Innovation in a Shrinking World

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Abstract

This paper explores the implications of reductions in tariffs or transport costs on the rate of innovation in a quality ladders model where firms from both countries innovate. If a country raises its tariffs, its wage rises relative to the other country and its firms become technology leaders for a larger fraction of products, but the aggregate rate of innovation falls. If transport costs fall symmetrically everywhere, then the aggregate rate of innovation rises, absent distributional consequences across countries. Additionally, diffusion of innovation technology to firms in the foreign country generates effects similar to a unilateral reduction in the protection of domestic markets through tariffs.

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1. Introduction

This paper uses a North-North quality ladders model to consider the effect of trade barriers on economic growth. In this model, successful innovators from similar countries export their products to markets abroad. Product cycle models generally have focused on a North-South setting, where firms in the developed North innovate and firms in the less developed South imitate. However, the bulk of trade, and especially of intraindustry trade, occurs *between developed countries* and the largest reductions in trade barriers have been *among developed countries*. Consequently, the role of reductions in trade barriers in a North-North growth model needs to be addressed. The contribution of this paper is to analyze the effects of freer trade in a product cycle model where firms from more than one country innovate.

Segerstrom *et al* (1990) show that tariffs protecting dying industries raise wages at the expense of thwarting economic growth. The reduction in profits due to reduced access to foreign markets cause firms to reduce their R&D effort (a costly activity). But access to foreign markets might be less important for rich countries with large domestic markets, which suggests that the results for developed countries may differ from those for developing countries. Ades and Glaeser (1999) examine whether the degree that openness leads to faster growth is greatest in the poorest countries. The measure of openness used for the sample of the U.S. states in the nineteenth century – proximity to major ports or railways – depicts transportation costs, whereas the measure used in the sample of poor countries in the late twentieth century – share of trade relative to GDP – captures both natural and artificial barriers to trade.

Rivera-Batiz and Romer (1991) show that economic integration between two developed counties can accelerate economic growth when innovations introduce new varieties. Grossman and Helpman (1991a) have shown that a quality ladders model may exhibit results that differ from a varieties based model. Thus, it remains to be seen whether different results are obtained in a North-North setting when innovations improve the quality of existing products.

Comparison of a North-North quality ladders model to North-South quality ladders models or to North-North varieties models can be useful for examining the theoretical robustness of the effect of openness on economic growth. The potential for underlying fragility in the theoretical predictions is suggested by the fragility of empirical studies of the effects of trade reform on economic growth. Lee (1993) finds empirical evidence of the damage done by tariffs to the growth rate of per capita income across countries. Harrison (1996) finds broad support for a positive link between different measures of openness and economic growth in a cross section and in panel data. Frankel and Romer (1999) use an instrumental variables approach – using geographic characteristics as instruments for openness – to estimate the effects of trade on growth, controlling for the possibility of reverse causality. But O'Rourke (2000) finds that tariffs were *positively* related to growth for a panel of ten countries between 1875 and 1914.

Similar to Ben-David and Loewy (1998), the differences between the effects of unilateral versus bilateral tariff reductions (or reductions in transport costs) can be examined. The trend toward freer trade has occurred through both improvements in transportation and reductions in government-imposed barriers to trade. Natural barriers to trade have been declining throughout recent history. Harley (1988) finds that metal ships and steam engines caused a major decline in freight rates after 1850. Finger and Yeats (1976) find that for U.S. imports in 1965, international transportation costs imposed a degree of protection at least as great as did tariffs for most goods, especially for bulky goods with low unit values. The GATT and its successor, the WTO, have achieved substantial reductions in tariffs and non-tariff barriers to trade over the past fifty years through multilateral negotiations, especially among developed countries.

The model is based on the quality ladders model of endogenous innovation by Grossman and Helpman (1991a) but with firms from both countries innovating. Changes in tariffs or transport costs alter the rate of innovation, relative wages and aggregate spending through the incentive to create quality improvements of existing products. A small increase in tariffs reduces profits and thus *reduces the rate of innovation but improves the relative wage*, as in Segerstrom (1991). Reducing tariffs (or transport costs) to the same degree in both countries can speed innovation while maintaining a constant relative wage. Liberalization, whether unilateral or multilateral, increases steady-state growth of all trading partners. Unilateral liberalization redistributes income away from the liberalizing country, whereas bilateral liberalization does not when both countries liberalize to the same degree. Unilateral liberalization may therefore be difficult to achieve, as the growth effects of faster innovation would need to dominate the level effect of lower income for a country to benefit from unilaterally lowering its tariffs. Unilateral liberalization also involves transitional dynamics that are eliminated if both countries reduce their tariffs to the same degree.

In addition to falling barriers to trade, the world has also been shrinking through improved communications and other links that may speed the spread of knowledge (which may in turn be related to expanding trade or foreign direct investment). An enhanced flow of information between countries may lead to a faster diffusion of technologies, including the knowledge of how to develop new products or better versions of existing products.

