensive products with the stringency of patent protection affecting the nature of this competition. Chin and Grossman (1988) adopt a North-South Cournot duopoly model where all innovation takes place in the North, and all imitation takes place in the South. They find that the interests of the North and South are generally opposed. Unless Northern R&D is very productive in lowering unit production costs, the Southern government's best policy is to "look the other way" while Southern firms infringe on Northern intellectual property. Diwan and Rodrik (1991) tempers this result somewhat by assuming the North and South differ in their preferences for certain technological breakthroughs. If preferences differ across regions, then the South may protect Northern intellectual property to facilitate the invention of technologies "appropriate" to the South.

While these earlier contributions have sharpened our understanding of the strategic and purely technological aspects of the TRIPs debate, they have necessarily abstracted from the complications, and the ensuing benefits, arising from adopting an explicitly dynamic and general equilibrium setting with active "technology transfer" across countries. There are three benefits to adopting such an approach. First, by employing a dynamic model we can examine how a change in the IPR regime affects investment decisions in R&D and hence subsequent growth rates in the world economy. Second, by employing a general equilibrium framework we can examine how a change in the IPR's regime affects trade patterns, relative wage rates, and the allocation of resources across manufacturing and research sectors of the economy. Finally, by allowing for technology transfer we can examine how a change in the IPR's regime affects the willingness of entrepreneurs to transfer technology abroad, and investigate how this affects the role technology transfer plays in equalizing factor incomes and raising worldwide growth rates.

In order to develop a tractable dynamic model capable of examining the TRIPs debate, much simplification is required. As a result, the strategic elements that loomed large in Chin and Grossman (1988) play a much smaller role here, and the realistic detail of Diwan and Rodriks' (1991) gradations of patent protection will be entirely absent. Moreover, I examine a particularly stark change in the intellectual property rights regime. Protection is changed from a perfectly symmetric protection regime for intellectual property to a regime where protection is perfectly asymmetric. Under symmetric protection, foreign made innovations are treated the same as domestic. Under asymmetric protection, each country only offers protection to domestically produced innovations.

While this comparison of symmetric and asymmetric protection regimes is necessarily devoid of much institutional detail, it is difficult to know which of the specifics of the ongoing discussions to capture.³ The discussions have ranged widely encompassing the issues of appropriate breadth of patent protection, the

² See also Taylor (1993b), and Deardorff (1992). Subsequent to the writing of this paper Rivera-Batiz and Romer (1991) developed a dynamic general equilibrium model to address the TRIPs debate. In stark contrast with the model presented here, their model assumes countries are identical in every respect and no technology transfer occurs.

³ The best source for recent negotiating positions is GATT's own newsletter the GATT FOCUS.

selection of commodities covered, the type of protection provided (process or product patents), provisions for enforcement, and guarantees for access to domestic courts in cases of suspected infringement. In the absence of a specific proposal to examine, it seems best to capture the essence of the debate by drawing a link between asymmetries in patent protection and resulting trade distortions.

The remainder of the paper proceeds as follows. Section 2 provides a sketch of the model's building blocks and presents some preliminary results.⁴ A complete description of the basic model is available in Taylor (1993a). In Section 3, I develop a specific variant of the basic model, and in Section 4 I extend this model to allow for technology transfer across countries. Section 5 presents a series of results concerning TRIPs. Section 6 contains a brief conclusion. All detailed calculations are relegated to the Appendix.

2. ASSUMPTIONS AND BASIC RESULTS

In Taylor (1993a) consumers share identical, time separable, and homothetic utility functions defined over a continuum of final products. They maximize the expected discounted value of lifetime utility and smooth expenditures over time by investing in the securities offered by firms active in innovation. The return to these shares is uncertain, but all risk is idiosyncratic. Lifetime utility is given by

$$(2.1) \quad U = \int_0^{\infty} e^{-\rho t} \left\{ \int_0^1 b(z) \ln [x(z, t)] dz \right\} dt$$

$$dB(z) = b(z)dz, B(1) = 1, B(0) = 0.$$

$x(z, t)$ is the quantity of good "z" consumed at time t , ρ is the rate of time preference, and $b(z)$ is the continuum counterpart to the many commodity budget share for good z .

The continuum of products is produced by labor power alone, but with methods reflecting the generation of technology employed. If we label generations of technology by "j" then unit labor requirements in goods production are $a(z)\phi(j, z)$ when generation $j \in (0, 1, 2, \dots)$ technology is in place in industry $z \in [0, 1]$. $a(z)$ is independent of technological progress, whereas $\phi(j, z)$ falls over time as successive generations of technology improve on their predecessors. The relationship between successive generations of technology is given by the inventive step " $n(z)$ " where $n(z) \in (0, 1)$ and $\phi(j + 1, z) = [1 - n(z)]\phi(j, z)$. To simplify the analysis, I will assume $n(z) = \nu$ for all z . As a result, all innovations are proportionally labor saving. This appears to be a useful, and innocuous, simplification.⁵

Successive generations of technology are discovered by innovators who obtain patents of infinite duration for their discoveries. While each innovation is protected by patent rights, the innovation also produces nonappropriable knowledge spill-

⁴ The basic model is constructed by embedding the 1 factor "Quality Ladders" model of Grossman and Helpman (1991a) within the continuum Ricardian framework of Dornbusch, Fischer, and Samuelson (1977).

⁵ Very few of the conclusions drawn here depend on $n(z)$ being constant over z . Any important qualifications are mentioned in footnotes where appropriate.

overs that enable other innovators working in the same field to search for further improvements. Hence each patent holder only earns monopoly profits until displaced by a subsequent innovator. When generation “ $j + 1$ ” technology appears, Bertrand competition between patent holders results in the patent holder of “ $j + 1$ ” limit pricing the “ j th” generation of technology out of the market. With demand unit elastic, the schedule of profits to innovators are independent of “ j ” and can be written $\Pi(z) = \nu b(z)E(t)$ for $z \in [0, 1]$.

Innovators worldwide seeking to earn these monopoly profits race to develop the “ $j + 1$ st” generation of technology, in each industry z , if generation “ j ” is already in place. The R&D discovery process is Poisson with the hazard rate rising proportionately with R&D effort “ i .” One unit of research at level “ i ” in industry z , denoted by $i(z)$, requires $a_I(z)$ units of labor. Hence if we let $V(z)$ denote the expected present discounted value of an infinite life patent in industry z , then free entry into R&D requires expected benefits equal costs or $V(z) = wa_I(z)$ when $i(z) > 0$.

To fund their R&D investments, firms sell equity shares to consumers. Shares from successful firms pay dividends at rate $\Pi(z) dt$, capital gains at rate $[[dV(z)/dt]/V(z)] dt$, and suffer a capital loss of $wa_I(z)$ with probability $i(z) dt$. Therefore, the expected rate of return earned on the shares in any industry z is given by $r(z) = [\Pi(z) + dV(z)/dt - wa_I(z)i(z)]/V(z)$. If consumers hold a well diversified portfolio of these shares containing a large number of these projects, then $r(z)$ must equal r for each project and the overall return to the portfolio is certain.

