Essays on Trade and Technological Change

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Address
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Peter Gustafsson

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EFI, The Economic Research Institute

Dissertation for the Degree of Doctor of Philosophy, Ph.D
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Stockholm in August 2006
Peter Gustafsson

Contents

Summary of Thesis

Introduction

The term globalization has as many interpretations as it has critics. This of course stems from the fact that the market integration that globalization often refers to has several different aspects to it that most often involve political decisions. As these political considerations deal with trade-offs between domestic- and foreign- as well as short- and long term interests, the heated debate surrounding globalization seems inevitable. Regardless of this debate, the importance of the on-going international integration of markets could hardly be doubted.

The efforts associated with the creation of the General Agreements on Tariffs and Trade (GATT) in 1947 and its successor, the World Trade Organization (WTO) have seen most tariff rates fall and the number of GATT/WTO members increase from 23 to 149 countries (December 2005). Considering also that transportation costs have decreased significantly during this period, it is perhaps not surprising that world trade has increased at an exponential rate since World War II, even outpacing growth in world GDP. Arguably one of the most important specific changes in the world trading community occurred in the late 1970's as Chinese leaders decided to reverse the Maoistic development strategy and open up China to international trade. Being a less-developed country containing one fifth of the world population, the Chinese adoption of a trade-friendly strategy[1] has had a huge impact on the world economy. Parallel to this expansion of the world trading system, Foreign Direct Investment has experienced a world-wide surge during the last couple of decades and is currently the largest source of external finance for developing countries, further contributing to the international integration of markets. As a result of this whole integration process, innovating countries have experienced increased regulatory needs to ensure that innovating firms are compensated for their ideas. In the WTO, this has formally materialized in the agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS), which aims to guarantee an adequate common protection of Intellectual Property Rights among members of the WTO.

[1] This was formally confirmed in 2001 as China, after 15 years of negotiation, became a member of WTO.

This thesis contains three papers which all aim to examine these different aspects of the international integration of markets. More specifically, the consequences for economic growth, technology transfers, international income differences and consumer welfare are addressed. Generally, the papers together suggest that specific outcomes crucially depend on what form the integration takes. In one of the papers, the strength of intertemporal knowledge spillovers is instrumental in determining growth- and welfare effects.

The first two papers contain North-South trade models where the two regions differ in terms of their ability to perform R&D. The North can be thought of as a fully industrialized country doing innovative R&D whereas the South refers to a less-developed country that devotes resources to transfer technology and production from the North to the South where production costs are lower. This transfer can occur either through southern imitation efforts (paper 1) or through the establishment of northern multinational companies in the South (paper 2). In contrast, the third paper considers a North-North trade model with technological change which is more concerned with understanding the consequences of trade liberalization on productivity growth. Whereas the regions considered have symmetric properties, firms within each of the regions are heterogeneous as they differ in productivity. Hence, this paper is related to the rapidly growing growth literature building on new empirical insights about firms' static and dynamic characteristics.

Summary of Papers

Paper 1: *Product Cycles in an Expanding Global Economy*

This paper presents a North-South trade model with technological change which aims to capture what Vernon (1966) called the "product cycle hypothesis" and assess its consequences for economic growth and the North-South wage-gap. Thinking of the world as consisting of two trading regions, the developed North and the less-developed South, innovation occurs in the North but as production processes become more standardized, the production of innovated goods is eventually shifted away from the North as producers benefit from lower costs of production in the South.

In the model, the North performs costly innovative R&D to expand the amount of consumer good varieties produced in the North whereas the South devotes resources to imitate northern varieties. Due to lower production costs in the South, successful imitation implies a complete transfer of production to the South as the original northern innovator is driven out of the market. The analysis departs from an earlier model developed by Grossman and Helpman (1991) by considering the criticism of all first generation endogenous growth models discussed in Jones (1995). Jones argues that an increase in the amount of labor devoted to R&D does not appear to have had any significant positive impact on rates of economic- and innovation growth in the post-war U.S. economy. Whereas Grossman and Helpman (1991) assumes that intertemporal knowledge spillovers are strong enough so that economic growth increases with economy size, this paper looks at what happens when intertemporal knowledge spillovers are assumed to be weaker, consistent with evidence on scale-invariant growth.

As the model predicts long-run innovation- and economic growth to be policy-independent, any policy-induced growth must be of a temporary nature. The wealth effects associated with transitional growth could nevertheless prove substantial as transitions between different steady-state equilibria in this type of model typically are quite slow.[2] Hence, public policy should still be expected to play a significant role for the well-being of individuals.

More specifically, the model predicts that a less-developed country's entry in the world trading system temporarily promotes growth and increases the rate at which

[2] See Steger (2003) and Jones (1995).

production shifts to the South which reduces the North-South wage-gap. In contrast, stronger protection of Intellectual Property Rights has the opposite effects. Finally, lower trade costs have no effect on the rates of innovation and imitation, but in an economy where trade is close to free and the North has a greater purchasing power than the South, a further lowering of trade costs would contribute to international income convergence. Investigating the steady-state welfare effects of these policies, southern consumers are shown to experience long-run welfare benefits from a larger trading community but suffer long-run welfare losses from stronger protection of IPR. The corresponding welfare effects for northern consumers are ambiguous. Lower trade costs are shown to make northern and southern consumers better off in the long-run.

Paper 2: *North-South Trade, Foreign Direct Investment and Economic Growth*

According to the World Development Indicators 2006, published by the World bank, Foreign Direct Investment is currently the largest source of external finance for developing countries. To better understand the importance of FDI, this paper studies the formation of multinational firms and investigates their role in generating economic growth and altering international income differences. The analysis is performed in a product cycle model framework similar to the one used in Paper 1. Northern firms still devote resources to extend the amount of varieties produced in the North. In addition, northern firms hire southern labor to adapt the northern production process to the southern environment to exploit lower southern production costs. This could be compared to the case of imitation where any technology transfer is involuntary as far as northern firm owners are concerned. Similar to the model in paper 1, the assumption of weak intertemporal knowledge spillovers ensure scale-invariant growth.

In a world economy characterized by free trade, international integration of product markets driven by a less-developed country's decision to adopt a free trade policy (and enter the world trading system) implies that size of the southern region increases. Apart from increasing the supply of labor in adaptation which raises the rate of adaptation, the greater demand for northern products increases the incentive to innovate. The higher rate of innovation is however shown to reduce innovator incentives so that the rate of innovation returns to its long-run rate. As the gains experienced by owners of multinational firms are outweighed by their costs of adaptation, a higher rate of adaptation is associated with an unchanged North-South wage-gap. The adoption of a southern FDI-friendly policy that makes adaptation less costly implies that, since labor is fully employed, multinationals must bid up the southern wage to attract labor to move into adaptation. Apart from increasing the rate of adaptation, the northern wage is now at a relatively lower level which makes it less expensive to hire labor for innovative R&D. The higher rate of innovation is however only temporary as it worsens innovator incentives.

Paper 3: *Trade Liberalization and Productivity Growth* (with Paul Segerstrom)

In contrast to the first two papers, this paper studies a North-North trade model with technological change where all trade between the two symmetric regions is subject to trade costs. As recent empirical evidence strongly suggests that firms in narrowly defined industries exhibit significant and persistent productivity differences[3], the representative firm framework is abandoned to allow for firms to differ in productivity. Moreover, according to a number of studies, trade liberalization appears to cause the most productive firms to engage in exporting activities and the least productive firms to exit the market.[4] The associated market share reallocation could be expected to have important consequences for productivity growth, something which has been shown in studies such as Melitz (2003) and Bernard, Eaton, Jensen and Kortum (2003).

In the model, firms first devote resources to innovate and then learn their productivity which is drawn from a Pareto distribution common to all firms. As local- and foreign market entry are associated with fixed entry costs, this heterogeneity divides profit-maximizing firms into non-sellers (least productive), local market sellers and exporters (most productive). Trade liberalization is shown to affect productivity growth in two ways. First, trade liberalization promotes productivity growth by reallocating market shares as the least productive firms exit and more firms start exporting. Second, more exporters imply that more firms incur the fixed cost associated with foreign market entry. Taking dynamic considerations into account, this increases the expected cost of developing a profitable variety which implies that firms temporarily reduce their innovation efforts and thereby reduce productivity growth. The net effect on productivity growth and long run welfare of consumers is shown to depend crucially on the strength of intertemporal knowledge spillovers in R&D. When spillovers are relatively weak, trade liberalization promotes productivity growth in the short run and makes consumers better off in the long run. Trade liberalization has the opposite effects when spillovers are relatively strong, retarding productivity growth in the short run and causing consumers to suffer long-run welfare losses.

[3] See Bartelsman and Doms (2000).
[4] See Tybout (2003) for a survey.

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Papers

PAPER 1

Product Cycles in an Expanding Global Economy

ABSTRACT. In this paper a dynamic general equilibrium model of North-South trade with scale-invariant technological change is developed. Northern firms do costly innovation to expand the number of available consumer good varieties while southern firms devote resources to imitate varieties produced in the North. Endogenous rates of innovation and imitation are determined as well as the North-South wage differential. The paper studies the steady-state consequences of three different public policies related to the international integration of product markets; the decision of a less-developed country to join the world trading system, stronger protection of Intellectual Property Rights and lower trade costs. The associated steady-state welfare implications are also examined.

1. Introduction

In considering the potential benefits of the international integration of product markets, domestic firms do not only face a greater demand for their products, but can also gain access to foreign knowledge to produce new or better products. Whatever the channel of knowledge transfer, the spread of knowledge through the global economy implies that the geographical location of production of goods no longer needs to be tied to the source of knowledge origin.

Relying partly on these observations, the "product cycle hypothesis", first discussed in Vernon (1966), suggests that the world economy can be discussed in terms of a developed northern region and a less-developed southern region. Relatively well developed R&D capabilities ensure that the development of new products occurs in the North.[1] Over time, production methods gradually become more standardized and eventually the technologies used in the production are (voluntarily or involuntarily) transferred to the South where costs of manufacturing are lower. Hence, the transfer of knowledge is followed by a shift in production which also reverses the initial pattern of trade.

While patterns of trade and investment implied by this hypothesis are rather easily described, the implications for economic growth and the inter-regional distribution of

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[1] This could for example be explained by a relative abundance of skilled labor.

income are less obvious. This calls for an investigation of how different public policies affect the shape of the product cycle.

Several attempts have been made to formalize the ideas of Vernon (1966). Krugman (1979) focus mainly on trade patterns and wage inequality but does not model the transfer of technology, something which severely reduces the scope for public policy analysis.[2] In two separate papers Grossman and Helpman (1991a,b) address this issue by endogenizing the product cycle using two different frameworks for modelling the innovation process. In the variety-expansion model, originally suggested by Romer (1990), firms do costly R&D to expand the number of available consumer good varieties (innovation conducted by northern firms) and to transfer variety-production to the South (imitation conducted by southern firms). In the quality-ladders model, building on Grossman and Helpman (1991c), innovation results in quality improvement of an existing product rather than variety-expansion.