Suppose one country's innovation technology is superior to another country's (for all products) and consider the effects of an improvement in the innovation technology of the lagging country. Unilateral improvements in innovation technology generate effects that bear close similarity to the effects of a unilateral reduction in trade barriers by the trading partner: innovation rises and the relative wage falls. Falling trade barriers operates on the benefit side – a given innovation earns a greater reward – while a reduction in innovation difficulty operates on the cost side – a given innovation is cheaper to make.

While the effects of a unilateral improvement in innovation technology seem quite plausible, a potential implication of these finding is more startling. The GATT (and now the WTO) have achieved substantial tariff reduction over the past fifty years. In the Uruguay Round, an agreement was reached that is leading to tougher standards for intellectual property rights protection. By curtailing the diffusion of innovation technology (or at least making the use of the superior technology of others illegal), the recent agreement on intellectual property rights may in fact work against the previous tariff reductions by reducing the incentives for innovation. More work needs to be done in this area, such as allowing for foreign direct investment as in Glass and Saggi (2002a, 2002b) or for technologies to differ across industries so that technological diffusion can occur bilaterally.

Section 2 establishes the behavior of firms choosing their efforts at innovation. Section 3 characterizes the steady-state equilibrium where firms serve markets abroad through exporting and Section 4 determines how increases in tariff or transportation costs (and increases in the difficulty of innovation) impact the variables of the model, including the rate of innovation. Section 5 concludes.

2. Product Cycle Model

Suppose that there are two developed countries in the world. Firms in each country can design improved versions of existing products and sell them both at home and abroad (after paying a tariff or transport cost). All consumers share the same preferences and value quality improvements to the same degree. The willingness of consumers to pay for quality improvements generates the incentive for innovation.

2.1. Consumers

The specification of consumer preferences follows that in Grossman and Helpman (1991a, 1991b). Consumers live in one of two countries, domestic or foreign $i \in \{D, F\}$, and choose from a continuum of products indexed by j, available in discrete quality levels indexed by m. Consumers view quality level m of product $j \in [0,1]$ as being better than the previous quality level $m-1$. Quality level m of product j provides quality $q_m(j) \equiv \lambda^m$. All products start at time $t = 0$ at quality level $m = 0$, so the base quality is $q_0(j) = (\lambda^\omega)^0 = 1$. By the definition of quality improvement, all consumers agree that new generations are better than the old: $q_m(j) > q_{m-1}(j) \rightarrow \lambda^m > \lambda^{m-1} \rightarrow \lambda > 1$. Firms know the magnitude of the quality increment λ, which is assumed to be the same across all products.

A consumer has additively separable intertemporal preferences given by lifetime utility

$$U_i = \int_0^\infty e^{-\rho t} \log u_i(t) dt, \tag{1}$$

where instantaneous utility is

$$\log u_i(t) = \int_0^1 \log \left[\sum_m \lambda^m x_{im}(j,t) \right] dj, \tag{2}$$

ρ is the common subjective discount factor, λ^m is the assessment by consumers of quality level m and $x_{im}(j,t)$ is consumption by consumers in country i of quality level m of product j at time t.

A consumer maximizes lifetime utility (1) by choosing an optimal time path for expenditure and by allocating expenditure optimally at each point of time across products and to quality levels of the products. Since preferences are homothetic, the aggregate demand of consumers in each country is found by maximizing lifetime utility subject to the aggregate intertemporal budget constraint

$$\int_0^\infty e^{-R(t)} E_i(t) dt \leq A(0) + \int_0^\infty e^{-R(t)} Y_i(t), \tag{3}$$

which equates the present value of lifetime expenditure to the value of initial asset holdings plus the present value of lifetime income. The aggregate income of consumers in country i is $Y_i(t) = L_i w_i(t)$, the aggregate spending of consumers in country i is

$$E_i(t) = \int_0^1 \left[\sum_m p_m(j,t) x_{im}(j,t) \right] dj, \tag{4}$$

$R(t) = \int_0^t r(s) ds$ is the cumulative interest rate up to time t, $A(0)$ is the value of any initial asset holdings, $w_i(t)$ is the wage rate in country i at time t, L_i is the exogenous labor supply in country i, and $p_m(j,t)$ is the price of quality level m of product j at time t.

The consumers maximization problem can be broken into three stages: allocation of lifetime wealth across time, allocation of expenditure at each instant across products, and allocation of expenditure at each instant for each product across available quality levels. Each consumer evenly spreads lifetime spending for each product across time, evenly spreads spending at each instant across products, and allocates spending for each product at each instant to the quality level that has the lowest quality adjusted price p_m/λ^m.