3. INTERNATIONAL TRADE WITHOUT TECHNOLOGY TRANSFER

Consider a two country world where each economy is as described above. In addition, assume financial capital is internationally mobile, production and R&D technologies are immobile, the inventive step between generations of technologies are the same in both countries, and knowledge spillovers created by successful innovation aid subsequent innovators in either country. Then the world equilibrium with trade is fully described by three relationships that must hold at all times.⁶ If we denote foreign variables with a “*” when necessary, these relationships can be written

$$(3.1) \quad \omega = A(\bar{z}) \equiv a^*(\bar{z})\phi(0, \bar{z})/a(\bar{z})\phi(0, \bar{z}) = a^*(\bar{z})/a(\bar{z})$$

$$(3.2) \quad \omega = RD(\bar{z}) = a_I^*(\bar{z})/a_I(\bar{z})$$

$$(3.3) \quad \omega = \frac{[L^* + \rho A_I^*]}{[L + \rho A_I]} \times \frac{\left[B(\bar{z}) - \int_{\bar{z}}^{\bar{z}} \nu b(z) dz \right]}{\left[1 - B(\bar{z}) + \int_{\bar{z}}^{\bar{z}} \nu b(z) dz \right]}$$

$$\text{where } A_I = \int_0^{\bar{z}} a_I(z) dz \quad A_I^* = \int_{\bar{z}}^1 a_I^*(z) dz.$$

⁶ See Taylor (1993a) for further discussion.

Equation (3.1) is a relative unit labor productivity schedule similar to that of Dornbusch et al. (1977), but amended to allow each country's unit labor requirements in production [$a(z)\phi(j, z)$ or $a^*(z)\phi(j, z)$] to fall over time as the result of successful innovation. Without loss of generality we can define $a(z)$ and $a^*(z)$ to ensure $j = 0$ at the outset of trade as shown in (3.1).

As in Dornbusch et al. (1977), $A(z)$ is continuous in z by assumption, and declining in z by construction. For given relative wages $\omega = w/w^*$, the $A(z)$ schedule at $t = 0$ divides the set of goods $z \in [0, 1]$ into those produced at least cost at home, $z \in [0, \bar{z}]$, and those produced at least cost abroad $z \in [\bar{z}, 1]$. The competitive margin good \bar{z} is implicitly defined by $\omega \equiv A(\bar{z})$. Both \bar{z} and ω will be constant over time, but continual innovation will perpetuate and sharpen the original technological differences across countries.

Equation (3.2) represents a similar relative unit labor productivity schedule for R&D, and " \bar{z} " is defined by $\omega \equiv a_I^*(\bar{z})/a_I(\bar{z})$. A similar division of R&D activities across countries is possible because innovation only takes place in the least cost location;⁷ but the exact nature of this division depends upon the properties of $RD(z)$ and hence further assumptions are required. I assume that it is costly to improve goods producing technologies in industries where the country already exhibits an absolute disadvantage. For example, if the home country has an absolute disadvantage in goods production in industry z' , then the home country is also at an absolute disadvantage in research in z' : $a(z') > a^*(z') \Rightarrow a_I(z') > a_I^*(z')$ for all z' . To obtain this correlation research and production technologies must be linked by a factor $\mu(z) > 0$ where $a_I(z) = \mu(z)a(z)$, and $a_I^*(z) = \mu(z)a^*(z)$ as well.⁸ By construction, $RD(z)$ is now continuous and monotonically declining, taking the form $a_I^*(z)/a_I(z) = \mu(z)a^*(z)/\mu(z)a(z) = a^*(z)/a(z) = A(z)$.

This particular description of the relationship between production and research technologies is both simple and intuitive. At bottom, differences in unit labor requirements across industries must arise from each industry benefitting differentially from some common and complementary factors. By linking R&D and production technologies by $\mu(z)$ we are assuming these factors are common to research and production activities in each industry, but have potentially different effects across industries. Examples of such complementary and public factors are basic education, certain types of infrastructure, and environmental quality.

Equation (3.3) is a balance of payments equation defining the relative wage needed to maintain balance of payments equilibrium when the home country conducts goods production over $z \in [0, \bar{z}]$ and undertakes R&D in industries $z \in [0, \bar{z}]$. Given our assumptions above, the competitive margin in goods and R&D will be the same: $\bar{z} = \bar{z}$. Hence the three equation system (3.1) through (3.3) can be reduced to just two equations in $\{\omega, \bar{z} = \bar{z}\}$; moreover, (3.3) simplifies to

⁷ Innovators choosing to conduct R&D in the high cost country could not attract investment funds from consumers since the identical research program conducted in the low cost country offers a higher expected rate of return. Grossman and Helpman (1991b) contains a proof of this assertion.

⁸ I am grateful to a referee for suggesting this interpretation of the link between research and production technologies.

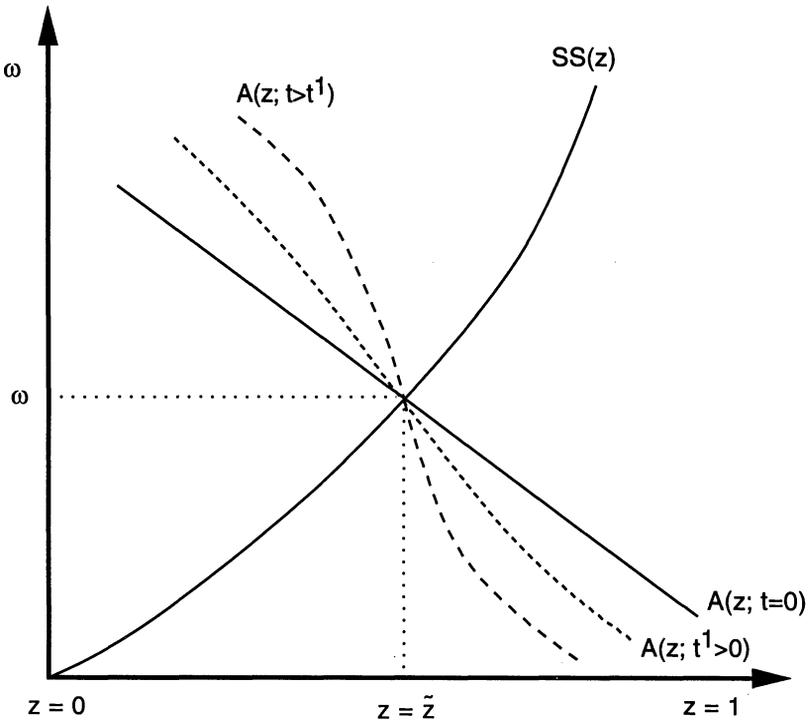


FIGURE 1

$$(3.4) \quad \omega = \frac{[L^* + \rho A_I^*][L + \rho A_I]}{[B(\bar{z})][1 - B(\bar{z})]} \equiv SS(\bar{z}).$$

This $SS(z)$ schedule is an exact dynamic analog to the balance of trade schedule introduced in Dornbusch et al. (1977). It is upward sloping as a function of \bar{z} starting at zero when $\bar{z} = 0$ and rising to infinity as \bar{z} approaches 1.⁹