The two papers by Grossman and Helpman have had a profound impact on the literature on North-South trade and technological change, not least judged by the number of papers extending the basic models in directions such as foreign direct investment and licensing. One result present in Grossman and Helpman (1991a,b) has however caused researchers some concern. In both of their papers, any change in public policy that increases northern R&D employment leads to faster economic growth.[3] As Jones (1995) has pointed out this property is clearly counterfactual when confronted with existing empirical evidence. In advanced countries R&D employment has increased dramatically since 1950 without generating any upward trend in economic growth rates.

Since then, so called scale-invariant closed economy models have been developed by Jones (1995), Kortum (1997), Segerstrom (1998) and Young (1998). Far less progress has been made in extending these models to study North-South trade. The scale-invariant North-South models that have been developed, such as Parello (2004), Dinopoulos and Segerstrom (2006) and Sener (2006), have a common feature in that they are all developed in the Grossman and Helpman (1991b) quality-ladders framework. Considering that a significant share of the trade and growth literature relies heavily on the variety-expansion framework for modelling innovation, a careful examination of the consequences of the choice of modelling framework appears important.

[2] In the Krugman (1979) model, new products are developed exclusively in the North and are traded for old goods produced by a commonly known technology in the South.

[3] This so-called scale effect is present in the first generation closed economy endogenous growth models developed by Romer (1990), Grossman & Helpman (1991c) and Aghion & Howitt (1992) but also features in several recent North-South models such as Lai (1998) and Glass & Saggi (2002).

This paper presents a scale-invariant version of the North-South trade model with expanding variety developed in Grossman and Helpman (1991a). In the model, northern firms do costly innovative R&D to benefit from the expansion of the number of available consumer good varieties. As firms in the South have access to northern varieties through international trade they do costly imitative R&D to benefit from the resulting transfer of technology. Since labor costs are assumed to be lower in the South, the transfer of technology is followed by a shift in production to the South. A northern firm whose variety has successfully been imitated by a southern firm can no longer compete and shut down production. The model is solved for a steady-state where relative R&D difficulty is constant over time. The concept of relative R&D difficulty (the difficulty of innovating relative to the size of the economy) has proved to be very useful for understanding the properties of scale-invariant quality-ladders models such as Segerstrom (1998) and Dinopoulos and Segerstrom (2006). This paper appears to be the first to show that the same concept is useful in corresponding North-South variety-expansion models, further clarifying the role of relative R&D difficulty in endogenous growth models. Furthermore, the model generates several interesting findings.

First, the decision of an additional less-developed country to leave autarky and join the world trading system (increasing the size of the South), induces the South to increase their imitation efforts. This increases the rate at which production shifts from the North to the South. Northern labor move from production to R&D, temporarily promoting innovation growth. Second, stronger protection of Intellectual Property Rights (IPR) has the opposite effect, making imitation harder. This reduces the shift in production towards the South with a growth-retarding movement of northern labor from R&D to the production of goods as a consequence. These policy-induced growth effects are temporary as R&D difficulty changes to ensure a return to long-run rates of innovation and economic growth.[4] Finally, lower trade costs are found to have no impact on the rates of innovation and imitation.

In a world economy experiencing close-to-free trade, more less-developed countries joining the world trading system is found to decrease the wage differential as production shifts relatively faster to the South. Stronger protection of IPR causes this shift in production to be relatively slower, increasing the North-South wage differential. Lowering trade costs is shown to reduce the wage inequality as long as the North is relatively richer than the South in terms of purchasing power. Moreover, southern consumers experience long-run benefits from a larger southern region and suffer long-run

[4] The policy relevance of transitionary growth associated with policy shifts should however not be neglected. As transitions between different steady-state equilibria in this type of model typically are relatively slow (see Steger (2003) and Jones (1995)), potential changes in consumer wealth could still be substantial.

welfare losses from stronger IPR protection. The long-run welfare effects of these policy changes are ambiguous for northern consumers. Lower trade costs are however found to increase the long-run welfare of both northern and southern consumers regardless of the distribution of purchasing power.

This paper is closely related to Dinopoulos and Segerstrom (2006), but uses variety-expansion rather than quality-ladders as the framework for modelling R&D. Dinopoulos & Segerstrom derive a dynamic general equilibrium model with quality-improving innovation, building on Grossman and Helpman (1991b). As in Segerstrom (1998), Dinopoulos and Segerstrom (2006) make the assumption that R&D difficulty increases over time by letting an innovated product be a quality improvement upon its predecessor and assume that the difficulty of innovation increases with the level of quality. By making this assumption and also introduce population growth into the model, the scale effect is successfully eliminated. As noted by Dinopoulos and Segerstrom (2006), the different implications found in the variety-expansion- and quality-ladder models developed by Grossman and Helpman can be explained by the assumptions made regarding the pricing behavior of the firms in the North and the South. Making the same assumptions about pricing behavior, it should therefore come as no surprise that the results found in this paper are qualitatively identical to those of the corresponding quality-ladders model developed in Dinopoulos and Segerstrom (2006). There are however interesting differences between the models in how results are obtained and model tractability. Whereas the quality-ladders approach requires somewhat more sophisticated calculations, the variety-expansion model appears to rely on a more careful interpretation of some of the key equations of the model.

The second section of this paper contains a description of the scale-invariant dynamic general equilibrium model of North-South trade and technological change. Full employment conditions and conditions governing R&D incentives are derived for both regions. This is followed by a section devoted to solving the model for a unique steady-state equilibrium. The fourth section contains an examination of the steady-state equilibrium properties of the model. Comparative static analysis is used to examine how different public policies related to the international integration of product markets affect economic growth rates, the North-South wage inequality and the long-run welfare of northern and southern consumers. The last section concludes.

2. The model

2.1. Economic environment. Building on Grossman and Helpman (1991a), labor is the primary factor of production, innovation and imitation and is inelastically supplied by households in the North and the South. There is a continuum of firms located in the North or the South producing consumption goods in a Dixit-Stiglitz monopolistic competition environment. Firms in the consumption good sector sell domestically and export to the foreign market, facing variable trade costs of the iceberg type. Northern firms engage in innovative R&D to extend the amount of varieties available to world consumers while southern firms engage in imitative R&D aimed at shifting production to the South. The paper differs from Grossman and Helpman (1991) by introducing population growth and using the R&D technology suggested in Jones (1995). Labor markets are perfectly competitive and labor can move freely between activities within each of the two regions. However, labor is immobile in the sense that southern labor can not work in the North and vice versa.

2.2. Households. Households are located in the North or the South and grow exponentially larger over time at the population growth rate $n > 0$. As each individual of a household is infinitely lived and inelastically supplies one unit of labor, the world supply of labor at time t is given by

$$L_t = L_{Nt} + L_{St}$$

where

$$L_{Nt} = L_{N0}e^{nt}, L_{St} = L_{S0}e^{nt}$$

are the labor supplies in the North and the South, respectively. In exchange for a unit of supplied labor, each individual receives wage w_N or w_S depending on household origin. Northern and southern households have identical preferences and each household maximizes the discounted lifetime utility

$$U = \int_0^\infty e^{-(\rho-n)t} \ln [u_t] \, dt \tag{2.1}$$

where $\rho > n$ is the subjective discount rate and u_t is the instantaneous utility of an individual at time t. The instantaneous C.E.S. utility function is given by

$$u_t = \left[\int_0^{m_t} x_t (\omega)^\alpha \, d\omega \right]^{\frac{1}{\alpha}} \qquad 0 < \alpha < 1 \tag{2.2}$$

where $x_t(\omega)$ is the per capita demanded quantity of a differentiated product in industry ω at time t and $m_t = m_{Nt} + m_{St}$ is the number of varieties available on the world market at time t, produced in the North (m_{Nt}) or the South (m_{St}). Assuming that varieties are substitutes, α measures the degree of product differentiation, implying an elasticity of substitution $\sigma = \frac{1}{1-\alpha} > 1$ between any two varieties. The optimization across industries could then be shown to yield the familiar demand function

$$x_t(\omega) = \frac{p_t(\omega)^{-\sigma}}{\int_0^{m_t} p_t(\omega)^{1-\sigma}\, d\omega} c_t \tag{2.3}$$

where c_t is the individual consumer expenditure at time t and $p_t(\omega)$ is the price of variety ω at time t. Maximizing (2.1) subject to (2.2) where (2.3) has been used to substitute for $x_t(\omega)$ yields the Euler-condition

$$\frac{\dot{c}_t}{c_t} = r_t - \rho \tag{2.4}$$

implying that the individual consumer expenditure grows over time only if the market interest rate r_t exceeds the subjective discount rate ρ.

2.3. Product markets. Regions are endowed with a single primary input, labor. For simplicity, production of one unit of any variety requires one unit of labor. The marginal cost of producing for the domestic market in region i is then w_{it}, $i = N, S$, where w_{it} is the wage determined in perfectly competitive labor markets. Trade costs are modelled as being of the iceberg form with $\tau > 1$ units having to be shipped for one unit to arrive at its destination. The marginal cost of producing for the foreign market in region i is therefore given by $w_{it}\tau$. It is assumed that due to differences in innovation productivity, only northern firms are capable of developing new varieties. Furthermore, to keep the analysis simple it is assumed that the relative cost structure between the regions satisfy

$$w_{Nt} > w_{St}\tau = \tau.$$

treating southern labor as the numeraire of the model. This condition ensures that imitation only will be profitable in the South.

As there exists a continuum of firms in the world economy, each producer takes prices of other firms products and the level of aggregate spending as given when choosing profit-maximizing local- and export prices. Letting superscript denote producer location whereas subscript denotes consumer location, northern firms charge local and export prices

$$p_{Nt}^{N} = \frac{\sigma - 1}{\sigma} w_{Nt} \text{ and } p_{St}^{N} = \frac{\sigma - 1}{\sigma} \tau w_{Nt}$$

whereas the corresponding prices charged by southern firms are

$$p_{St}^{S} = \frac{\sigma - 1}{\sigma} \text{ and } p_{Nt}^{S} = \frac{\sigma - 1}{\sigma} \tau.$$

Prices are thus determined by a markup over marginal cost and the prices of exported varieties are higher to compensate for the trade cost involved in their sales. Substituting for prices, the profit of a northern firm is

$$\pi_t^N = \left(\frac{1}{\sigma - 1}\right) w_{Nt} \overline{x}_t^N L_t \tag{2.5}$$

where the per capita world demand for a northern variety is

$$\overline{x}_t^N \equiv \frac{\left(x_{Nt}^N L_{Nt} + \tau x_{St}^N L_{St}\right)}{L_t}. \tag{2.6}$$

The northern and southern demands for a northern variety,

$$x_{Nt}^N = \frac{\left(p_{Nt}^N\right)^{-\sigma}}{P_{Nt}} c_{Nt} \text{ and } x_{St}^N = \frac{\left(p_{St}^N\right)^{-\sigma}}{P_{St}} c_{St}, \tag{2.7}$$

are derived using (2.3). While c_{Nt} and c_{St} are the expenditures of representative northern and southern consumers at time t,

$$P_{Nt} = \int_0^{m_{Nt}} \left(p_{Nt}^N(\omega)\right)^{1-\sigma} d\omega + \int_0^{m_{St}} \left(p_{Nt}^S(\omega)\right)^{1-\sigma} d\omega$$

and

$$P_{St} = \int_0^{m_{St}} \left(p_{St}^S(\omega)\right)^{1-\sigma} d\omega + \int_0^{m_{Nt}} \left(p_{St}^N(\omega)\right)^{1-\sigma} d\omega$$

are the price indices in the North and the South.