The logic for these arguments is the same as in Grossman and Helpman (1991a, 1991b). In the final stage, to maximize instantaneous utility (2), the representative consumer allocates spending for each product at each instant to the quality level $\widetilde{m}(j,t)$ offering the lowest quality-adjusted price, $p_m(j,t)/\lambda^m$. Settle indifference in favor of the higher quality level so the quality level selected is unique. In the second stage, the representative consumer then evenly spreads spending across the unit measure of all products, $E_i\left(j,t\right) = E_i\left(t\right)$, as the elasticity of substitution is constant at unity. Consumers demand $x_{\widetilde{m}}(j,t) = E_i(t)/p_{\widetilde{m}}(j,t)$ units of quality level $\widetilde{m}(j,t)$ of product j and no units of other quality levels of that product. Thus lifetime utility (1) becomes

$$U_i = \int_0^\infty e^{-\rho t}\left[\log E_i(t) + \int_0^1 \left[\widetilde{m}\left(j,t\right)\log\lambda - \log p_{\widetilde{m}}(j,t)\right]dj\right]dt \qquad (5)$$

by substituting for instantaneous utility and demand. The consumer is assumed able to borrow and lend at an endogenous instantaneous interest rate r, which the representative consumer views as given. In the first stage, the consumer chooses the optimal time profile of expenditure to maximize (5) subject to the intertemporal budget constraint (3). As is well known, the solution to this problem requires the time path of expenditure to satisfy $\dot{E}/E = r - \rho$. In equilibrium, the representative consumer will evenly spread lifetime spending across time, $E_i\left(t\right) = E_i$, as the utility function is time separable and the aggregate price level will not vary across time $\log p_{\widetilde{m}}(j,t) = \log p_{\widetilde{m}}(j)$. Since aggregate spending is constant across time, the interest rate at each point in time reflects the discount rate $r(t) = \rho$, so $R(t) = \rho t$ in the intertemporal budget constraint.

2.2. Incentives to Innovate

Innovation here takes the form of the unique knowledge of how to produce a higher quality level of a product than any other firm. Modeling innovation as a continuous Poisson process follows Grossman and Helpman (1991a, 1991b) but without any imitation. No imitation occurs if imitation costs are close enough to innovation costs as the profits from imitation would be smaller than from innovation. As opposed to Segerstrom (1991), here collusion between an imitator and an innovator is not possible due to delays in retaliation following a deviation or antitrust regulations.

Innovation races occur simultaneously for all products, with all firms able to target the quality level above the current highest quality level. Undertaking innovation intensity $\widetilde{\iota}_i$ for a time interval dt requires $a_i\widetilde{\iota}_i dt$ units of labor at a cost of $w_i a_i \widetilde{\iota}_i dt$ and leads to success with probability $\widetilde{\iota}_i dt$ for any industry. Innovation resembles a lottery: firms endure a cost for a chance at winning a payoff. An innovation success means that the firm discovers how to produce the quality level m, where the previous quality level in the industry was $m - 1$. A higher investment in innovation yields a higher probability of success, but no level of investment in innovation can guarantee success. Only the current level of innovation activity determines the chance of innovation success, since innovation is memory-less for simplicity. Assume free entry into innovation, with an endless pool of potential innovators.

Given the innovation intensity ι of other firms, a firm's strategy is to pick an innovation intensity $\widetilde{\iota}_i$ and a price p to charge for its product once successful in innovation. Look for the steady-state equilibrium in stationary strategies, where firms' strategies are time invariant (but may depend on the current state of the economy). Firms already producing a quality level of a product can be shown to not engage in further innovation on that product – the proof mirrors that in Grossman and Helpman (1991a, 1991b). Producing firms lose value when subsequent innovation is successful, so other firms stand to gain more (net) and undertake innovation. Once a quality level of a product has been developed, another firm never invents the same quality level due to Bertrand competition in the product market as a second innovation would earn no profits to compensate for the innovation costs.

A firm's problem can be broken down into two stages. First, when undertaking innovation, the firm chooses its intensity of innovation to maximize its expected value, given the innovation intensities of other firms. Once successful in innovation, the firm then chooses the price of its product to maximize its value, given prices and innovation intensities of other firms. Each nonproducing firm chooses its intensity of innovation to maximize its expected value, given the innovation intensities of other firms.

In the innovation stage, a firm endures innovation costs of $w_i a_i \tilde{\iota}_i dt$ and gains an expected reward of $v_i \tilde{\iota}_i dt$ (enjoys gains v_i with probability $\tilde{\iota}_i dt$). Each nonproducing firm chooses its intensity of innovation $\tilde{\iota}_i$ to maximize its expected gain from innovation, which is the difference between the expected reward and the costs of innovation. These expected values from engaging in innovation have an upper bound of zero; otherwise, if expected gains exceeded costs, innovation intensities would be infinite. On the other hand, if expected gains fall short of costs, innovation intensities are zero. To generate finite rates of innovation, expected gains must not exceed their cost, with equality when innovation occurs with positive intensity

$$v_i \leq w_i a_i, \ \tilde{\iota}_i > 0 \longleftrightarrow v_i = w_i a_i, \tag{6}$$

where v_i is the value a firm gains from successful innovation. Focus on equilibria where the domestic and foreign intensities of innovation are positive, so that firms from both countries have leadership in some industries. This case will arise if the labor supply of each country is large enough.