We can combine either equation (3.1) or (3.2) with (3.4) to solve for the competitive margin in both goods and R&D, and the equilibrium relative wage ω . This solution can be depicted graphically by combining the $A(z)$ and $SS(z)$ schedules as shown in Figure 1. As Figure 1 shows the $A(z)$ schedule together with $SS(z)$ determines the competitive margin \bar{z} and the initial relative wage rate ω . At $t = 0$ the world economy jumps to its steady state. Innovators at home and abroad survey the entire set of production technologies, but incentives lead them to target their R&D efforts towards improving only those technologies already in use. As successful innovation occurs it lowers unit labor requirements, and sharpens the existing differences across countries in comparative advantage. Since the R&D process is stochastic, the resulting deformation of $A(z)$ is discontinuous in time as depicted in Figure 1. Nevertheless, the equilibrium level of country and world

⁹ This is necessarily true if $i(z) > 0$ for all z , and I will assume this throughout. The world economy will exhibit two way trade in goods, but no intertemporal trade in assets. Any deficit in the goods trade account is met by a surplus on the services account. This feature arises since consumers in both countries have identical homothetic preferences and face a common rate of interest.

expenditures and the allocations of labor to R&D and goods production are all constant over time.

If we take home labor as the numeraire in every period, the steady state solutions for world expenditure, R&D effort levels, and the growth rate in expected utility are¹⁰

$$(3.5) \quad E + E^* = w^*L^* + L + \rho VP \quad \text{where } VP \equiv A_I + w^*A_I^*$$

$$(3.6) \quad i(z) = \nu b(z)[E + E^*]/a_I(z) - \rho \quad z \in [0, \bar{z}]$$

$$(3.7) \quad i^*(z) = \nu b(z)[E + E^*]/w^*a_I^*(z) - \rho \quad z \in [\bar{z}, 1]$$

$$(3.8) \quad \hat{u}(t) = -\ln [1 - \nu] \left[\int_0^{\bar{z}} b(z)i(z) dz + \int_{\bar{z}}^1 b(z)i^*(z) dz \right].$$

Expenditures are given by the sum of factor plus profit income. Factor income is measured by resource endowments times wage rates, while profit income is equal to the steady state return “ ρ ” earned on the value of the world portfolio of assets “ VP .” “ VP ” is given by the value of innovating firms both at home and abroad, measured over their respective ranges of $[0, 1]$. R&D effort levels $i(z)$ respond positively to the size of flow profits earned on the new innovation $\nu b(z)[E + E^*]$, and negatively to the unit costs of conducting R&D in either country $a_I(z)$ or $w^*a_I^*(z)$.

The growth rate in expected utility is just a weighted average of the research efforts in each industry. This simple equation for the growth rate arises because the per-period indirect utility function is separable in price and expenditure components. To understand (3.8) consider the impact of an innovation in industry z' . Given an innovational success in z' , production costs in z' immediately fall by $[1 - \nu]$ percent and because of limit pricing the price of z' falls by $[1 - \nu]$ percent as well. With unitary elastic demand, consumption of z' rises by $[1 - \nu]$ percent. Therefore, to capture the level rise in instantaneous utility associated with this innovation we apply the percentage increase in consumption $[1 - \nu]$ to $b(z')$ to correct for the scale of consumption in z' . The final step is to note that (3.8) captures the expected utility gains arising from these innovations since they occur with an instantaneous probability of $i(z)dt$ in each industry.

4. INTERNATIONAL TRADE WITH TECHNOLOGY TRANSFER

Following Dornbusch et al. (1977) I assume technology transfer is costless, and assume foreign labor is just as productive with home research technologies as are home workers.¹¹ If innovators can carry their research technologies abroad then

¹⁰ See Taylor (1993a) for a derivation.

¹¹ This is an assumption of convenience. Technology transfer could be costly if foreign workers were not as productive with home research technologies as were home workers. For example, assume the home labor force is uniformly more productive at employing any research technology by a factor $\gamma > 1$. Then moving home research technologies aboard is costly since the marginal product of foreign labor is

only the most efficient will ever be in use. Define the set of *best practice research technologies* $a_I^w(z)$ as the set $\{a_I^w(z) | a_I^w(z) = \min [a_I^*(z), a_I(z)] \text{ for } z \in [0, 1]\}$. No innovator would ever employ a research technology outside of this best practice set. Moreover, since innovators can undertake research in either country wages must be equalized in any equilibrium where R&D is undertaken in both countries.

The division of production and R&D activities across countries is determined by cost minimization as before, but with technology transfer it is as if both countries shared a common schedule $RD(z) = a_I^w(z)/a_I^*(z) = 1$. The competitive margins in goods production, \bar{z} , and R&D, \bar{z} , will now differ and \bar{z} should be interpreted as the fraction of industries with their R&D conducted in the home country. For example, if $\omega > 1$ in equilibrium, then all R&D is conducted in the foreign country, $\bar{z} = 0$, and the home country produces goods $z < \bar{z}$ where $A(\bar{z}) = \omega > 1$. If $\omega < 1$ in equilibrium, then all R&D is conducted in the home country, $\bar{z} = 1$, and the home country produces goods $z < \bar{z}$ where $A(\bar{z}) = \omega < 1$. If $\omega = 1$, then $A(\bar{z}) = 1$ determines the competitive margin in goods, R&D activities are diversified across countries, and \bar{z} is determined by either country's labor market clearing condition.

A new balance of payments schedule must be constructed to reflect these specialization and diversification regions. This schedule, denoted $BP(z)$, is obtained from (3.3) by letting \bar{z} take on all possible values in $[0, 1]$. The schedule is derived in the Appendix and presented in Figure 2. As shown, $BP(z)$ has three constituent parts: (1) an initial segment starting at $\omega(\min)$ and rising until z' ; (2) a factor price equalization segment over $[z', z'']$ with $\omega = 1$; and (3), a remaining segment beginning at z'' and ending at $\omega(\max)$. Combining this composite $BP(z)$ with $A(z)$ solves for relative wages ω , and the competitive margins in both R&D and goods production (i.e. \bar{z} and \bar{z}).

As shown in Figure 2, the $BP(z)$ schedule has three distinct segments, but this is not a necessity. First consider the FPE segment.¹² The likelihood of a factor price equalization equilibrium depends on both technologies and factor endowments. On the technology side it is necessary that each country has an absolute advantage in at least one industry. From Figure 2 it is clear that for $A(z)$ to cut $BP(z)$ at $\omega = 1$ it must be true that $A(z) > 1$ for some z and $A(z) < 1$ for some other z . This seems a weak condition on relative technologies and I will assume that it holds throughout.

Given an $A(z)$ as described, the likelihood of FPE then depends on the relative and absolute size of factor endowments. Using the definitions of z' and z'' given in the Appendix it is not difficult to show that $z'' > z'$ whenever any R&D is profitable when $\omega = 1$. This will always be true if the world market size (as determined by L and L^*) is large in relation to the unit costs of conducting R&D ($a_I^w(z)$). Moreover, the factor price equalization segment expands with balanced increases in L and L^* since innovation activities rise with population sizes. As a result, the larger the

lower. Active research would only occur in both countries if $w = \gamma w^*$. I assume $\gamma = 1$ to ease the notation, but all of the results of this paper will continue to hold if $\gamma \neq 1$ and technology transfer is costly.