Similarly, the profit of a southern producer is given by

$$\pi_t^S = \left(\frac{1}{\sigma - 1}\right) \overline{x}_t^S L_t \tag{2.8}$$

where the per capita world demand for a southern variety is

$$\overline{x}_t^S \equiv \frac{\left(x_{St}^S L_{St} + \tau x_{Nt}^S L_{Nt}\right)}{L_t} \tag{2.9}$$

and

$$x_{St}^S = \frac{\left(p_{St}^S\right)^{-\sigma}}{P_{St}} c_{St} \text{ and } x_{Nt}^S = \frac{\left(p_{Nt}^S\right)^{-\sigma}}{P_{Nt}} c_{Nt} \tag{2.10}$$

are the southern and northern demands for a southern variety derived from (2.3). Northern and southern profits increase as consumer expenditures increase, whereas higher trade costs cause export sales to decrease in each of the two regions.

2.4. Innovation and imitation. The resources devoted to industrial research in the North (innovation) and the South (imitation) result in blueprints, effectively used as entry tickets to the world market. In addition, a new innovation gives rise to an externality as it adds to the knowledge available to northern and southern labor employed in R&D, affecting the future productivity in these activities.

To innovate and develop a new product variety, a representative northern firm j must devote $\frac{a_D}{K_t^\phi}$ units of labor to innovation, where a_D is the fixed innovation productivity and K_t is the disembodied stock of knowledge which grows over time and is available to all firms in the world economy. Whereas Grossman and Helpman (1991a) assume that intertemporal knowledge spillovers are quite strong, setting $\phi = 1$, this paper instead follows Jones (1995) by assuming that intertemporal knowledge spillovers satisfy $\phi < 1$. That is, intertemporal knowledge spillovers are bounded from above but can be positive or negative.[5] For $\phi > 0$ ($\phi < 0$) labor becomes more (less) productive and a northern firm needs to devote relatively less (more) units of labor to innovation as the stock of knowledge increase. The stock of knowledge is assumed to be proportional to the total number of varieties innovated in the past. Choosing units so that $K_t = m_t$, the rate at which the northern firm j discovers new products is given by

$$\dot{m}_{jt} = \frac{l_{Djt}}{\frac{a_D}{K_t^\phi}} = m_t^\phi \frac{l_{Djt}}{a_D}$$

where $\dot{m}_{jt}$ is the time derivative of m_{jt} and l_{Djt} is the labor used for innovative activities by firm j. Summing over individual northern firms causes the aggregate number of innovations in the North to evolve according to

$$\dot{m}_t = m_t^\phi \frac{L_{Dt}}{a_D} \tag{2.11}$$

where $\dot{m}_t$ is the time derivative of m_t and $L_{Dt} = \sum_j l_{Djt}$ is the total amount of northern labor employed in innovative activities.

Similarly, to master the production process of a randomly chosen northern variety, a southern entrepreneur k must devote $\frac{a_I}{K_t^\phi}$ units of labor to imitation. a_I could be interpreted simply as the fixed imitation productivity or as a parameter governing the strength of Intellectual Property Rights (IPR) protection. A high value of a_I would with this interpretation represent stronger protection as this make it harder for a southern firm to imitate. Furthermore, intertemporal knowledge spillovers can be of different strengths and are governed by the parameter $\phi < 1$. Using that $K_t = m_t$, the rate at

[5] This assumption is also supported by a declining patents-per-researcher ratio observed by Kortum (1997), suggesting negative intertemporal knowledge spillovers.

which the southern firm k discovers new products evolves according to

$$\dot{m}_{Skt} = \frac{l_{Ikt}}{\frac{a_I}{K_t^{\phi}}} = m_t^{\phi}\frac{l_{Ikt}}{a_I}$$

where l_{Ik} is the labor used for imitative activities by firm k. Considering all southern firms causes the aggregate number of imitations in the South to evolve according to

$$\dot{m}_{St} = m_t^{\phi}\frac{L_{It}}{a_I} \tag{2.12}$$

where $L_{It} = \sum_k l_{Ikt}$ is the total amount of southern labor employed in imitative activities.

2.5. R&D incentives. A representative northern firm holding a blueprint that has not yet been imitated earns the profit π_t^N during a time interval dt. Northern firms face an on-going risk of imitation and with random selection from a uniform distribution, any given northern firm will lose its monopoly position during such an interval with probability $\frac{\dot{m}_{St}}{m_{Nt}}dt$. In the event that this occurs, owners of the firm will suffer a capital loss of size V_{Nt}. If the variety is not imitated firm owners instead receive capital gain $\dot{V}_{Nt}$ during time interval dt, where $\dot{V}_{Nt}$ represents the change over time in the discounted profits a typical northern firm is expected to generate.

An entry into innovation is financed by an equity offering. Returns to innovation are independently distributed across the continuum of industries. By the law of large numbers this implies that there is no aggregate risk in the economy, making it possible for households to earn a safe return by holding the northern market portfolio. Hence, ruling out any arbitrage opportunities implies that the total return on equity claims must equal the opportunity cost of invested capital which is given by the risk free market interest rate r_t. Hence, the northern no-arbitrage condition could be written

$$r_t V_{Nt} dt = \pi_t^N dt - \frac{\dot{m}_{St}}{m_{Nt}} V_{Nt} dt + \dot{V}_{Nt} dt.$$

If innovation were to offer pure profits, entry by entrepreneurs would generate an excess demand for northern labor. Hence, in an equilibrium with free entry the present discounted value of northern profits must exactly equal the cost of innovation

$$V_{Nt} = \frac{w_N a_D}{m_t^{\phi}}. \tag{2.13}$$

Dividing the northern no-arbitrage condition by $V_{Nt}dt$ on both sides and defining the rate of imitation as $\mu \equiv \frac{\dot{m}_{St}}{m_{Nt}}$, the no-arbitrage condition can be combined with (2.13) to yield

$$r_t + \mu = \frac{\pi_t^N}{\frac{w_{Nt} a_D}{m_t^\phi}} + \frac{\dot{V}_{Nt}}{V_{Nt}}. \tag{2.14}$$

(2.14) can be interpreted as the risk-adjusted interest rate being equal to the sum of the instantaneous profit rate and the capital gain rate. The risk premium equals the imitation rate, which is the conditional probability of suffering a total loss of earnings capacity.

Turning to the South, the efforts of imitators cause technological know-how to be transferred from the North to the South. Once a southern firm has mastered the production process of a northern variety, the production of this variety shifts to the South and the firm earns an infinite stream of monopoly profits. Owners of the southern firm collect the profit $\pi_t^S dt$ in a time interval of length dt and also realize a capital gain of $\dot{V}_{St} dt$, where $\dot{V}_{St}$ is the time derivative of the expected discounted profit of a southern firm. Access to a well-diversified southern portfolio ensures that southern households earn a safe return. With no arbitrage opportunities the return on equity claims must equal the risk free market interest rate r_t which implies

$$r_t V_{St} dt = \pi_t^S dt + \dot{V}_{St} dt.$$

If southern imitators were to earn pure profits, the demand for southern labor would increase, raising the southern wage until the expected present discounted value of southern profits equals the cost of imitation. Free entry thus ensures

$$V_{St} = \frac{a_I}{m_t^\phi}. \tag{2.15}$$

Dividing the southern no-arbitrage condition by $V_{St} dt$ on both sides and substituting for V_{St} using (2.15), the southern no-arbitrage condition can be written as

$$r_t = \frac{\pi_t^S}{\frac{a_I}{m_t^\phi}} + \frac{\dot{V}_{St}}{V_{St}}. \tag{2.16}$$

This can be interpreted as the risk-free interest rate being equal to the instantaneous profit rate plus the capital gain rate of a southern firm.

2.6. Labor market clearing. Labor markets are perfectly competitive and wages adjust instantaneously to make labor supply equal labor demand. In the North, labor is employed in production or innovative R&D and there is frictionless movement between these activities. Successful innovative R&D requires $\frac{a_D}{m_t^\phi}$ units of labor and for $\phi > 0$ ($\phi < 0$) the labor necessary to innovate decreases (increases) as the amount of existing varieties is expanded. Labor used to produce a variety for the local and foreign market is $\overline{x}_t^N L_t$ per northern firm. As L_{Nt} denotes the exogenous labor supply in the North, full employment requires

$$L_{Nt} = \frac{a_D}{m_t^\phi}\dot{m}_t + X_t^N L_t \tag{2.17}$$

where $X_t^N \equiv \overline{x}_t^N m_{Nt}$ is the per capita world demand for all northern varieties.

In the South, labor is employed in production or imitative R&D. Imitative R&D requires $\frac{a_I}{m_t^\phi}$ units of labor and for $\phi > 0$ ($\phi < 0$) the labor necessary to imitate decreases (increases) with the number of innovated varieties. Labor used to produce a variety for the local and foreign market is $\overline{x}_t^S L_t$ per southern firm. Full employment of southern labor thus requires

$$L_{St} = \frac{a_I}{m_t^\phi}\dot{m}_{St} + X_t^S L_t \tag{2.18}$$

where $X_t^N \equiv \overline{x}_t^S m_{St}$ is the per capita world demand for all southern varieties.

This completes the description of the model.

3. Solving the model

The model is solved for a unique steady-state equilibrium where all endogenous variables grow over time at constant (but not necessarily identical) rates. It turns out that, in steady-state, the model can be represented by two conditions. In each region one condition was found by assuming labor market clearing and another was found by assuming no arbitrage opportunities on the stock market. These four conditions can then be narrowed down to one northern and one southern steady-state condition with two unknowns; the rate of imitation μ and the relative R&D difficulty (which is yet to be defined). Furthermore, the simplicity of these two conditions makes it straight forward to examine the steady-state effects associated with changes in policy parameters of the model.

The Euler-condition in (2.4) implies that the market interest rate is constant by definition of the steady-state equilibrium. As southern labor is used as the numeraire, it then follows that steady-state nominal wages, prices and consumer expenditures in both regions must be constant as well. Moreover, the labor supply in each of the two regions grows at the population growth rate n and consists of workers employed in production or R&D activities. This implies that the number of innovators L_{Dt} and the number of imitators L_{It} must grow at this rate as well. If we denote the steady-state growth rate of the number of innovations $g \equiv \frac{\dot{m}_t}{m_t}$, then dividing both sides of (2.11) by m_t yields

$$g = \frac{m_t^{\phi-1} L_{Dt}}{a_D}.$$

As g must be constant over time by definition of the steady-state equilibrium, this is true if

$$g = \frac{n}{1-\phi}. \tag{3.1}$$

Hence, steady-state innovation growth is proportional to the growth rate of R&D labor and scale-invariant, in line with the empirical evidence discussed in Jones (1995).