Once successful in innovation, each producing firm then chooses the price of its product to maximize its value, given the prices and innovation intensities of other firms. All firms are exposed to further innovation by firms from both countries. Let

$$\iota \equiv \iota_D + \iota_F \longleftrightarrow \iota_F = \iota - \iota_D \tag{7}$$

denote the aggregate rate of innovation, the sum of the intensity of innovation by firms from each country. The mixture of the domestic and foreign innovation intensities in the aggregate rate of innovation influences the likelihood that any given innovation will be made by a domestic versus a foreign firm.

At each instant, a producer earns instantaneous profits $\pi_i dt$ and its value appreciates by $\dot{v}_i dt$ if no innovation occurs. With probability ιdt, an innovation occurs and the current producer suffers a capital loss of $v_i dt$ as it is priced out of the market by the firm that just innovated the next generation of that product. This risk is idiosyncractic and can be averaged out by consumer holding a diversified portfolio of shares. Consequently, consumers require the expected rate of return to equal the risk free interest rate r. Using (6) and $\dot{E}/E = r - \rho$, the no-arbitrage condition can be rewritten as requiring

$$\frac{\dot{E}}{E} = \frac{\pi_i}{w_i a_i} + \frac{\dot{w}_i}{w_i} - \rho - \iota \tag{8}$$

The rate of growth of expenditure increases with the level of expenditure (through profits) and decreases with the aggregate rate of innovation. In a steady-state equilibrium, the no-arbitrage condition can be rewritten to specify that the reward to innovation is the discounted stream of profits from production.

$$v_i = \frac{\pi_i}{\rho + \iota}, \tag{9}$$

As in Grossman and Helpman (1991b), aggregate expenditure is a jump variable that immediately takes its equilibrium value.

2.3. Product Market Profits

Consumers spend E on each product and are willing to pay a premium λ for a one quality level improvement in a product. Of the total spending, $E_D = f_D E$ is spent by domestic consumers and the remaining $E_F = f_F E$ is spent by foreign consumers (subscripts denote country i). Suppose in each industry, one firm can produce the highest quality level and another firm (from the same country) can produce the quality level one below. Normalize prices by the foreign wage and normalize the unit labor requirement in production to one in each country. The relative wage $w \equiv w_D/w_F = w_D$ is the domestic wage relative to the foreign wage. The relative wage is always (weakly) greater than one $w \geq 1$ by choice of country labels. The marginal cost of producing one unit of output of any quality is $c_D = w$ (the relative wage) in the domestic country and $c_F = 1$ in the foreign country.

Under Bertrand competition, the market outcomes depend on the extent of competition from rivals priced out of the market in equilibrium. Firms maximize profits by engaging in limit pricing. The most recent innovator for each product is the only firm able to produce the highest quality level available of that product due to assumed perfect patent protection. A firm just successful in innovation has a one quality level lead over its closest rival (the firm able to produce the next highest quality level of that product). The firm engages in limit pricing to keep its closest rival from earning a positive profit from production. Choosing a price equal to the quality increment λ times the closest rival's marginal cost just keeps the rival out of the market and thus maximizes the value of a firm. Given its rival's price, if the firm were to raise its price, consumers would by from its rival. If the firm were to lower its price, it would not gain because industry demand functions are unit elastic. Similarly, if the rival were to lower its price, it would make negative profits and any higher price would not matter since it does not have any sales.

A market is called *domestic-led* if a domestic firm made the most recent innovation (and thus can produce the highest quality level of that product) and *foreign-led* otherwise. The closest rivals when selling to foreign consumers will be foreign firms, with marginal cost of one. A foreign firm could potentially license the technology from the domestic owner of the old technology if necessary (as when the current foreign firm had successfully targeted a domestic firm's product for improvement). Similarly, the closest rivals when selling to domestic consumers will be domestic firms, with marginal cost of w, as a domestic firm could potentially license the old technology from a foreign firm if necessary. Free access to old technologies was also assumed in Glass (1997). Licensing of old technologies need never actually takes place since the old technologies are never actually produced in equilibrium. The potential marginal cost of producing the old technologies merely ties down the maximum price the new innovator can charge for the state-of-the-art.