¹² If $BP(\bar{z}) = A(\bar{z}) = 1$ then this FPE equilibria is identical to the equilibria that would arise if we assumed internationally mobile labor and immobile production and research technologies. Therefore, some of the results in Propositions 2 and 3 could be reinterpreted as comparisons of world equilibria with and without labor mobility.

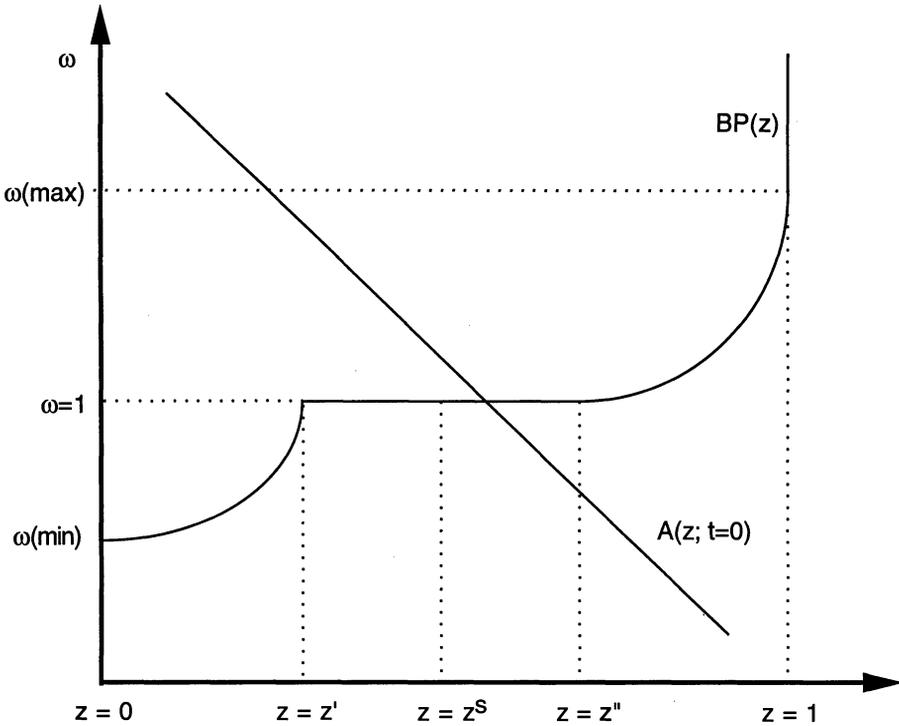


FIGURE 2

world economy the greater is the likelihood that $BP(\bar{z}) = A(\bar{z})$ falls between z' and z'' .

Finally, consider the specialization segments of $BP(z)$. If an equilibrium is to occur in either segment, then one country must be able to provide all the world's R&D. Not surprisingly this is only possible if the country conducting R&D is not too small relative to its partner. For example, if the home economy is relatively small then even with its entire labor force dedicated to R&D it may not be able to meet the world's demand for R&D. Consequently, the point labelled z' is driven to zero and an equilibrium with home the sole producer of R&D does not exist. Alternatively with a relatively small foreign country, z'' is driven to one. The intuition here is identical to a 2 good, 2 country, Ricardian model. If one country is small relative to its partner, then the larger country must produce both goods (read R&D results and some goods production) in equilibrium. The small country cannot be the sole producer of one of the goods (i.e. R&D results). Hence Figure 2 depicts a $BP(z)$ schedule where countries do not differ radically in relative size.

It is now possible to show that the equilibria with mobile research technologies differs from that in Figure 1 in 3 significant ways. First, if $BP(\bar{z}) = A(\bar{z})$ for $\bar{z} \in [0, z']$ then the home country is the sole producer of R&D, whereas if $\bar{z} \in [z'', 1]$ the foreign country is the sole producer of R&D. In either case innovators would be discovering new generations of technology in one country, and implementing them on production technologies in the other. If $\bar{z} \in [0, z']$ then multinational

corporations conducting R&D at home would be undertaking production abroad, and exporting their products back to the home country. The number (measure) of such multinationals would be $1 - \bar{z}$. In contrast, in all equilibria depicted by Figure 1 both countries conduct R&D, and there are no multinational corporations.

Second, if $BP(\bar{z}) = A(\bar{z})$ for $\bar{z} \in [z', z'']$ then factor price equalization arises and the equilibrium almost surely exhibits trade in R&D results. Moreover, both home and foreign innovators may undertake R&D domestically but implement their discoveries on production technologies in the other country. Hence two way trade in R&D results is also a possibility. In the Appendix I show that if $BP(\bar{z}) = A(\bar{z})$ for $\bar{z} = z^s$ then the home country would be conducting just enough R&D to meet the needs of its goods producing industries. Hence it is possible that trade in R&D results is zero at this point on the FPE segment. Not surprisingly it is also true that at z^s , $BP(z^s) = SS(z^s)$; consequently if $\bar{z} = z^s$, (a probability zero event) technology transfer and trade in R&D results may be zero and the equilibrium with technology transfer is virtually identical to the equilibrium without technology transfer.

Since zero trade in R&D is a possible outcome when $BP(z^s) = A(z^s)$, then if an equilibrium occurs to the left of z^s ; i.e. at $\bar{z} < z^s$, less home resources are allocated to production and more are allocated to R&D. Home's *net exports* of R&D are positive. The *minimum* number of home multinationals in this equilibrium is given by $\bar{z} - \bar{z} > 0$. The minimum number of foreign multinationals is zero. Conversely, moving rightwards from z^s more of home's labor is allocated to production and less to R&D. If $\bar{z} > z^s$, then home *net imports* of R&D are now positive. Foreign multinationals must number at least $[(1 - \bar{z}) - (1 - \bar{z})] > 0$. In contrast to these results, the possibility of FPE in Figure 1 is a probability zero event, there is no trade in R&D results, and clearly no two way trade in R&D results either.

The final difference between the equilibria is technology transfer. In all equilibria where $BP(\bar{z}) = A(\bar{z})$ entrepreneurs in one or both countries are almost surely transferring their domestic research technologies abroad and conducting R&D in the least cost location. This assertion is not difficult to show but its proof is relegated to the Appendix.

PROPOSITION 1. *If $\bar{z} > z^s$, then the home country must be a net importer of R&D results. If $\bar{z} < z^s$, then home must be a net exporter of R&D results. In either case, active technology transfer occurs across countries.*

Apart from the differences spelt out above, the equilibria depicted in Figures 1 and 2 are much the same. Innovators improve only those production technologies that are least cost given initial relative wages, research successes deform the $A(z)$ schedule, but \bar{z} , \bar{z} , and ω remain constant over time. The steady state exhibits constant country and world expenditure levels, a constant division of labor across R&D and manufacturing, and a constant division of R&D and production activities across countries.

Steady state solutions for world expenditure, R&D intensities, and the growth rate in expected utility again follow from (3.5) through (3.8) if we taken into account three minor modifications. First, \bar{z} , \bar{z} , and ω must be determined as described

above, and \bar{z} in (3.6), (3.7) and (3.8) must be replaced by \bar{z} . Secondly, \bar{z} must be replaced by \bar{z} in the definitions of A_I and A_I^* , and the set of best practice research technologies $a_I^w(z)$ must replace their country specific equivalents. Lastly, if factor price equalization arises then the research effort in any industry should be denoted $[i(z) + i^*(z)]$ since only the aggregate effort level, and not its division across countries, is determined.