Furthermore, let $m_t^{-\phi}$ denote the R&D difficulty, which increases over time if $\phi < 0$ and decreases over time if $0 < \phi < 1$. $\frac{L_{Nt}}{m_t}$ could be thought of as a measure of the size of the northern economy from the perspective of an innovating firm. By taking the ratio of R&D difficulty and this measure of the size of the northern economy, relative R&D difficulty is defined as

$$z_{Nt} \equiv \frac{m_t^{-\phi}}{\frac{L_{Nt}}{m_t}} = \frac{m_t^{1-\phi}}{L_{Nt}}. \tag{3.2}$$

Log-differentiating (3.2) and using (3.1) it can easily be shown that z_{Nt} is constant in steady-state.[6]

In contrast to existing scale-invariant quality ladder-models such as Segerstrom (1998), where R&D difficulty is assumed to increase over time, this model allows for R&D difficulty to decrease over time. In steady-state, an increasing R&D difficulty ($\phi < 0$) implies that the market size is increasing over time since population growth is higher than innovation growth. Similarly, a decreasing R&D difficulty ($0 < \phi < 1$) implies that the market size is decreasing over time as innovation growth is relatively faster in steady-state.

Next, from $m_{Nt} + m_{St} = m_t$, three steady-state observations can be made. First, the number of varieties produced in each region must grow at the same rate as the total number of existing varieties, hence $g \equiv \frac{\dot{m}_t}{m_t} = \frac{\dot{m}_{Nt}}{m_{Nt}} = \frac{\dot{m}_{St}}{m_{St}}$. Second, letting $\frac{m_i}{m} = \gamma_i$, $i = N, S$ denote the share of all varieties produced in each region, these shares are necessarily constant in any steady-state since $\gamma_{Nt} + \gamma_{St} = 1$. Third, γ_N and γ_S can be determined using that $\frac{\dot{m}_{Nt}}{m_{Nt}} = \frac{\dot{m}_{St}}{m_{St}}$ and that the rate of innovation can be written as $g = g\gamma_N + \mu\gamma_N$. Solving for the northern share of variety production yields

$$\gamma_N = \frac{g}{g+\mu}$$

and the southern share is given by

$$\gamma_S = \frac{\mu}{g+\mu}.$$

[6] The relative R&D difficulty-state variable is defined to relate to the size of the northern region in order to isolate comparative static effects from changing the initial size of the South. Had we instead defined relative R&D difficulty to relate to the world or the South, changing the size of the South would cause a jump in the chosen state variable, making the comparative static analysis less tractable.

To see how the rewards to R&D are related to the northern market share of a variety, profits of northern and southern firms can be rewritten using (2.6), (2.7), (2.9) and (2.10). Multiplying profits by the northern market share term $\frac{L_{Nt}}{m_t}$ yields

$$\pi_t^i = \left(\frac{1}{\sigma - 1}\right) w_i \Phi_i \frac{L_{Nt}}{m_t},\ i = N, S$$

where

$$\Phi_N \equiv \left(\frac{p_{NL}^{-\sigma} c_N}{\gamma_N p_{NL}^{1-\sigma} + \gamma_S p_{SE}^{1-\sigma}} + \frac{\tau p_{NE}^{-\sigma} c_S \frac{L_{S0}}{L_{N0}}}{\gamma_S p_{SL}^{1-\sigma} + \gamma_N p_{NE}^{1-\sigma}}\right)$$

and

$$\Phi_S \equiv \left(\frac{p_{SL}^{-\sigma} c_S \frac{L_{S0}}{L_{N0}}}{\gamma_S p_{SL}^{1-\sigma} + \gamma_N p_{NE}^{1-\sigma}} + \frac{\tau p_{SE}^{-\sigma} c_N}{\gamma_N p_{NL}^{1-\sigma} + \gamma_S p_{SE}^{1-\sigma}}\right)$$

are constant in steady-state. Consequently, π_t^N and π_t^S are proportional to $\frac{L_{Nt}}{m_t}$.

In solving the model, (2.4) and (2.5) are used to substitute for the market interest rate and northern profits in (2.14). As wages are constant in steady-state equilibrium, the capital gains rate $\frac{\dot{V}_{Nt}}{V_{Nt}} = -\phi g$ is found by log-differentiating (2.13). Using (3.2) to solve for a steady-state equilibrium where X^N and z_N are constant over time, (2.14) can be rewritten to yield the northern innovation condition

$$\frac{\left(\frac{1}{\sigma-1}\right) X^N \frac{1}{\gamma_N} L_0}{\rho + \mu + \phi g} = a_D z_N L_{N0} \tag{3.3}$$

where g is given by (3.1). The left hand side of (3.3) is related to expected discounted profits from innovation in the North, whereas the right hand side is related to the cost of innovation.

First note that an increase in the relative R&D difficulty ($z_N \uparrow$) increases the cost of innovation. Second, since x_{Nt}^N and x_{St}^N decrease over time due to expansion of the number of varieties, the per capita world demand for a northern variety $\overline{x}_t^N$ does not serve as a good measure of how much the average consumer buys of a specific variety. Noting however that X^N is a measure of the demand for northern varieties in general and that $X^N\left(1 + \frac{\mu}{g}\right) = X^N \frac{m_t}{m_{Nt}}$ is constant in steady-state, changes in X^N can also be seen as representing changes in the demand for a specific northern variety as long as the ratio $\frac{m_t}{m_{Nt}}$ remains constant. Hence, any change in $\frac{m_t}{m_{Nt}}$ reflects how much a representative world consumer spend on a specific northern variety given what is spent on northern varieties in general. Using this interpretation, expected discounted profits are higher when the average world consumer buys more of northern varieties in general ($X^N \uparrow$), when the average world consumer spends more on a specific northern variety ($\frac{1}{\gamma_N} = \frac{m_t}{m_{Nt}} \uparrow$) given X^N and when profits are less heavily discounted ($\rho \downarrow$).

To better understand the intuition of the term capturing the capital gain/loss of a firm, we first note that the discounted profit of a firm in either region was shown to be proportional to $\frac{L_{Nt}}{m_t}$. Hence firms experience steady-state capital gains as a result of increasing market shares if the northern population grows faster than the number of innovations, that is when $\phi < 0$. If instead $0 < \phi < 1$ firms incur capital losses as the northern market share of a firm decreases over time.

The southern no-arbitrage condition can similarly be rewritten by substituting for the market interest rate and the southern profit using (2.4) and (2.8) in (2.16). Log-differentiating (2.15) to get $\frac{\dot{V}_{St}}{V_{St}} = -\phi g$ and solving for a steady-state equilibrium where X^S and z_N are constant over time, the southern imitation condition is given by

$$\frac{\left(\frac{1}{\sigma-1}\right) X^S \frac{1}{\gamma_S} L_0}{\rho + \phi g} = a_I z_N L_{N0} \tag{3.4}$$

where g is given by (3.1). The left hand side of (3.4) is related to expected discounted profits from southern imitation, whereas the right hand side is related to the cost of imitation. An increase in the relative R&D difficulty ($z_N \uparrow$) increases the cost of imitation. Expected discounted profits increase when the average consumer buys more of southern varieties in general ($X^S \uparrow$), when consumer expenditure on a particular variety increases ($\frac{1}{\gamma_S} = \frac{m_t}{m_{St}} \uparrow$) given X^S, and when profits are less heavily discounted ($\rho \downarrow$).

The innovation-, imitation- and labor market conditions of the North and the South together pin down the unique steady-state of the model. To simplify the analysis these four conditions are combined to yield one condition for each region, together determining the two unknowns μ and z_N. Using that $g \equiv \frac{\dot{m}_t}{m_t}$ in steady-state, the northern full employment condition (2.17) is written as

$$L_{N0} = a_D z_N L_0 g + X^N L_0.$$

Substituting for X^N using the northern no-arbitrage condition (3.3), the *northern steady-state condition* is

$$a_D z_N g + a_D z_N g \left(\frac{\rho + \mu + \phi g}{g + \mu} \right) (\sigma - 1) = 1 \tag{3.5}$$

where g is given by (3.1). (3.5) has a simple interpretation as the first term is the share of northern labor devoted to R&D while the second term represents the share of labor producing northern varieties. Assuming that the steady-state real interest rate exceeds the population growth rate, $\rho > n$, a higher rate of imitation decreases the left-hand-side of (3.5).[7] To keep the left-hand-side of (3.5) constant, this requires relative R&D difficulty z_N to increase. Hence, the northern steady-state condition is upward-sloping in (z_N, μ) space.[8]

The intuition behind the upward-sloping curve is the following. An increase in the rate of imitation causes a higher share of the existing varieties to be produced in the South, decreasing northern production employment. For full employment to be maintained in the North, relative R&D difficulty must increase, causing northern R&D employment to increase.

To find the corresponding steady-state condition for the South, the full employment condition (2.18) is written as

$$L_{S0} = a_I z_N L_{N0} \gamma_S g + X^S L_0$$

having used (3.2) and that $g \equiv \frac{\dot{m}_t}{m_t}$. Substituting for X^S using the southern no-arbitrage condition (3.4), the *southern steady-state condition* is

$$a_I z_N g \frac{L_{N0}}{L_{S0}} \left(\frac{\mu}{g+\mu}\right) + a_I z_N (\rho + \phi g) \frac{L_{N0}}{L_{S0}} \left(\frac{\mu}{g+\mu}\right) (\sigma - 1) = 1. \tag{3.6}$$

The steady-state rate of innovation g is given by (3.1). Similar to the interpretation of the northern steady-state condition, the first term in (3.6) is the share of southern labor devoted to imitation while the second term is the share of southern labor devoted to production of southern varieties. An increase in the rate of imitation μ increases the left-hand-side of (3.6) which would require z_N to decrease to keep the left-hand-side constant. Hence the southern steady-state curve is downward-sloping in (z_N, μ) space (and has no intercepts).

As the rate of imitation increases there are two channels through which southern labor is reallocated between production and imitation. A higher rate of imitation requires more southern labor to be devoted to imitation. At the same time, the higher rate of imitation causes a higher share of the existing varieties to be produced in the South, increasing the southern production employment. A decrease in the relative R&D difficulty is needed to maintain full employment in the South. This reduces the imitation employment needed to maintain the imitation rate, and for a southern firm to break even in their R&D investment with a lower relative R&D difficulty, the per capita demand for southern varieties must decrease, effectively reducing southern production employment.

[7] This can be seen by using that $g = \frac{n}{1-\phi}$ and noting that $\frac{d}{d\mu}\left[\frac{\rho+\mu+\phi g}{g+\mu}\right] = \frac{(n-\rho)}{(g+\mu)^2} < 0$ if $\rho > n$, which was assumed.

[8] The intercept of the northern steady-state curve is given by $z_N = \frac{1}{a_D[g+(\phi g+\rho)(\sigma-1)]} > 0$ and is found by evaluating (3.5) at $\mu = 0$.

The steady-state rate of imitation μ and relative R&D difficulty z_N are uniquely determined by the intersection of the northern and the southern steady-state curves governed by (3.5) and (3.6), as shown in Figure 1. Note also that trade costs affect neither (3.5) nor (3.6) and hence does not affect the steady-state rate of imitation or the steady-state level of relative R&D difficulty.

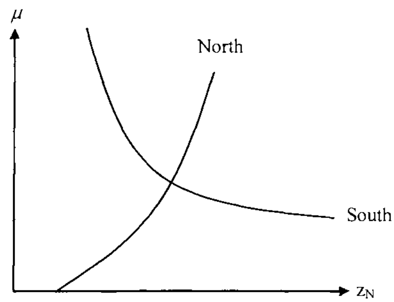

Figure 1. The steady-state equilibrium.