Prices will be $p_D = \lambda w$ when selling to domestic consumers and $p_F = \lambda$ when selling to foreign consumers, each a mark-up of the quality increment relative to local marginal costs. With these prices, sales are $x_D = E_D/(\lambda w)$ when selling to domestic consumers and $x_F = E_F/\lambda$ when selling to foreign consumers. Thus, a domestic exporter earns instantaneous profits of the form $\pi = (p - c)\, x$, which are

$$\begin{aligned} \pi_D &= E_D\,(1-\delta) + E_F\,(1-\tau_F - w\delta) \\ &= E\,[1 - f_F\tau_F - (f_D + f_F w)\,\delta]\,, \end{aligned} \tag{10}$$

where τ_i is the *ad valorem* tariff on imports into country i and $\delta \equiv 1/\lambda$. The two terms in the initial profit expression reflect profits from sales to the domestic and foreign consumers, respectively. The foreign tariff must not be too large $\tau_F < 1 - w\delta$ if the domestic firm is to serve the foreign market through exports. A foreign exporter earns instantaneous profits

$$\begin{aligned}\pi_F &= E_F\left(1-\delta\right)+E_D\left(1-\tau_D-\tfrac{\delta}{w}\right)\\ &= E\left[1-f_D\tau_D-\left(\tfrac{f_D}{w}+f_F\right)\delta\right].\end{aligned} \tag{11}$$

Similarly, the domestic tariff must not be too large $\tau_D < 1-\delta/w$ if the foreign firm is to serve the domestic market through exports. The tariff τ_i (or transport cost) places a wedge between the price consumers pay and the revenue the firm receives net of the tariff. As can be seen from the profit expressions (10) and (11), an import tariff cuts into the profits of firms from the other country: a domestic tariff lowers foreign firm profits while a foreign tariff lowers domestic firm profits. Changes in these profits influence the incentives for firms to innovate.

3. Steady-state Exporting Equilibrium

In equilibrium, consumers in both countries maximize their intertemporal utility subject to the intertemporal budget constraint, firms in both countries maximize their value given prices and innovation intensities of other firms, and labor markets in both countries clear. This section characterizes the unique steady-state equilibrium with exporting.

3.1. Labor Constraints

Firms from both countries produce in their home market and export to serve the market abroad. As common in product cycle models, the labor supply in each country is assumed to be fixed. The fixed supply of labor is allocated between innovation and production in each country: for equilibrium in the labor market, the demand for labor must equal the supply of labor in each country. Under two-way exporting, the domestic resource constraint is

$$a_D\iota_D + n_D\left(\frac{f_D}{w}+f_F\right)E\delta = L_D \tag{12}$$

and the foreign resource constraint is

$$a_F \iota_F + n_F \left(\frac{f_D}{w} + f_F \right) E\delta = L_F \tag{13}$$

The first term of each labor constraint is demand for labor in innovation and the second term is demand for labor in production. The identity of the technology leader for each product dictates where production of that product occurs.

3.2. Constant Leadership Measures

Let n_i denote the percentage of markets where a firm from country i is the technology leader. Whether a product is produced by a domestic or a foreign firm changes over time as innovation occurs. Successful innovation by domestic firms that targets foreign led markets increases domestic leadership, while successful innovation by foreign firms that targets domestic led markets decreases domestic leadership. Thus the fraction of products that are domestic led must obey the differential equation

$$\dot{n}_D = \iota_D n_F - \iota_F n_D. \tag{14}$$

The solution is

$$n_D(t) = \overline{n}_D + [n_D(0) - \overline{n}_D] e^{-\iota t} \tag{15}$$

The fraction of markets that are domestic led is a state variable that is determined by past innovation intensities. Its steady-state value is

$$\overline{n}_D = \frac{\iota_D}{\iota_D + \iota_F} = \frac{\iota_D}{\iota} \tag{16}$$

More markets are domestic led when domestic innovation is higher relative to foreign innovation.

To achieve a steady-state equilibrium, the same fraction of products must become domestic led as become foreign led (and hence no longer domestic led) at each point in time so the extent of domestic leadership remains constant $\dot{n}_D = 0$. The flows into domestic leadership are $\iota_D n_F$ while the flows out are $\iota_F n_D$, and these flows must be equal:

$$\iota_D n_F = \iota_F n_D. \tag{17}$$

Additionally, the measures of market leadership must sum to one:

$$n_D + n_F = 1 \longleftrightarrow n_F = 1 - n_D. \tag{18}$$

While the fraction of products where domestic firms are the technological leaders remains constant in the steady-state equilibrium, each product cycles between domestic and foreign leadership. The equilibrium will determine the steady-state extent of domestic leadership. When domestic leadership increases, domestic firms have the ability to produce the state-of-the-art quality level for a larger fraction of all markets.