5. ASYMMETRIC PROTECTION, TRADE AND GROWTH

In this section I compare and contrast the world equilibria that obtain under two possible regimes for intellectual property rights protection. Under both regimes, I assume any patents granted are of infinite duration and assume innovators may transfer research technologies abroad if they so wish. In the symmetric protection regime innovators can obtain patent protection for their innovations regardless of where the R&D was undertaken and regardless of their own nationality. Domestic and foreign innovations are treated symmetrically. In the asymmetric protection regime innovators can only obtain patent protection for their innovations if the R&D was conducted at home by domestic firms. Domestic and foreign innovations are treated asymmetrically.¹³

To examine the effects of asymmetric protection we need to determine where the world economy would have settled with symmetric protection. For example, start with an equilibrium at $\bar{z} = z^s$. Although this is a probability zero event, it is a useful starting point to fix our ideas. When $\bar{z} = z^s$ trade in R&D results and technology transfer could be zero in equilibrium. As a result, asymmetric protection has no effect on equilibrium magnitudes. All innovations implemented at home will be discovered at home using home country R&D technologies. The number of home and foreign multinationals will be zero, and since each country conducts just enough R&D to meet its own needs this geographic constraint has little effect. The equilibria with symmetric and asymmetric protection are virtually the same.

These results change dramatically if either country was a net exporter of R&D results under symmetric protection. In this case, the move to asymmetric protection brings about a loss in export opportunities for the country exporting R&D results. Figure 3 presents four equilibria relevant to our comparisons in this case. In all cases I assume the home country would be a net exporter of R&D results under symmetric protection.¹⁴ The move from symmetric to asymmetric protection represents a change in potential equilibria from points 1 and 2 along $BP(z)$, to points 1* and 2* along $SS(z)$.

To verify these claims reconsider the technology transfer decisions of agents under asymmetric protection. When $\omega < 1$, innovators would like to conduct R&D at home and export their results to the foreign country but cannot since patents on their innovations in the foreign country are now worthless. Similarly, when $\omega > 1$ innovators would like to supply the entire world's R&D demand from the foreign

¹³ Foreign here applies to innovations made by foreign firms or innovations made by domestic firms in the foreign country.

¹⁴ Identical results hold if we assume the foreign country was a net exporter under symmetric protection.

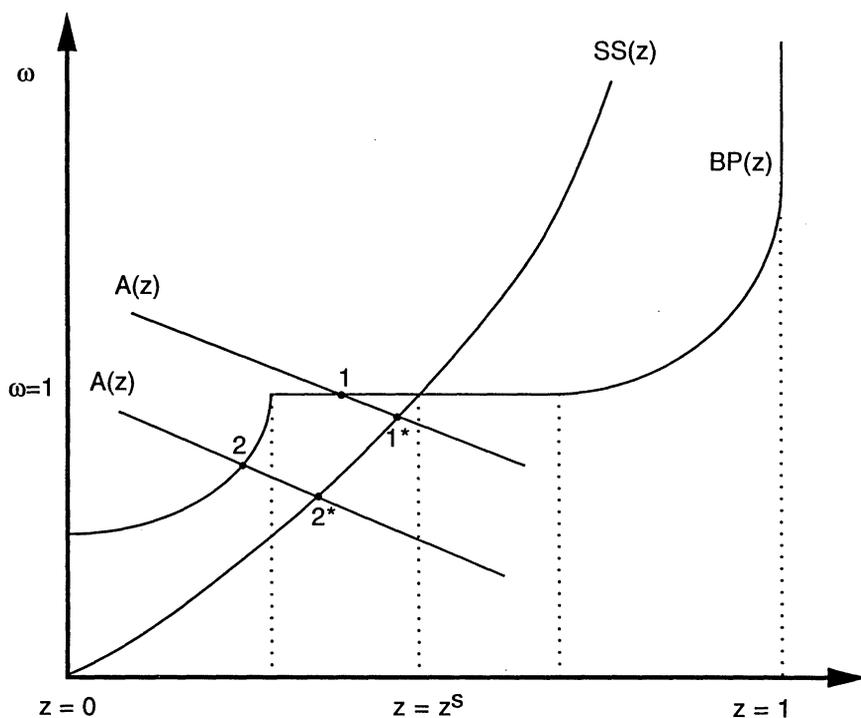


FIGURE 3

country but cannot because of the lack of patent protection for foreign made innovations in the home country. When $\omega = 1$ each country can supply its own domestic needs for R&D results but no more. Hence, even though technology transfer is feasible—it is clearly not profitable—and world equilibria must occur along $SS(z)$ rather than along $BP(z)$.¹⁵

Four consequences of asymmetric protection are apparent from Figure 3. First, relative wages change in favor of the R&D importing country. Second, the R&D exporting country loses export markets for home conducted R&D, and hence the pattern of trade in R&D is distorted by asymmetric protection. Third, since the attendant fall in home's relative wage leads to an increase in the slate of goods produced at home and exported abroad, asymmetric protection also distorts the pattern of trade in goods. Fourth, since technology transfer occurs at 1 and 2 but not at either 1* or 2*, asymmetric protection eliminates technology transfer between countries.

To examine the effect asymmetric protection has on aggregate R&D and growth rates we need to combine Figure 3 with our previous results on the steady state allocations to R&D. Let a superscript "s" denote equilibrium magnitudes under symmetric protection, while "a" denotes magnitudes under asymmetric protec-

¹⁵ While the threat of imitation of patented technologies by competitors abroad exists in the asymmetric protection regime, no imitation ever arises in equilibrium. For an examination of imitation in related models see Grossman and Helpman (1991b, c) and Segerstrom (1990).

tion. Then employ (3.6) and (3.7) to find the difference across equilibria in the allocation of labor to R&D activities. Defining this difference as $I^s - I^a$ we obtain

$$(5.1) \quad I^s - I^a = [1 - \nu] \left[\rho \int_{z^b}^{\bar{z}^a} [a_I(z) - a_I^w(z)] dz \right] + \nu L^* [1/\omega^s - 1] > 0$$

$$I^s = \int_0^1 \{[i(z)^s + i^*(z)^s] a_I^w(z)\} dz$$

$$I^a = \int_0^{\bar{z}^a} i(z)^a a_I(z) dz + \int_{\bar{z}^a}^1 i^*(z)^a a_I^*(z) dz,$$

where z^b is defined by $A(z^b) \equiv 1$. Since $A'(z) < 0$ and $\omega < 1$ in the asymmetric protection equilibria, $\bar{z}^a > z^b$. Moreover, with $A(z^b) \equiv 1$ and $A'(z) < 0$, $a_I^w(z) = a_I^*(z)$ for $z > z^b$ and hence $[a_I(z) - a_I^w(z)]$ is strictly greater than zero for all $z > z^b$. Therefore, the first term in (5.1) is necessarily positive and it captures the technology choice inefficiency created by asymmetric protection. Over the range $[z^b, \bar{z}^a]$ the home country now employs its relatively inefficient research technologies rather than the world's best practice technologies. The further are home's inefficient technologies from the best practice frontier, the greater the fall in R&D coming from this source.