Next, the steady-state level of consumer expenditures is derived for each of the two regions. This is done to better understand the behavior of the northern relative wage w_N and to simplify welfare calculations later in the paper. It is assumed that northern consumers own firms located in the North and southern consumers own firms located in the South. This implies that aggregate assets in the North and South are given by

$$A_{it} = V_{it} m_{it} \qquad i = N, S.$$

From (2.13) and (3.2), northern asset holdings can be expressed as

$$A_{Nt} = w_N a_D z_N L_{Nt} \gamma_N$$

while (2.15) and (3.2) implies that the corresponding asset holding of the southern population is

$$A_{St} = a_I z_N L_{Nt} \gamma_S.$$

In steady-state, the individual budget constraints of consumers satisfy

$$\dot{a}_{it} = 0 = w_i + (\rho - n)\, a_{it} - c_i \qquad i = N, S.$$

which implies that the northern and southern individual consumer expenditure levels are given by

$$c_N = w_N \left(1 + (\rho - n)\, a_D z_N \gamma_N\right) \tag{3.7}$$

and

$$c_S = 1 + (\rho - n)\, a_I z_N \frac{L_{N0}}{L_{S0}} \gamma_S. \tag{3.8}$$

(3.7) and (3.8) could also be interpreted in terms of consumer income as the first term is labor income and the second term represent the returns to firm ownership. Moreover, the northern relative aggregate expenditure could be defined as

$$\eta_N \equiv \frac{c_N L_{Nt}}{c_S L_{St}} = w_N \left(\frac{L_{N0} + (\rho - n)\, a_D z_N L_{N0} \gamma_N}{L_{S0} + (\rho - n)\, a_I z L_{N0} \gamma_S} \right).$$

To fully characterize the steady-state equilibrium and also understand how the North-South wage differential is affected by changes in parameters, a wage condition is derived using the northern and southern no-arbitrage conditions (3.3) and (3.4). Noting that $X_t^N = \overline{x}_t^N m_{Nt}$ and $X_t^S = \overline{x}_t^S m_{St}$, the wage condition is given by

$$\frac{\overline{x}_t^N}{\overline{x}_t^S} \left(\frac{\rho + \phi g}{\rho + \mu + \phi g} \right) = \frac{a_D}{a_I}.$$

Using (2.6), (2.7), (2.9) and (2.10) to substitute for $\overline{x}_t^N$ and $\overline{x}_t^S$, the *northern relative wage condition* is given by

$$\frac{\left(\tau^{\sigma-1} + \eta_N \tau^{1-\sigma}\right) \frac{\gamma_N}{\gamma_S} + w_N^{\sigma-1} (1 + \eta_N)}{\frac{(1+\eta_N)}{w_N} w_N^{1-\sigma} \frac{\gamma_N}{\gamma_S} + \frac{\eta_N \tau^{\sigma-1} + \tau^{1-\sigma}}{w_N}} = \left(\frac{\rho + \phi g}{\rho + \mu + \phi g} \right) \frac{a_I}{a_D}. \tag{3.9}$$

As $\frac{\eta_N}{w_N}$ is independent of w_N, the numerator on the left-hand-side of (3.9) increases in w_N while the denominator decreases in w_N which implies that the left-hand-side of (3.9) increases in the northern relative wage w_N. As (3.9) uniquely determines the northern relative wage, equations (3.5), (3.6) and (3.9) together pin down the value of each of the unknowns μ, z_N and w_N and thereby fully characterize the unique steady-state equilibrium.[9]

Having derived steady-state consumer expenditure levels, it is also easy to pin down individual steady-state utility levels. This is done to simplify later welfare calculations and determine economic growth rates. For a representative northern consumer (2.2) can be simplified to yield

$$u_{Nt} = \left[\int_0^{m_{Nt}} \left(x_{Nt}^N\right)^{\alpha} d\omega + \int_0^{m_{St}} \left(x_{Nt}^S\right)^{\alpha} d\omega \right]^{\frac{1}{\alpha}} = \left[m_{Nt} \left(x_{Nt}^N\right)^{\alpha} + m_{St} \left(x_{Nt}^S\right)^{\alpha} \right]^{\frac{1}{\alpha}}.$$

[9] To accurately verify the existence of a unique steady-state equilibrium, parameters of the model must ensure that $w_N > \tau$ is satisfied.

Combining this with equations (2.7), (2.10) and (3.7) and using that $\alpha = \frac{\sigma-1}{\sigma}$, the instantaneous utility of a northern consumer is found to be

$$\text{(3.10)} \quad u_{Nt} = c_N P_N^{\frac{1}{\sigma-1}} = (1 + (\rho - n) a_D z_N \gamma_N) \left(\frac{\sigma - 1}{\sigma}\right) \left[m_{Nt} + m_{St} \left(\frac{w_N}{\tau}\right)^{\sigma-1}\right]^{\frac{1}{\sigma-1}}.$$

Considering also the instantaneous utility of a southern consumer, (2.2) is simplified to yield

$$u_{St} = \left[\int_0^{m_{St}} \left(x_{St}^S\right)^\alpha d\omega + \int_0^{m_{Nt}} \left(x_{St}^N\right)^\alpha d\omega\right]^{\frac{1}{\alpha}} = \left[m_{St}\left(x_{St}^S\right)^\alpha + m_{Nt}\left(x_{St}^N\right)^\alpha\right]^{\frac{1}{\alpha}}.$$

Using (2.7), (2.10), (3.8) and $\alpha = \frac{\sigma-1}{\sigma}$, the instantaneous utility of a southern consumer is given by

(3.11)

$$u_{St} = c_S P_S^{\frac{1}{\sigma-1}} = \left(1 + (\rho - n) a_I z_N \frac{L_{N0}}{L_{S0}} \gamma_S\right) \left(\frac{\sigma - 1}{\sigma}\right) \left[m_{St} + m_{Nt} \left(\frac{1}{\tau w_N}\right)^{\sigma-1}\right]^{\frac{1}{\sigma-1}}.$$

Finally, economic growth rates measured as the growth rates of individual utility can be derived. Using that the number of northern and southern varieties grows at the common rate g and that wages, consumer expenditures and the relative R&D difficulty are constant in steady-state equilibrium, log-differentiation of (3.10) and (3.11) yields the common economic growth rate

$$\frac{\dot{u}_t}{u_t} \equiv \frac{\dot{u}_{St}}{u_{St}} = \frac{\dot{u}_{Nt}}{u_{Nt}} = \frac{n}{(\sigma - 1)(1 - \phi)}$$

which is proportional to the steady-state rate of innovation. Considering that steady-state economic growth rates are policy independent (3.10) and (3.11) will prove useful in evaluating the long-run welfare effects associated with the discussed shifts in public policy.

4. Steady-state properties of the model

In this section a comparative static analysis is used to highlight several important implications of the model. Three specific policy shifts related to the international integration of product markets will be investigated: (i) the decision of a less-developed country to join the world trading system and thereby increase the size of the southern region ($L_{S0} \uparrow$), (ii) stronger protection of Intellectual Property Rights measured as an increase in the labor requirement in imitation ($a_I \uparrow$) and (iii) a lowering of trade costs ($\tau \downarrow$). The long-run welfare effects of these policies are also examined.

When studying the properties of the model, it is assumed that the North and the South are initially in the steady-state equilibrium determined by (3.5) and (3.6) and that at some point in time a policy change ($L_{S0} \uparrow$, $a_I \uparrow$ or $\tau \downarrow$) takes place.

First, the decision of a less-developed country to join the world trading system ($L_{S0} \uparrow$) does not affect (3.5) but shifts the southern curve governed by (3.6) outwards. In the new steady-state, relative R&D difficulty z_N and the rate of imitation μ have increased to new, higher levels. Stronger IPR protection ($a_I \uparrow$) does not affect (3.5) but shifts the southern curve given by (3.6) inwards. For a given rate of imitation μ, the relative R&D difficulty z_N must decrease to offset the increase in a_I. In the new steady-state, relative R&D difficulty z_N and the rate of imitation μ have decreased to new, lower levels. Finally the steady-state rate of imitation and the level of relative R&D difficulty are both independent of the level of trade costs.

From the definition of relative R&D difficulty in (3.2) it follows that any increase in z_N must be accompanied by a temporary increase in the growth rate of m_t.[10] For a corresponding decrease in z_N, the growth rate of m_t must temporarily decrease. Thus it has been established

THEOREM 1. *(i) A permanent increase in the size of the South ($L_{S0} \uparrow$) leads to a permanent increase in the rate of imitation ($\mu \uparrow$), a temporary increase in the rate of innovation ($z_N \uparrow$), no change in the long-run rate of innovation ($g = \frac{n}{1-\phi}$). (ii) A permanent strengthening of Intellectual Property Rights protection ($a_I \uparrow$) leads to a permanent decrease in the rate of imitation ($\mu \downarrow$), a temporary decrease in the rate of innovation ($z_N \downarrow$), no change in the long-run rate of innovation ($g = \frac{n}{1-\phi}$). (iii) A change in the level of trade costs does not affect the rates of innovation and imitation.*

The comparative static effects from $L_{S0} \uparrow$ and $a_I \uparrow$ can be seen in Figures 2 and 3.

[10] This can be compared to the permanent growth effect found in Grossman and Helpman (1991a), where it is assumed that $\phi = 1$.

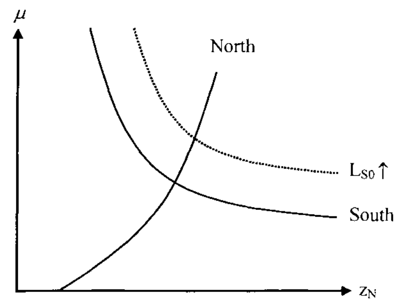

Figure 2. An increase in the size of the southern region.

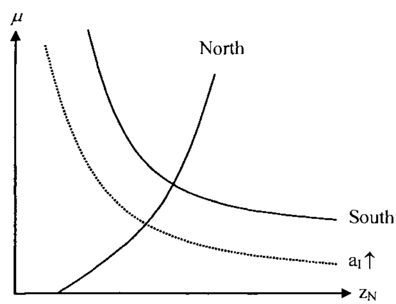

Figure 3. Stronger protection of Intellectual Property Rights.

The intuition behind these results is as follows. A larger southern region implies that more southern workers are devoted to the imitation of northern products, causing the rate of imitation to increase. A higher rate of imitation implies that more production of varieties is transferred from the North to the South, decreasing the demand for northern production labor. As a result of this, the northern wage adjusts downwards, making it more attractive to hire R&D workers. Greater R&D efforts in the North cause the rate of innovation to exceed its steady-state rate. For $\phi > 0$, that is, an economy with a relatively high steady-state rate of innovation, a new innovation decreases R&D difficulty ($m_t^{-\phi} \downarrow$) while it decreases the northern market share of a variety even more ($\frac{L_{Nt}}{m_t} \downarrow\downarrow$). This reduces the incentives to innovate until the rate of innovation has returned to its steady-state rate. In an economy that experiences a relatively lower steady-state rate of innovation associated with $\phi < 0$, the transition looks somewhat different. As the rate of innovation exceeds its steady-state rate, new innovations cause R&D difficulty to increase ($m_t^{-\phi} \uparrow$) and the northern market share of a variety to shrink ($\frac{L_{Nt}}{m_t} \downarrow$). Incentives to innovate are reduced until the rate of innovation has returned to its steady-state rate.