3.3. Steady-state System of Equations

Firms from each country serve the other country through exports. The first two equations are the domestic and foreign resource constraints (12) and (13):

$$wa_D n_D \iota + n_D \left(f_D + w f_F\right) E\delta - wL_D = 0 \tag{19}$$

$$wa_F \left(1 - n_D\right) \iota + \left(1 - n_D\right) \left(f_D + w f_F\right) E\delta - wL_F = 0. \tag{20}$$

The remaining two equations are the innovation valuation conditions (6) with the producing firm valuation equations (9) and profits (10) and (11) inserted:

$$E \left[1 - f_F \tau_F - \left(f_D + w f_F\right) \delta\right] - wa_D \left(\rho + \iota\right) = 0 \tag{21}$$

$$E\left[w - wf_D\tau_D - \left(f_D + wf_F\right)\delta\right] - a_F\left(\rho + \iota\right) = 0. \tag{22}$$

I substituted $\iota_F = \iota - \iota_D$, $n_F = 1 - n_D$ and $\iota_D = n_D\iota$ from the market measures conditions (17) and (18) to convert the system into only the four variables: the relative wage, aggregate spending, domestic leadership, and the aggregate rate of innovation $\{w, E, n_D, \iota\}$.

3.4. Uniqueness and Stability

The laws of motion for the share of products with domestic leadership (14) can be used to demonstrate the stability of the steady-state equilibrium. Solve the foreign resource constraint (20) and the foreign valuation condition (22) for the relative wage w and aggregate expenditure E. The remaining domestic resource constraint (19) and domestic valuation condition (21) then determine the share of domestic leadership n_D and the aggregate rate of innovation ι.

The economy must be at a point on the resource constraint because labor demand can never exceed labor supply. The law of motion can be rewritten as

$$\dot{n}_D = \iota_D\left(1 - n_D\right) - \iota_F n_D \tag{23}$$

by using that the leadership measures must sum to one ($n_F = 1 - n_D$). A steady-state equilibrium requires $\dot{n}_D = 0$. When the measure of domestic leadership is above its equilibrium value $\overline{n}_D$, domestic leadership will fall as more foreign innovation will successfully target domestic leaders than domestic innovation will displace foreign leadership $\dot{n}_D > 0$ (the second term will be larger than the first term). Similarly, domestic leadership that is too low $n_D < \overline{n}_D$ will result in domestic leadership rising $\dot{n}_D > 0$. Thus, the world economy will move along the labor constraint in the direction needed to achieve the equilibrium values of domestic leadership and the aggregate rate of innovation that also solve the domestic valuation condition. Only one pair (n_D, ι) solves the domestic resource constraint and domestic valuation condition for a positive aggregate rate of innovation $\iota > 0$ and a measure of domestic leadership that is strictly between zero and one $0 < n_D < 1$ so that some markets are led by domestic firms while others are led by foreign firms.

4. Effects of a Shrinking World

A shrinking world may manifest itself along several dimensions. First, transport costs may fall, making international trade easier. Second, governments may negotiate the removal of artificial impediments to trade such as tariffs; the reduction in tariffs may be unilateral (undertaken by one country) or bilateral (undertaken by both countries). Both countries lowering tariffs but to differing degrees would be equivalent to both lowering tariffs by the lesser degree combined with one country additionally lowering its tariffs by the remaining difference. A third way in which the world may shrink is through improvements in communication. Better communication may result in greater spread of knowledge, including the knowledge of how best to innovate. Any superiority of firms in one country over forms elsewhere in the ability to innovate may lessen over time as word spreads of any special methods. This section explores the effects of changing the magnitude of tariffs or transport costs τ_i and of international technology diffusion lowering the foreign resource requirement in innovation a_F.

4.1. Unilateral Tariffs

To determine the effects of a domestic or a foreign tariff τ_D or τ_F on the steady-state equilibrium values of these four variables, I totally differentiate the above system of four equations; details of this procedure appear in the Appendix. Assuming that firms serve markets abroad through exports, I find the following main result:

Proposition 1 *An increase in the domestic tariff decreases the aggregate rate of innovation and increases domestic leadership, aggregate expenditure, and the relative wage; an increase in the foreign tariff decreases the aggregate rate of innovation, domestic leadership, aggregate expenditure and the relative wage.*

The adverse effect of tariffs on the rate of innovation is natural: by reducing the realized gains from exchange, tariffs reduce the reward to innovation. Tariffs are protectionist and bad for growth since they reduce the reward to innovation. However, when the domestic tariff is increased, the reward to innovation is most severely reduced for foreign firms, so the fraction of products where domestic firms are the market leaders increases. Also, domestic tariffs achieve a positive level effect through a higher relative wage. Since I normalized by the foreign wage, the higher aggregate expenditure indicates a lower foreign wage, and a negative level effect for the foreign country when the domestic country increases its tariff.

As for the transition path, the domestic labor constraint is unaffected by tariffs since tariffs do not consumer real resources. An increase in the domestic tariff causes the valuation condition to shift down to require a lower aggregate rate of innovation for any value of domestic leadership. The transition occurs by a movement along the labor constraint as domestic leadership adjusts smoothly toward its new equilibrium, such as described by (15). Because the labor constraint does not shift, the transition for all variables is simply a gradual move toward the values in the new steady-state equilibrium.