The second term in (5.1) captures the inefficient diversification of R&D activities across countries. If $\omega^s < 1$ in the symmetric protection equilibria, then all R&D is conducted at least cost in the home country. With asymmetric protection some R&D is now conducted at higher cost abroad and the second term in (5.1) is positive. This forced diversification of R&D activities across countries adds to the technology choice inefficiency and both serve to lower aggregate R&D in the world.¹⁶

While equation (5.1) indicates that R&D worldwide necessarily falls in the move to asymmetric protection, it tells us nothing about how this decrease is effected. Do both countries conduct less R&D, or does one country gain R&D activities at the expense of the other? These distributional issues are surely an important concern for both country governments. To address this question consider the pairs of equilibria (1, 1*) and (2, 2*) in Figure 3. At 2, $\omega < 1$ and the foreign country conducts no R&D under symmetric protection. Conversely, at 2* R&D is conducted in the foreign country in industries $z \in [\bar{z}^a, 1]$. Consequently, R&D activities in the foreign country are necessarily higher with asymmetric protection. Moreover, since world R&D falls the home country must be conducting less R&D under asymmetric protection.

Now consider the equilibria at 1 and 1*. Since the foreign country conducts some R&D at 1 the simple deduction employed above will not suffice; nevertheless, the same result obtains.¹⁷ Not surprisingly asymmetric protection has strong distribu-

¹⁶ If $n(z) \neq \nu$ then two further terms appear in (5.1) capturing terms of trade effects. These terms of trade effects move in opposite direction but cancel if the inventive step is constant across all industries. See Taylor (1990) for further discussion.

¹⁷ See the Appendix.

tional consequences. R&D in the home country falls since asymmetric protection removes export opportunities for home conducted R&D, and constrains technology choice. R&D rises in the foreign country since asymmetric protection grants foreign innovators a captive domestic market for their innovations.

Although the foreign country conducts more R&D under asymmetric protection, it does not follow that goods producing industries active in the foreign country now experience faster technological progress than previously. Quite the contrary, all industries in the foreign country experience slower technological progress under asymmetric protection! To examine this claim consider the segment of goods producing industries $z \in [\bar{z}^a, 1]$. The foreign country is the sole goods producer in these industries under both asymmetric and symmetric protection. Since $\bar{z}^a > z^b$ we know $a_I^w(z) = a_I^*(z)$ for $z \in [\bar{z}^a, 1]$; therefore to compare R&D allocations across equilibria it suffices to check the effort levels of R&D. From (3.7) we can conclude $[i(z)^s + i^*(z)^s] > i^*(z)^a$, if $[E + E^*]^s > [E + E^*]^a / w^{*a}$. Examining (3.5) under the two regimes shows this is indeed true.¹⁸ Technological progress is therefore slower in all foreign industries under asymmetric protection.

Now consider the home country, and at first restrict our attention to the range of goods producing industries $z \in [0, z^b]$. The home country is the sole goods producer in these industries under both regimes. Over this segment $a_I^w(z) = a_I(z)$, and $i(z)^a > i(z)^s$ if $[E + E^*]^a > [E + E^*]^s$. Examining (3.5) under the two regimes shows this is indeed true. Therefore, home industries $z \in [0, z^b]$ receive more R&D under asymmetric protection. Finally, consider the middle range $z \in [z^b, \bar{z}^a]$. Over this range of industries home entrepreneurs employ their relatively less efficient research technologies $a_I(z)$ instead of the world's best practice technologies $a_I^w(z) = a_I^*(z)$. This factor tends to reduce the amount of R&D conducted over $z \in [z^b, \bar{z}^a]$ since it raises R&D costs. However, world expenditure measured in units of home labor rises with asymmetric protection and this tends to raise R&D in these industries. Without specific assumptions little more can be said.

These results follow because asymmetric protection affects the relative cost of conducting R&D at home and abroad by altering relative wage rates and constraining technology choice. Whereas the foreign country always conducts more R&D under asymmetric protection, R&D effort is now lower and technological progress thereby slower, in all industries active in the foreign country. This is a direct consequence of the general equilibrium effect asymmetric protection has in raising foreign relative wages. A similar response occurs in the home country where asymmetric protection removes all export opportunities for home conducted R&D, lowers domestic relative wages, and hence leads to an increase in R&D efforts in many of the home country's good producing industries. In summary, the following collects our results.

PROPOSITION 2. *Asymmetric protection of intellectual property rights:*

(1) *distorts the pattern of trade in both goods and R&D, raises the relative wage*

¹⁸ This is straightforward but tedious to show.

rate of the country that imported R&D, and eliminates technology transfer between countries;

(2) lowers the amount of labor allocated to R&D activities worldwide. This reduction in R&D is greater if the home country is the sole producer of R&D under symmetric protection;

(3) lowers R&D in the country that exported R&D, and raises R&D in the country that imported R&D. All industries active in the country that imported R&D receive less R&D under asymmetric protection, some industries active in the country that exported R&D receive more R&D under asymmetric protection.

With Proposition 2 in hand, it is now possible to examine how asymmetric protection affects the growth rate in per-period utility $u(t)$. The difference in growth rates across regimes, $\hat{u}(t)^s - \hat{u}(t)^a$, can be rearranged to find

$$(5.2) \quad [\hat{u}(t)^s - \hat{u}(t)^a] \propto \left[\int_0^1 [b(z)/a_I^w(z)][RD(z)^s - RD(z)^a] dz + \int_{z^b}^{\bar{z}^a} b(z)[RD(z)^a/a_I(z)][[a_I(z) - a_I^w(z)]/a_I^w(z)] dz \right].$$

Where $RD(z)^s = [i(z)^s + i(z)^{*s}]a_I^w(z)$ for $z \in [0, 1]$, $RD(z)^a = i(z)^a a_I(z)$ for $z \in [0, \bar{z}^a]$, and $RD(z)^a = i^*(z)^s a_I^*(z)$ for $z \in [\bar{z}^a, 1]$.

In (5.2) I have rearranged the equation to emphasize the two effects asymmetric protection has on growth. The first term captures the effect on aggregate R&D activity, while the second reflects the effect on technology choice. Consider the technology choice term. Note that $[a_I(z) - a_I^w(z)] > 0$ for $z \in [z^b, \bar{z}^a]$ and therefore the technology choice term in (5.2) is necessarily positive. Over $z \in [z^b, \bar{z}^a]$ the home country is at an absolute disadvantage in research, but asymmetric protection constrains home innovators to use only domestic R&D technologies and this constraint raises R&D costs and lowers worldwide growth. An exact measure of this reduction in growth is found by multiplying the home country's R&D intensity, $[RD(z)^a/a_I(z)] = i^a(z)$, by the percentage excess labor requirements of home research technologies over best practice methods, $[a_I(z) - a_I^w(z)]/a_I^w(z)$, and integrating over the relevant range $z \in [z^b, \bar{z}^a]$ taking into account the severity of this reduction to growth by weighting by the market shares $b(z)$.