Considering next the effects from strengthening the protection of IPR. In the model, stronger protection of IPR makes it harder for southern firms to imitate northern products, decreasing the rate of imitation. Varieties that previously would have been produced in the South are now produced in the North. As the northern wage adjusts upwards, this reduces R&D employment in the North and cause the rate of innovation to drop below its steady-state rate. A lower rate of innovation implies that relative R&D difficulty decreases. As innovator incentives are improved, the rate of innovation increases and eventually returns to its steady-state rate.

Finally, lower trade costs do not affect innovation- or imitation rates and leave the level of relative R&D difficulty unchanged. Firms in both the North and the South experience lower profits as competition from foreign firms become fiercer while profits increase as export sales are higher. Due to the choice of preferences in this model, the net effect is however zero, implying that incentives to innovate and imitate remain unaffected.

It still remains to examine how the northern relative wage responds to the discussed policy shifts. This turns out to be less straightforward compared to the general results stated above. Computer simulations could easily be used to improve the understanding of effects on international wage inequality, but to keep the analysis simple we consider a special case where analytical results can be obtained, namely that of free trade between the North and the South, that is when $\tau = 1$.

In this case, the wage equation in (3.9) reduces to

$$w_N^\sigma = \left(\frac{\rho + \phi g}{\rho + \mu + \phi g}\right) \frac{a_I}{a_D}. \tag{4.1}$$

Before performing comparative statics, it is first necessary to verify the existence of a free trade steady-state equilibrium, that is, show under what condition the northern relative wage exceeds unity. First, from (3.5) and (3.6) it is noted that the rate of imitation μ can be written as a function $\mu = f(L_{S0})$. To satisfy $w_N^\sigma > 1$, the right-hand-side of (4.1) must exceed unity. Solving this inequality for the rate of imitation μ yields

$$\mu = f(L_{S0}) < (\rho + \phi g)\left(\frac{a_I}{a_D} - 1\right) \equiv \overline{\mu}$$

as a necessary condition for $w_N > 1$ to hold, requiring L_{S0} to be sufficiently small. To ensure that μ and $\overline{\mu}$ both are greater than zero it is sufficient to assume that $a_I > a_D$.[11] Hence, it has been established

THEOREM 2. *Given that the world economy experiences free trade* $(\tau = 1)$*, the model has a unique steady-state equilibrium if* L_{S0} *is sufficiently small and* $a_I > a_D$.

The assumption $a_I > a_D$ could be thought of as reflecting how the common available stock of knowledge (including the most recent technological know-how) could be systematically less appropriate for imitators compared to innovators.

Examining the consequences on the North-South wage-gap of intensified international integration of product markets, an increase in the size of the South increases the steady-state rate of imitation according to Theorem 1. From (4.1) the northern relative wage must respond by decreasing to a lower level in the new steady-state equilibrium. Similarly, Theorem 1 states that stronger IPR protection induces the rate of imitation to decrease. (4.1) then implies that the northern relative wage must increase to a higher level in the new steady-state equilibrium. Thus it has been established

THEOREM 3. *In a world economy experiencing free trade* $(\tau = 1)$*, a permanent increase in the size of the South* $(L_{S0} \uparrow)$ *permanently decreases the northern relative wage* $(w_N \downarrow)$*, whereas permanent stronger IPR protection* $(a_I \uparrow)$ *serves to permanently increase the northern relative wage* $(w_N \uparrow)$.

The intuition is quite simple. An increase in the size of the southern region increases the imitation efforts of the southern labor force. As the rate of imitation increases, more production shifts from the North to the South, reducing the demand for northern labor. The associated fall in the northern relative wage must be large enough to ensure that all workers having lost their job in production are hired in northern R&D activities.

Treating the Chinese entrance into world trade as an increase in the size of the southern region, the model predicts a decreasing global wage inequality. Considering both between-country- and within-country income inequality, Sala-i-Martin (2002) argues that there indeed has been a significant reduction of global income inequality since 1980. This reduction appears to be driven mainly by the large increases in income of chinese citizens.

Stronger IPR protection has the opposite effect as it makes imitation harder. Relatively less production shifts to the South, increasing the demand for northern production labor. The northern relative wage adjusts upwards to ensure that the higher demand for production labor is matched by a lower level of northern R&D employment.

[11] Using the assumption $\rho > n$ and substituting for g using (3.1), $\overline{\mu}$ must be positive since $\rho + \phi g = \left(\frac{\rho - \phi(\rho - n)}{1-\phi}\right)$ is positive for any $\phi \in (-\infty, 1)$.

To be able to understand the effect on the relative wage associated with lowering trade costs, the case of a marginal increase in trade costs starting from free trade is considered. This is done by first differentiating the left-hand-side of (3.9), which will be denoted $f(w_N, \tau)$, with respect to τ and w_N and then evaluate at $\tau = 1$. This yields

$$\frac{\delta f(w_N, \tau)}{\delta \tau}|_{\tau=1} = (\sigma - 1)\left(\frac{1-\eta_N}{1+\eta_N}\right) w_N^{\sigma}$$

and

$$\frac{\delta f(w_N, \tau)}{\delta w_N}|_{\tau=1} = \sigma w_N^{\sigma-1},$$

having taken into account that η_N is a function of w_N. Using the implicit function theorem these two conditions can then be combined to yield

$$\frac{dw_N}{d\tau}|_{\tau=1} = -\frac{\frac{\delta f(\tau, w_N)}{\delta \tau}|_{\tau=1}}{\frac{\delta f(\tau, w_N)}{\delta w_N}|_{\tau=1}} = \left(\frac{\sigma-1}{\sigma}\right)\left(\frac{\eta_N - 1}{\eta_N + 1}\right) w_N. \tag{4.2}$$

From (4.2), an increase in the level of trade costs starting from free trade causes the northern relative wage to increase (locally) if the North has greater purchasing power than the South ($\eta_N > 1$). Hence it has been established

THEOREM 4. *In the neighborhood of free trade, a permanent decrease in trade costs ($\tau \downarrow$) permanently decreases the northern relative wage ($w_N \downarrow$) if the North is larger than the South in terms of purchasing power ($c_N L_{Nt} > c_S L_{St}$) and permanently increases the northern relative wage if the North is smaller than the South in terms of purchasing power ($c_N L_{Nt} < c_S L_{St}$).*

As trade costs are reduced, the price paid by foreign consumers decrease. Greater export sales for firms in both regions then increase the demand for production labor as well. On the other hand, northern and southern firms face tougher competition in their domestic markets lowering the demand for production labor. In the neighborhood of free trade, the "competition-effect" dominates the "export-effect" for the larger of the two regions, while the opposite is true for the smaller region. The shift in labor demand from the large to the small region implies that the relative wage of the large region decreases. Assuming that the North has a greater purchasing power than the South, the northern relative wage decreases.

The implications of stronger protection of IPR are similar to those of the literature emphasizing the negative impact on rates of innovation and imitation such as Grossman and Helpman (1991a), Glass and Saggi (2002), Sener (2006), and Dinopoulos and Segerstrom (2006). The so-called "wide-gap case"[12] of the Grossman and Helpman

[12] This is the case most closely related to the model presented in this paper, where northern and southern firms use unconstrained monopoly pricing.

(1991a) variety-expansion model and the Glass and Saggi (2002) quality-ladders model yield predictions that are similar to the ones found in this model.

In another paper, Lai (1998) also finds that when imitation is the channel of technological transfer, stronger protection of IPR decreases the incentives to innovate and hence imply a lower steady-state rate of innovation. Assuming instead that foreign direct investment is the channel of technology transfer, the opposite holds: stronger protection of IPR promotes innovation growth. Lai (1998) also analyzes the role of simultaneous Foreign Direct Investment and (exogenous) imitation. In this case, the magnitude of the rate of multinationalization (voluntary technology transfers from the North to the South) turns out to be crucial in determining whether innovation growth is promoted or retarded. Moreover, modelling licensing as the channel of technology transfer, Yang & Maskus (2001) find that the rate of innovation increases as IPR protection is strengthened. Hence, the basic fact that imitation is just one channel of technology transfers out of several should be kept in mind when interpreting the results of the model.

The model in this paper differs from all these papers as public policy changes have temporary effects on the rate of innovation rather than permanent. In contrast, the quality-ladders models in Dinopoulos and Segerstrom (2006) and Sener (2006) predict innovation growth to be scale-invariant and the effects are similar to this paper. Whereas Dinopoulos and Segerstrom (2006) mirrors the comparative static results found in the variety-expansion model, the model in Sener (2006), where innovators are assumed to engage in rent protection to deter potential competitors from innovation and imitation, predicts that stronger protection of IPR has a permanent negative effect on innovation growth.

Since the model contains policy-independent steady-state economic growth rates, long-run welfare effects can be determined by comparing individual utility levels for steady-state equilibria with different policy parameter values. Note that from (3.10) and (3.11) that welfare effects can be understood by considering effects on the income of consumers (through individual consumer expenditures given by (3.7) and (3.8)) and effects on the northern and southern price indices P_{Nt} and P_{St}. First, the long-run welfare effects of a larger southern region and stronger IPR protection are studied.

From Theorem 1, an increase in the size of the southern population ($L_{S0} \uparrow$) increases the rate of imitation μ and relative R&D difficulty z_N and decreases the share of varieties produced in the North γ_N. Considering (3.5) this implies that an increase in the rate of imitation μ requires $z_N\gamma_N$ to decrease. An increase in the size of the South was also shown to decrease the northern relative wage according to Theorem 3. Hence the northern consumer expenditure in (3.7) must decrease. To pin down the effect on the northern price index it can first be noted that, in the case of free trade, a common price index for both regions can be written as

$$P_t \equiv P_{Nt} = P_{St} = \left(\frac{\sigma - 1}{\sigma}\right) m_t \left[\gamma_N w_N^{1-\sigma} + \gamma_S\right]^{\frac{1}{\sigma-1}}.$$

An increase in the rate of imitation implies that γ_S increases while γ_N decreases. As $w_N^{1-\sigma} < 1$, the increase in γ_S must dominate the decrease in γ_N even after considering that $w_N^{1-\sigma}$ increases as the size of the South increases. Furthermore, an increase in $z_N = \frac{m_t^{1-\phi}}{L_{Nt}}$ implies that m_t must increase for all future t, since the northern population grows at the positive rate n and $\phi < 1$. Hence, the effect on the common price index must be positive. Taking both consumer expenditure and the price index into account, an increase in the size of the South then has an ambiguous effect on long-run northern consumer welfare.

Southern consumers are also affected by an increase in the size of the southern region. From (3.6), an increase in the size of the southern population necessarily leaves the term $z_N \frac{L_{N0}}{L_{S0}} \gamma_S$ unaffected. Hence, the southern consumer expenditure in (3.8) is not affected by a larger southern region. As the price index for consumers in both regions was shown to increase, it has been established

THEOREM 5. *An increase in the size of the South ($L_{S0} \uparrow$) has an ambiguous effect on the long-run welfare of northern consumers ($u_N \uparrow$ or $u_N \downarrow$) while it increases the long-run welfare of southern consumers ($u_S \uparrow$).*

Northern consumers are better off as a larger southern region causes varieties to be cheaper but also suffer from a lower wage rate and lower returns to firm ownership, leaving the net long-run welfare effect ambiguous. Southern consumers benefit from a larger southern region simply because they are only experiencing lower prices while their income remains unchanged.