In a steady-state equilibrium, instantaneous utility is given by

$$\log u_i(t) = \log E_i + \overline{m} \log \lambda - \log \overline{p}_i, \tag{24}$$

where the expected number of innovations arriving in time period t is $\overline{m} = \iota t$ and the average price paid by consumers is $\overline{p}_i = \lambda$ (under $w = 1$). Instantaneous utility can be written as:

$$\log u_i(t) = \log E_i + (\iota t - 1) \log \lambda. \tag{25}$$

Lifetime utility takes the form:

$$U_i = \frac{\log E_i + \left(\frac{\iota}{\rho} - 1\right) \log \lambda}{\rho}. \tag{26}$$

The expression for lifetime utility enables weighing the benefits of a faster rate of innovation against the cost of a lower level of real expenditure. If the discount rate is slight enough, indeed the rate of innovation is the most crucial determinant of national welfare. Nonetheless, the negative level effect of tariff reductions may make them politically difficult to achieve.

4.2. Bilateral Tariffs or Transport Costs

Let $\partial\tau = \partial\tau_D = \partial\tau_F$ represent an equal change in both tariff (or transport cost) wedges. A direct implication of Proposition 1 is that if transportation costs fall everywhere, the rate of innovation rises. A reduction in tariffs or transportation costs in a country raises innovation according to Proposition 1. If both countries lower their tariffs equally, as through bilateral negotiations, innovation rises all the more.

Corollary 1 *An reduction is transportation costs or tariffs, anywhere or everywhere, increases the aggregate rate of innovation.*

Plus, the relative wage remains constant, so distributive effects between countries are absent when both countries lower their tariffs equally. Also, domestic leadership remains constant since innovation incentives increase for domestic and foreign firms to the same degree. Since the leadership measures do not need to adjust, the transition from the old to the new steady-state equilibrium is immediate: the rate of innovation jumps to its new level. The same phenomenon that could occur through bilateral tariff reductions can also arise through a "shrinking world" – a reduction in transport costs due to improved transportation technologies (which are likely to be similar across all developed countries).

4.3. International Diffusion of Innovation Technology

In addition to declining trade barriers (both natural and artificial) another way that the world can shrink is through the international diffusion of technology. The model already supposes that the knowledge of in innovation itself diffuses across countries sufficiently that firms can improve upon an existing innovation regardless of their location.

However, improvements in communication may also lead to a narrowing of any gaps in the ability to engage in innovation. The foreign resource requirement in innovation may exceed that of the domestic economy $a_F > a_D$, implying that any given effort at innovation yields success with a lower probability abroad. Many aspects of a shrinking world may lead to the foreign resource requirement in innovation falling as foreigners learn some of what makes the domestic economy more productive at innovation.

Similar techniques to those used to address tariffs may be used to examine the effects of a reduction in the foreign resource requirement in innovation a_F. The Appendix provides expressions for the derivatives to support the following result.

Proposition 2 *An decrease in the resource requirement in foreign innovation increases the aggregate rate of innovation and decreases domestic leadership, aggregate expenditure, and the relative wage.*

Comparison to Proposition 1 indicates that international diffusion of the technology for engaging efficiently in innovation, by reducing the resource requirement in innovation abroad, leads to effects that are similar, at least in direction, to those of a unilateral lowering of tariffs. Providing freer access to the domestic market works through the benefit side to increase the incentives for innovation abroad, while providing for easier innovation works on the cost side. An implication of this analysis is that negotiating for stronger protection of intellectual property abroad may be a substitute for protection of domestic markets from imports: innovation abroad becomes more difficult and consequently there are fewer foreign produces that can effectively compete with domestically produced goods.

5. Conclusion

This paper has constructed a dynamic model of endogenous innovation to determine the impact of tariffs or transport costs on innovation, where similar developed countries trade with each other. A tariff raises a country's relative wage, a positive level effect, but reduces the rate of innovation, a negative growth effect. This trade-off between positive level effect and negative growth effect indicates that protection may be adopted if discounting is sufficiently severe. Equal tariff reductions allow the positive growth effect to be enjoyed by both countries without the negative level effect that occurs through the relative wage when a tariff reduction is unilateral. Additionally, restrictions on the diffusion of innovation technology abroad may act like increases in tariffs in that both generate positive level effects but reduce innovation. Given the predictions of this model, perhaps it is no coincidence that the substantial negotiated reductions in tariffs have been followed by efforts to strengthen the protection of intellectual property worldwide.