The first term in (5.2) represents the aggregate R&D effect. The terms $[RD(z)^s - RD(z)^a]$ are equal to the difference in labor allocated to R&D across equilibria. The weights applied to these raw R&D labor allocations, $[b(z)/a_I^w(z)] > 0$, transform them into their ultimate impact on growth by correcting for variations across industries in market size and in R&D productivities. Proposition 2 tells us that an unweighted integral of $[RD(z)^s - RD(z)^a]$ over $z \in [0, 1]$ is positive since less R&D is conducted under asymmetric protection. Therefore if $[b(z)/a_I^w(z)]$ was constant over z , then world growth must necessarily fall with the move to asymmetric protection. Under general circumstances a correlation argument yields similar results.

Recall that $\Pi(z) = \nu b(z)[E + E^*]$; hence variations in market size $[b(z)]$ across

industries are perfectly correlated with variations in the flow profits from innovation. As well, variations in $[a_I^y(z)]$ reflect the varying productivity of research efforts aimed at capturing these flow profits. Consequently, industries where $[b(z)/a_I^y(z)]$ is relatively large are very attractive prospects for R&D, and we can think of $[b(z)/a_I^y(z)]$ as measuring the "market potential" for R&D. This interpretation is justified since, if $i(z)$ was constant across z then industries with relatively large $[b(z)/a_I^y(z)]$ would offer the highest expected return to innovation. With this definition in hand it is now straightforward to show the following.

PROPOSITION 3. *If all industries have the same market potential for R&D, then world growth falls with the move to asymmetric protection. If the correlation between market potential and $[RD(z)^s - RD(z)^a]$ is positive or zero, then world growth falls with the move to asymmetric protection.*

The intuition behind Proposition 3 is straightforward. Recall that asymmetric protection lowers aggregate R&D in the world, constrains technology choice, and alters the distribution of R&D effort across z . The first two of these effects necessarily lowers the growth rate. The third has an ambiguous effect on growth, but unless asymmetric protection happens to distort R&D towards those industries with a relatively high market potential and away from those industries with a relatively low market potential, world growth must fall. Moreover, there is no reason to believe that this is the case. Over $z \in [0, z^b]$ R&D rises under asymmetric protection, over $z \in [\bar{z}^a, 1]$ R&D falls. By definition $A(z^b) = 1$ and $SS(\bar{z}^a) = A(\bar{z}^a)$, and both \bar{z}^a and z^b are unaffected by the specifics of the $a_I^y(z)$ schedule. Hence there is little reason to believe that R&D is distorted towards (away) industries with high (low) market potential. In general we are left with a presumption that world growth falls with the move to asymmetric protection.

While Proposition 3 presents a sufficient condition for the growth rate in utility to fall, could asymmetric protection create a level rise in instantaneous utility and thereby raise welfare? Comparing exact measures of welfare across these alternative time paths for the world economy is not a trivial exercise since incomes, stock holdings and relative prices differ across equilibria. Nevertheless, an approximate welfare comparison is possible if we focus on changes in the purchasing power of wage income across equilibria. This approximation should be a good one because portfolio income must be small in relation to wage income in the world economy.¹⁹

Since home relative wages fall with the move to asymmetric protection it is straightforward to show that the real purchasing power of home labor income, and hence home instantaneous utility, necessarily falls. If home instantaneous utility is lower and its growth rate slower, aggregate discounted utility for home residents must fall in the move to asymmetric protection. In contrast, foreign country residents benefit from a once for all increase in their relative wages but this must be set against the permanent fall in the growth rate asymmetric protection may create.

¹⁹ Portfolio income must be small in relation to labor income for R&D to be profitable. For example, set $a_I^y(z) = a$, $b(z) = 1$, $\nu = .05$, and assume factor price equalization arises in equilibrium, then a few calculations will show $i(z) > 0$ if and only if the share of portfolio income in total income, $[\rho a / (L + L^* + \rho a)]$, is less than 5 percent.

Consequently, both home and foreign welfare may fall in the move to an asymmetric intellectual property rights regime. More concrete welfare results are possible, but only under much more stringent assumptions on tastes and technologies. Moreover since the world economy under symmetric and asymmetric regimes is second best, uncertain welfare effects are likely to remain unless we adopt specific parameter values. This seems a questionable alternative to the correlation results presented above.

6. CONCLUSIONS

This paper presented a simple dynamic model of endogenous growth to examine the role intellectual property rights play in world trade, growth, and technology transfer. If innovators can carry their research technologies across borders, then technology transfer creates a region of factor price equalization, an improvement in the allocation of the world's technical resources, and, in many cases, a rise in world growth. These benefits, however, will fail to accrue if countries offer only partial protection for intellectual property. By disregarding protection for foreign made innovations, asymmetric protection distorts natural trading patterns, leads innovators to employ less than best practice research methods, and lowers aggregate R&D. While disregarding protection for foreign made innovations will lead to a one time increase in relative wages for an R&D importing country, this beggar thy neighbor policy can have deleterious effects on worldwide growth.

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APPENDIX

1. *Constructing the BP(z) Schedule.* If $\omega < 1$, then $\bar{z} = 1$ and (3.3) requires

$$(1.1) \quad \omega = [L^*/[L + \rho A_I]] \left[B(\bar{z}) + \nu \int_{\bar{z}}^1 b(z) dz \right] / \left[\int_{\bar{z}}^1 [1 - \nu] b(z) dz \right].$$

This segment starts at $\omega(\min)$ when $z^p = \bar{z} = 0$ and rises as the home country undertakes some goods production. As \bar{z} rises, (1.1) shows ω must rise as well. When the home country is the sole producer of R&D we have

$$(1.2) \quad E + E^* = L + w^* L^* + \rho \int_0^1 a_I^w(z) dz$$

$$(1.3) \quad i(z) = \nu b(z) \left[L + w^* L^* + \rho \int_0^1 a_I^w(z) dz \right] / a_I^w(z) - \rho \quad z \in [0, 1].$$

Consider an equilibria at $\omega > 1$ and hence $\bar{z} = 0$. At $\bar{z} = 0$ (3.3) requires

$$(1.4) \quad \omega = \left[\frac{L^* + \rho A_I^*}{L} \right] \left[\int_0^{\bar{z}} [1 - \nu] b(z) dz \right] \left/ \left[[1 - B(\bar{z})] + \nu \int_0^{\bar{z}} b(z) dz \right] \right.$$

This segment has a maximum at $\omega(\max)$ when $z^P = \bar{z} = 1$. When the foreign country is the sole producer we have

$$(1.5) \quad E + E^* = w^* L^* + L + \rho \int_0^1 w^* a_I^w(z) dz$$

$$(1.6) \quad i^*(z) = \nu b(z) \left[w^* L^* + L + \rho \int_0^1 w^* a_I^w(z) dz \right] \left/ w^* a_I^w(z) - \rho \right.$$

$$z \in [0, 1].$$

To construct the factor price equalization segment we need to solve for the points where the segment begins and ends. Denote these z' and z'' . Then setting $\omega = 1$ in (1.1) implicitly defines z' and setting $\omega = 1$ in (1.4) implicitly defines z'' . Rearranging shows

$$(1.7) \quad L^* = \int_{z'}^1 [1 - \nu] b(z) [E + E^*] dz \text{ and } L = \int_0^{z''} [1 - \nu] b(z) [E + E^*] dz.$$

Over this factor price equalization segment we have

$$(1.8) \quad E + E^* = L^* + L + \rho \int_0^1 a_I^w(z) dz$$

$$(1.9) \quad i(z) + i^*(z) = \nu b(z) \left[L^* + L + \rho \int_0^1 a_I^w(z) dz \right] \left/ a_I^w(z) - \rho \right.$$

$$z \in [0, 1].$$

2. *Proof to Proposition 1.* First, I show that each country is self sufficient in R&D when $A(\bar{z}) = SS(\bar{z}) = BP(\bar{z})$. Second, I show that when $\bar{z} < z^S$ the home country is a net exporter of R&D. Lastly, I show that when $\bar{z} \neq z^S$ active technology transfer must occur.