Turning to the long-run welfare implications of stronger IPR protection ($a_I \uparrow$), it has been established in Theorem 1 that stronger IPR protection decreases the rate of imitation μ, the relative R&D difficulty z_N and the share of varieties produced in the South γ_S. From (3.5), a decrease in the rate of imitation μ requires $z_N \gamma_N$ to increase. Furthermore, as Theorem 3 showed that stronger IPR protection also increases the northern relative wage, the northern consumer expenditure in (3.7) increases. Stronger protection of IPR is also associated with a decrease in $z_N = \frac{m_t^{1-\phi}}{L_{Nt}}$ which implies that m_t must decrease for all future t, since the northern population grows at the positive rate n and $\phi < 1$. Hence, using that $w_N^{1-\sigma} < 1$, the decrease in γ_S must dominate the increase in γ_N, decreasing the common price index, also having taken into account that

$w_N^{1-\sigma}$ decreases as imitation gets harder. Considering these effects on expenditures and prices, the net long-run welfare effect is once again ambiguous for northern consumers.

Similarly, from (3.6) it is clear that stronger IPR protection ($a_I \uparrow$) requires the term $a_I z_N \frac{L_{N0}}{L_{S0}} \gamma_S$ to remain unchanged. Hence, the southern consumer expenditure in (3.8) is unaffected. As stronger IPR protection decreases the common price index, it has been established

THEOREM 6. *Stronger IPR protection ($a_I \uparrow$) has an ambiguous effect on the long-run welfare of northern consumers ($u_N \uparrow$ or $u_N \downarrow$) while it reduces the long-run welfare of southern consumers ($u_S \downarrow$).*

Stronger IPR protection has a negative impact on prices, making varieties more expensive. At the same time, the northern relative wage increases, causing the overall long-run welfare effect of northern consumers to be ambiguous. Meanwhile, southern consumers do not experience any effect on their income, but suffer from higher variety prices.

Finally, let's consider what would happen with long-run welfare of northern and southern consumers if trade costs are marginally reduced for an economy where trade costs are close to zero (τ close to 1). From (3.10) it is clear that the steady-state utility level of a northern consumer, is positively related to the term $\frac{w_N}{\tau}$. Using (4.2) yields

$$\frac{\delta\left(\frac{w_N}{\tau}\right)}{\delta\tau}|_{\tau=1} = w_N\left(\left(\frac{\sigma-1}{\sigma}\right)\left(\frac{\eta_N-1}{\eta_N+1}\right)-1\right) < 0 \text{ for all } \eta_N > 0.$$

Thus, increasing trade costs decreases the utility of a representative northern consumer.

Similarly, from (3.11), the steady-state utility level of southern consumers is negatively related to the term $w_N\tau$. From (4.2) this term is affected by τ according to

$$\frac{\delta\left(w_N\tau\right)}{\delta\tau}|_{\tau=1} = w_N\left(\left(\frac{\sigma-1}{\sigma}\right)\left(\frac{\eta_N-1}{\eta_N+1}\right)+1\right) > 0 \text{ for all } \eta_N > 0.$$

which implies that higher trade costs hurt the representative southern consumer as well. Thus, it has been established

THEOREM 7. *In the neighborhood of free trade, a permanent decrease in trade costs ($\tau \downarrow$) increase the long-run welfare of northern and southern consumers ($u_N \uparrow$ and $u_S \uparrow$).*

When the world economy (excluding autarkies) is in the neighborhood of free trade, lower trade costs are associated with long-run benefits for consumers in both regions. Consumers benefit because the lower prices they face due to lower trade costs outweigh the negative impact that lower trade costs have on their wage incomes.

5. Concluding remarks

This paper investigates how different public policies associated with the international integration of product markets affect the product cycle, economic growth and the North-South wage-gap. A model of North-South trade and scale-invariant technological change is developed, building on Grossman and Helpman's variety-expansion model of endogenous product cycles. In the model, rates of innovation and imitation as well as the North-South wage differential are all endogenously determined. Growth is scale- and policy-invariant as the long-run rate of innovation is determined by the growth rate of R&D employment and the strength of intertemporal knowledge spillovers. In general, public policies nevertheless affect citizens by promoting or retarding innovation- and economic growth during transitions between different steady-state equilibria.

Turning to specific policies, comparative static effects related to the product cycle are stated in Theorem 1. The decision of a less-developed country to step out of autarky enhances innovation growth in the short run, while it permanently increases the rate of imitation. Second, stronger protection of Intellectual Property Rights is found to have the opposite effects as it harms innovation growth in the short run and permanently lowers the rate of imitation. Finally a change in the level of trade costs leaves rates of innovation and imitation unaffected. Considering the North-South wage differential in a free-trading world economy, an increase in the size of the South reduces wage inequality, while stronger IPR protection serves to increase wage inequality (Theorem 3). For the case where the world economy experiences close-to-free trade, lower trade costs reduce the wage inequality as long as the purchasing power of the North is greater than that of the South (Theorem 4). A steady-state welfare analysis of a world economy characterized by free trade shows that southern consumers benefit from a larger South but suffer from stronger IPR protection. These public policy shifts have ambiguous long-run welfare effects for northern consumers (Theorem 5 and 6). However, for the case of close-to-free trade, lower trade costs make both northern and southern consumers better off in the long run, independent of the distribution of purchasing power (Theorem 7).

One way to better understand welfare effects and effects on the North-South wage-differential would be to study this kind of model more carefully using numerical analysis. This is left for future research. Moreover, to be able to stake out desirable directions for policy, one would ideally like to identify and consider potential interactions between different important channels of technological transfer. However, in a general equilibrium framework, such extensions has a tendency to greatly complicate existing models, something which has led researchers to focus on modelling one specific channel of technological transfer at the time. As with most related models, this calls for a careful interpretation of the identified growth-, wage inequality- and long-run welfare effects.

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PAPER 2

North-South Trade, Foreign Direct Investment and Economic Growth

ABSTRACT. This paper aims to shed some light on the determinants of Foreign Direct Investment and how the formation of multinational firms affects the global economy in terms of economic growth and production patterns. To do this a dynamic general equilibrium model of North-South trade with increasing variety and scale-invariant growth is developed. Northern firms do costly R&D to expand the number of available consumer good varieties, while also devoting resources to adapt the production process to southern conditions and thereby benefit from lower costs of production. Endogenous rates of innovation and adaptation are determined as well as the wage differential experienced by Northern and Southern workers. Policies supporting the international integration of product markets are shown to temporarily increase the rate of innovation and permanently increase the rate of adaptation. Whereas a less-developed country's decision to adopt a free trade policy and open up for FDI has no effect on the North-South wage gap in this case, the southern adoption of a FDI-friendly policy serves to reduce this wage-gap.

1. Introduction

The adoption of free trade-oriented policies around the world has been accompanied by a rapid growth in firms acting multinationally, shifting labor-intensive activities to parts of the world where labor is relatively cheap. In developing countries, the inward stock of foreign direct investment (FDI) as a percentage of gross domestic product has increased from 12,4% to 31,4% between 1980 and 2003.[1] Furthermore, by judging from the UNCTAD Inward FDI Performance Index, the ratio of a country's share in global FDI inflows to its share in global GDP, developing countries have on aggregate been relatively more successful at attracting FDI than their developed counterparts during the period 1988-2003.[2] This increase in inward FDI could be of great importance for

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[1] United Nations, UNCTAD. World Investment Report 2004 - The Shift towards Services. Geneva and New York. Annex Table B.6. p. 400.

[2] The UNCTAD Inward FDI Performance Index is a measure of the extent to which host countries receive inward FDI. The Index ranks countries by the amount of FDI they receive relative to their economic size, calculated as the ratio of a country's share in global FDI inflows to its share in global GDP. United Nations, UNCTAD. World Investment Report 2004 - The Shift towards Services. Geneva and New York. p.12.

developing countries as potential benefits include a greater world market presence and access to foreign technology.

Because of the growing economic importance of FDI, this paper is concerned with understanding the formation of multinational firms and the associated shifts in trade- and production patterns. Consequences for economic growth and international wage inequality are also addressed as the incentives to innovate and the wage differential between investor countries and recipients of FDI could be expected to be closely related to international shifts in production and trade.

To study these issues a dynamic general equilibrium model of North-South trade and technological change is developed. In the model, R&D is performed exclusively in the technologically superior North. After successful innovation, which takes the form of an expansion of the number of available consumer good varieties, northern firms compare costs and benefits associated with multinational activity to determine how much resources should be devoted to the transfer of production to the South. The benefits associated with FDI stems from an endogenously determined wage differential between the northern and the southern region, making it attractive to move production to the South to exploit lower labor costs. As in Lai (1998), the process of shifting production to the low-cost South is modelled to be costly, with firms using resources to successfully adapt the production process to the prevalent conditions in the South.[3] A shift in production is associated with a reversal of the direction of trade, having potential implications for international wage inequality.

The model is solved for a steady-state where R&D difficulty can increase or decrease over time depending on whether intertemporal knowledge spillovers in R&D are positive or negative. By allowing for population growth and putting an upper bound on intertemporal knowledge spillovers, this paper combines the modelling framework originally suggested by Romer (1990) and later extended by Grossman and Helpman (1991a) with the influential insights of Jones (1995). In contrast to Gustafsson (2006) where technology is transferred through southern imitation, this paper involves voluntary transfers of technology by multinational firms.

Using the described theory, a comparative static analysis is performed to look at the consequences of two specific policy changes supporting the international integration of product markets. Apart from examining the effects associated with an additional less-developed country deciding to adopt a free trade policy, the southern adoption of a "FDI-friendly" policy is analyzed.

[3] One could also think of this as the standardization phase of the production process envisaged by Vernon (1966).

While both of these policies have similar positive permanent effects on the rate of adaptation, they are also shown to promote economic growth. The growth effect is however temporary as the high growth rates are shown to reduce incentives to innovate by affecting the market share of firms as well as R&D difficulty. This implies a gradual return to a long-run growth rate determined by population growth and the strength of intertemporal knowledge spillovers. Apart from affecting the speed of production shifts and rates of innovation and economic growth, the discussed policies have consequences for international income convergence.

An increase in the number of less-developed countries adopting free trade policies is shown to have no effect on the North-South wage-gap. Hence transferring technology and production to the South through FDI does not per se contribute to international income convergence. This can be compared to the corresponding result found in Gustafsson (2006) where imitation is the channel of technology transfer. In that case, successful southern imitation reduces the wage-gap by driving a northern innovator out of the market to create profits for the southern firm. The reason for the difference in results is that when northern FDI is the channel of technology transfer, a larger South implies that northern firms earn additional profits as technology and production are transferred to the South. These profits are however cancelled out by the adaptation cost incurred to initiate the technology transfer. As there is no change in the profitability of production in the North or the South, the North-South wage-gap remains unaffected. Hence, the consequences for international income convergence look very different when technology transfer is voluntary and when it's not. This does however not mean that policy-induced income convergence is out of reach when FDI is the primary channel of technology transfers. By adopting policies that simplify the establishment of multinational firms, southern decision makers are shown to have the possibility of reducing the North-South wage-gap.