A Appendix

The proof is seen by totally differentiating the system

$$\begin{bmatrix} a_D n_D w & b_{12} & b_{13} & b_{14} \\ w a_F n_F & b_{22} & b_{23} & b_{24} \\ -w a_F & 0 & b_{33} & b_{34} \\ -w a_D & 0 & b_{41} & b_{41} \end{bmatrix} \begin{bmatrix} \partial \iota \\ \partial n_D \\ \partial E \\ \partial w \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ w f_D E \partial \tau_D \\ f_F E \partial \tau_F \end{bmatrix}$$

where

$$b_{12} = wa_D\iota + E\delta\left(f_F w + f_D\right)$$

$$b_{13} = n_D\delta\left(f_F w + f_D\right)$$

$$b_{14} = a_D n_D \iota + f_F n_D E\delta - L_D$$

$$b_{22} = -wa_F\iota - E\delta\left(f_F w + f_D\right)$$

$$b_{23} = \delta n_F\left(f_F w + f_D\right)$$

$$b_{24} = a_F \iota n_F + E\delta f_F n_F - L_F$$

$$b_{33} = w\left(1 - f_D\tau_D - f_F\delta\right) - f_D\delta$$

$$b_{34} = E\left(1 - f_D\tau_D - f_F\delta\right) - a_F\left(\rho + \iota\right)$$

$$b_{43} = 1 - f_F\tau_F - \left(f_D + f_F w\right)\delta$$

$$b_{44} = -f_F E\delta - a_D\left(\rho + \iota\right)$$

to find the derivatives

$$\frac{\partial \iota}{\partial \tau_D} = -\frac{\iota\delta f_D f_F\left[n_D w + n_F\right]}{1-\delta} < 0$$

$$\frac{\partial n_D}{\partial \tau_D} = \frac{\delta f_D f_F n_D n_F\left(w-1\right)}{1-\delta} > 0$$

$$\frac{\partial E}{\partial \tau_D} = \frac{f_D E\left[1 - \delta + f_D n_D\delta\left(w-1\right)\right]}{1-\delta} > 0$$

$$\frac{\partial w}{\partial \tau_D} = \frac{w f_D\left(1 - f_D\delta - f_F w\delta\right)}{1-\delta} > 0$$

and

$$\frac{\partial \iota}{\partial \tau_F} = -\frac{\iota \delta f_D f_F \left[n_D w + n_F\right]}{w\left(1-\delta\right)} < 0$$

$$\frac{\partial n_D}{\partial \tau_F} = -\frac{\delta f_D f_F n_D n_F \left(w-1\right)}{w\left(1-\delta\right)} < 0$$

$$\frac{\partial E}{\partial \tau_F} = -\frac{\delta E f_D f_F n_D \left(w-1\right)}{w\left(1-\delta\right)} < 0$$

$$\frac{\partial w}{\partial \tau_F} = -\frac{f_F \left[w\left(1-\delta\right) + f_D \delta \left(w-1\right)\right]}{1-\delta} < 0$$

where

$$|B| = \frac{wE^3\left(1-\delta\right)}{\iota} > 0$$

and impose $\tau_D = \tau_F = 0$ initially and take the limit as $\rho \to 0$ to simplify the expressions. The model can be further simplified by assuming that the two countries are exactly identical: same labor supplies, same innovation technologies and same tariffs always. In that special case, the relative wage would always be one and domestic leadership would always be exactly one-half. If the common tariff were set to zero, the model would then reduce to the one-country quality ladders model (for a country with its labor supply equal to the world labor supply).

Total differentiation also generates the following effects of an increase in the foreign resource requirement in innovation:

$$\frac{\partial \iota}{\partial a_F} = -\frac{\iota^2 \left[f_F n_D \delta w + n_F \left(1-\delta f_D\right)\right]}{E\left(1-\delta\right)} < 0$$

$$\frac{\partial n_D}{\partial a_F} = \frac{\iota n_D n_F \left[1-\delta\left(f_D + f_F w\right)\right]}{E\left(1-\delta\right)} > 0$$

$$\frac{\partial E}{\partial a_F} = \frac{\iota n_D \left[1-\delta\left(f_D + f_F w\right)\right]}{\left(1-\delta\right)} > 0$$

$$\frac{\partial w}{\partial a_F} = \frac{\iota w\left[1-\delta\left(f_D + f_F w\right)\right]}{E\left(1-\delta\right)} > 0$$

The signs of the derivatives are of course reversed for a reduction in a_F.

One possible extension of the model would be if labor-leisure choice led to an upward sloping labor supply curve instead of the fixed labor supply assumed in the base model. Suppose labor supply in country i is $L_i\left(w_i\right)$and is an increasing function of the wage in country i: $\partial L_i/\partial w_i > 0$. A unilateral increase in the domestic tariff increases the relative wage, which would then increase the domestic relative labor supply. The resulting increase in the domestic relative labor supply will in turn increase domestic innovation relative to foreign innovation and thus increase the measure of domestic leadership. The additional effect on the aggregate rate of innovation would depend on the second derivative of the labor supply curve, which determines whether the increase in domestic labor supply exceeds the decrease in the foreign labor supply. Compared to the base model with exogenous labor supplies, only the magnitude of the effects, not their direction would be affected.

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