2.1. *Derivation of the zero net export point for R&D.* When $\omega = 1$ the actual distribution of home and foreign R&D efforts across the spectrum of z industries is indeterminate. Nevertheless let the total allocation of home labor to these efforts be I and the allocation of foreign labor be I^* . To find the point where the home country becomes a net importer or exporter of R&D results it is useful to construct a hypothetical commodity z^S such that

$$(2.1) \quad \int_0^{z^s} i(z)a_I^w(z) dz = I \quad \text{and} \quad \int_{z^s}^1 i^*(z)a_I^w(z) dz = I^*.$$

Where $i(z)$ and $i^*(z)$ are understood to be equal to the actual (world total) R&D intensity conducted in industry z when factor prices are equalized. If $\bar{z} = z^s$ the home country produces just enough R&D to match the R&D needs coming from its final goods sector. Impose $\bar{z} = z^s$ and employ I and I^* in each country's labor market clearing condition to obtain

$$(2.2) \quad 1 = \left[\left[L^* + \rho \int_{z^s}^1 a_I^w(z) dz \right] \left/ \left[L + \rho \int_0^{z^s} a_I^w(z) dz \right] \right. \right] [B(z^s)/[1 - B(z^s)]].$$

Equation (2.2) implicitly defines the self-sufficiency point z^s . At $\omega = 1$ the $SS(z)$ schedule given in the text equation (3.4) is identical to equation (2.2) if $a_I^w(z) = a_I(z)$ over $[0, z^s]$, and if $a_I^w(z) = a_I^*(z)$ over $[z^s, 1]$. Since at $z^s = \bar{z}$, $A(\bar{z}) = RD(\bar{z}) = 1$, and $A'(z) < 0$ this last requirement is met. Self sufficiency occurs when $A(\bar{z}) = SS(\bar{z}) = BP(\bar{z})$.

2.2. *If $\bar{z} < z^s$ the home country must be a net exporter of R&D results.* Let $[0, z^r]$ be the segment of industries the home country conducts research on when factor prices are equalized; hence z^r plays the same role as z^s except that now I will not impose $\bar{z} = z^r$. Then the labor market conditions are

$$(2.3) \quad L = \int_0^{z^r} [1 - \nu]b(z)[E + E^*] dz + \int_0^{z^r} i(z)a_I^w(z) dz$$

$$(2.4) \quad L^* = \int_{\bar{z}}^1 [1 - \nu]b(z)[E + E^*] dz + \int_{z^r}^1 i^*(z)a_I^w(z) dz.$$

Again $i(z)$ and $i^*(z)$ are set at the world totals for R&D intensity. Note that in the factor price equalization segment, $E + E^*$ is independent of z^r . Examine (2.3) in light of this fact. We know if $z^r = \bar{z} = z^s$ then the home country is self sufficient in R&D. If $\bar{z} < z^s$, and world expenditure is the same in this equilibrium, then it must be the case that $z^r > z^s$. As a result, the home country is conducting more R&D and producing a smaller segment of commodities: the home country's net exports of R&D results must be positive.

2.3. *Technology transfer is positive.* Define z^b as $RD(z^b) \equiv 1$ and recall $A'(z) < 0$. Hence the set $a_I^w(z) = \min [a_I^*(z), a_I(z)]$ is just $a_I^w(z) = a_I(z)$ for $z \in [0, z^b]$ and $a_I^w(z) = a_I^*(z)$ for $z \in [z^b, 1]$ regardless of relative factor prices. Technology transfer will always occur when z^b does not equal \bar{z} . If $\bar{z} \neq z^b$ then either some home research technologies on $[0, \bar{z}]$ or some foreign research technologies on $[\bar{z}, 1]$ are not least cost; consequently, it will be profitable for an entrepreneur to transfer the least cost technology abroad to conduct R&D. If $z^b = \bar{z}$, two results are possible: either $z^b = \bar{z} \neq z^s$, or $z^b = \bar{z} = z^s$. If $z^b = \bar{z} = z^s$

trade in R&D results and technology transfer could be zero—see point 1 above. Without loss of generality suppose $z^b = \bar{z} < z^s$. Since $z^b = \bar{z}$ we are on the factor price equalization segment, since $\bar{z} < z^s$ the home country is a net exporter of R&D. Since $z^b = \bar{z}$ the home country's R&D technologies on $[0, \bar{z}]$ are the world's best practice, but some R&D conducted at home must be targeted towards improving foreign goods technologies. The least cost R&D technologies in these industries are foreign—hence technology transfer must occur.

3. *Home Conducts Less R&D, while Foreign Conducts More R&D.* Labor market clearing at home requires in the two regimes that

$$(3.1) \quad L = [1 - \nu]B(\bar{z}^s)[E + E^*]^s + \int_0^{\bar{z}^s} i(z)^s a_I^w(z) dz$$

$$(3.2) \quad L = [1 - \nu]B(\bar{z}^a)[E + E^*]^a + \int_0^{\bar{z}^a} i(z)^a a_I(z) dz.$$

Since 2^* lies to the right of 2, $\bar{z}^a > \bar{z}^s$. As well, recall $B(z)$ is necessarily increasing. Hence if $[E + E^*]^a > [E + E^*]^s$, we can conclude that less labor is allocated to R&D at home in the asymmetric protection equilibrium. A simple comparison of equation (3.5) in the text under the two regimes shows $[E + E^*]^a > [E + E^*]^s$. Therefore, less R&D is conducted at home under asymmetric protection. Consider the foreign country's labor market clearing condition in the two equilibria. These are

$$(3.3) \quad L^* = [1 - \nu][1 - B(\bar{z}^s)][E + E^*]^s + \int_{\bar{z}^s}^1 i^s(z) a_I^w(z) dz$$

$$(3.4) \quad L^* = [1 - \nu][1 - B(\bar{z}^a)][E + E^*]^a/w^{*a} + \int_{\bar{z}^a}^1 i(z)^a a_I^*(z) dz.$$

We know $[1 - B(\bar{z}^s)] > [1 - B(\bar{z}^a)]$, since $\bar{z}^a > \bar{z}^s$. Moreover, employing equation (3.5) from the text it is straightforward to show $[E + E^*]^s > [E + E^*]^a/w^{*a}$; therefore, the foreign country conducts more R&D under asymmetric protection.

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