Apart from this paper, several attempts have been made to formalize the so-called Product cycle, originally suggested in the seminal work by Vernon (1966). According to the "product cycle hypothesis" relatively well developed R&D capabilities ensure that the development of new products occurs in the North. Northern firms then take measures to standardize the product making a transfer of the production to the low-cost South possible. The transfer of technology is followed by a shift in production, reversing the pattern of trade.

Krugman (1979) was the first paper to formalize these ideas but focused more on explaining changes in trade and relative wages, not modelling innovation or the transfer of technology. In two separate papers Grossman and Helpman (1991a,b) endogenized innovation and technology transfer and thereby made it possible to study growth-related public policy issues such as R&D subsidies and international intellectual property rights within the North-South model framework. In their models the North does costly R&D to innovate while the rate of technological transfer is determined not by FDI, but by costly southern efforts to imitate northern products. The two papers by Grossman and Helpman (1991a,b) differed primarily in that innovation was modelled either as an expansion of the available number of consumption good varieties (variety-expansion model) suggested by Romer (1990) or a quality improvement on an existing good (quality-ladder model) building on the closed-economy analysis in Grossman and Helpman (1991c). It can be noted that the quality-ladder framework generates a product cycle where trade is reversed between the North and South every time a quality improvement of a good occurs. Considering that Vernon (1966) does not discuss a regular reversal of international trade patterns, the variety-expansion framework appears to be somewhat more closely related to the original product cycle hypothesis in this aspect.

Instead of modelling southern imitation, several papers have studied models more in line with Vernon's original argument, where northern FDI is the channel through which technology is transferred. While the model by Feenstra & Hanson (1995) is concerned with factor endowment-driven FDI, this paper models FDI as being driven by differences in technology. This work thereby follows several other papers including variety-expansion models such as Helpman (1993), Lai (1998) and quality-ladder models such as Glass and Saggi (2001, 2002) and Dinopoulos and Segerstrom (2005). This paper is closely related to Lai (1998) but departs from the analysis in Lai (1998) in two important respects. Lai includes an exogenously determined rate of imitation to analyze policies related to intellectual property rights, something which could be done for this paper as well. More importantly though, the model in Lai (1998) has a setback in that it restricts intertemporal knowledge spillovers to be quite strong. This assumption about the strength of intertemporal knowledge spillovers is common for all first-generation endogenous growth models and implies that these models exhibit a so-called scale property. This property was first discussed by Jones (1995) in a closed economy analysis. Jones argued that the common prediction of these models that any increase in the amount of labor devoted to R&D gives rise to an increase in the long-run rate of innovation is at odds with existing empirical evidence. Following Jones (1995), the introduction of population growth and an upper bound on intertemporal knowledge spillovers in the Grossman and Helpman (1991a) variety-expansion model eliminates this undesirable property. It can also be noted that the two papers by Grossman and Helpman (1991ab) that use different innovation frameworks generate quite different results regarding growth and the North-South wage-gap. This further motivates a careful examination of the consequences of modelling scale-invariant growth in the presence of multinational firms in a variety-expansion setting.

The second section describes a scale-invariant dynamic general equilibrium model of North-South trade and technological change where multinational firms are responsible for the technology transfer between the regions. Conditions capturing innovation- and adaptation incentives are derived as well as conditions describing the labor markets of the two regions. This is followed by a section devoted to solving the model and determining the unique steady-state equilibrium. Section four contains a discussion of the main features of the model and the last section concludes.

2. The model

2.1. Economic environment. The economic environment is described by a continuum of industries $\omega \in [0, m_t]$ located in the North or in the South (through multinationals) producing consumer good varieties. The two regions trade consumer good varieties freely. To extend the amount of varieties available to world consumers, northern firms engage in innovative R&D. As the costs of production is lower in the southern region, northern firms also find it profitable to devote resources to move production (and the associated technological know-how) to the South through adaptation. Labor is the only physical input needed for successful innovation, adaptation and production. Both regions are assumed to have perfectly competitive labor markets where labor is inelastically supplied. Furthermore, labor is immobile between regions but can move freely between activities within regions. The FDI-driven product cycle is illustrated in Figure 1.

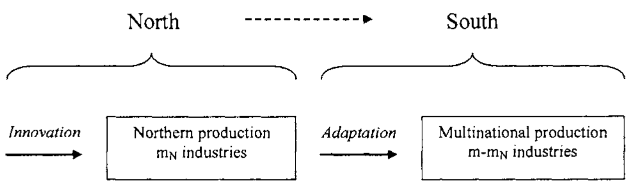

Figure 1. The FDI-driven product cycl

2.2. Households. A household is located either in the North or in the South and grows exponentially larger over time at the exogenous population growth rate $n > 0$.

Each household consists of infinitely lived individuals who inelastically supply a unit of labor each. Hence,

$$L_t = L_{Nt} + L_{St}$$

where the labor supply in each region is given by

$$L_{Nt} = L_{N0}e^{nt} \text{ and } L_{St} = L_{S0}e^{nt}.$$

Each unit of northern labor supply is paid the wage rate w_N whereas the corresponding compensation for a southern worker is w_S. Households in the world economy all have identical preferences and their welfare is given by the discounted flow of utility

$$U = \int_0^\infty e^{-(\rho-n)t} \ln [u_t] \, dt \tag{2.1}$$

where $\rho > n$ is the subjective discount rate and u_t is the instantaneous utility of an individual at time period t. The individual utility is assumed to be represented by the C.E.S. aggregate of the number of varieties available on the market $m_t = m_{Nt} + m_{Mt}$, produced either in the North (m_{Nt}) or by a multinational firm in the South (m_{Mt}):

$$u_t = \left[\int_0^{m_t} x_t (\omega)^\alpha \, d\omega \right]^{\frac{1}{\alpha}} \qquad 0 < \alpha < 1. \tag{2.2}$$

$x_t(\omega)$ is the per capita demanded quantity of a differentiated product in industry ω at time t. As varieties are assumed to be substitutes, the parameter α measures the degree of product differentiation, implying a constant elasticity of substitution $\sigma = \frac{1}{1-\alpha} > 1$. The optimization across industries yields the familiar variety demand function

$$x_t(\omega) = \frac{p_t(\omega)^{-\sigma}}{P_t} c_t \tag{2.3}$$

where

$$P_t = \int_0^{m_t} p_t(\omega)^{1-\sigma} \, d\omega$$

is a price index measuring the general price level of available varieties. $p_t(\omega)$ and c_t represent the price of a variety and the individual consumer expenditure at time t. As consumers take prices and the number of available varieties as given, dynamic optimization implies that individual consumption growth is determined by the Euler condition

$$\frac{\dot{c}_t}{c_t} = r_t - \rho, \tag{2.4}$$

that is, the rate of consumption growth increases when the market interest rate r_t exceeds the subjective discount rate ρ.

2.3. Product markets. Regions are endowed with a single primary factor, labor. For simplicity it is assumed that the production of any variety requires one unit of labor per unit of output. As southern labor is treated as the numeraire throughout the model, the northern and the southern marginal costs of production for the domestic and foreign markets are w_{Nt} and $w_{St} = 1$. Wages in both regions are determined in perfectly competitive labor markets. The model will be solved for a steady-state equilibrium where a complete transfer of production to the South is beneficial. This implies that parameters of the model must ensure that the endogenously determined North-South wage-gap satisfies

$$w_{Nt} > w_{St} = 1,$$

that is, the northern marginal cost exceeds the southern marginal cost.

It is further assumed that a variety can only be adapted by its innovator as the innovator enjoys a sufficient productivity advantage in adapting his variety to deter any other northern producer from trying to adapt the variety.[4] Each industry then consists of one producing firm which implies that northern and multinational producers earn monopoly profits. As there exists a continuum of firms, the prices of other firms products and the level of aggregate spending are taken as given when firms maximize profits.

If superscript denotes producer type (northern producer (N) or multinational producer in the South (M)), the world price that maximizes northern profits is

$$p_t^N = \frac{\sigma}{\sigma - 1} w_{Nt}$$

whereas a multinational firm charges

$$p_t^M = \frac{\sigma}{\sigma - 1}.$$

Prices reflect the common mark up of price over marginal cost induced by the assumed preference structure. Substituting for prices a northern firm earns the profit

$$\pi_t^N = \left(\frac{1}{\sigma - 1}\right) w_{Nt} \overline{x}_t^N L_t \tag{2.5}$$

where the per capita world demand for a northern variety is given by

$$\overline{x}_t^N \equiv \frac{\left(p_t^N\right)^{-\sigma} \overline{c}_t}{P_t} \tag{2.6}$$

[4] Alternatively this assumption could be stated in terms of having sufficient patent protection to stop any other firm from trying to adapt an already patented variety.

and $\overline{c}_t = \frac{c_{Nt}L_{Nt}+c_{St}L_{St}}{L_t}$ denotes the per capita world consumer expenditure at time t.

Similarly, the profit earned by owners of a multinational firm is

$$\pi_t^M = \left(\frac{1}{\sigma - 1}\right) \overline{x}_t^M L_t \tag{2.7}$$

where

$$\overline{x}_t^M \equiv \frac{\left(p_t^M\right)^{-\sigma} \overline{c}_t}{P_t} \tag{2.8}$$

denotes the world per capita demand for a southern variety. Hence per capita variety demands and firm profits increases in consumer expenditures.

2.4. Innovation and adaptation. To produce and sell a northern variety, resources first have to be devoted to the innovation of a variety. Apart from making market entry possible, successful innovative R&D is also the source of an externality. Every new innovation contributes to the stock of knowledge used for future innovation and adaptation but firms cannot appropriate the value of the (positive or negative) intertemporal knowledge spillover the new innovation generates.

Assuming that the disembodied stock of knowledge is proportional to the number of existing innovations and making the appropriate choice of units, the stock of knowledge used in innovation and adaptation is given by the total number of varieties m_t. To innovate and develop a new product variety, a representative northern firm j must then devote $\frac{a_D}{m_t^\phi}$ units of labor to innovation where a_D is a measure of the fixed innovation productivity and intertemporal knowledge spillovers are captured by the parameter ϕ.

The rate at which a northern firm j discovers new products evolves according to

$$\dot{m}_{jt} = \frac{l_{Djt}}{\frac{a_D}{m_t^\phi}} = m_t^\phi \frac{l_{Djt}}{a_D}$$

where $\dot{m}_{jt}$ is the time derivative of m_{jt} and l_{Djt} is the labor used in innovative activities by firm j. Considering all firms where innovative R&D takes place, the aggregate number of innovations evolves according to

$$\dot{m}_t = m_t^\phi \frac{L_{Dt}}{a_D} \tag{2.9}$$

where $\dot{m}_t$ is the time derivative of m_t and $L_{Dt} = \sum_j l_{Djt}$ is the total amount of northern labor employed in innovative activities.

Apart from innovative R&D, northern firms also devote resources to adapt varieties to southern production conditions to benefit from lower costs of production. Successful adaptation results in a complete transfer of knowledge and production to the South. As the stock of knowledge available to labor employed in adaptation is m_t, a northern firm k must devote $\frac{a_M}{m_t^\phi}$ units of southern labor to successfully adapt a variety. a_M is a measure of the fixed adaptation productivity but could also be interpreted as a parameter measuring the "friendliness" of southern FDI-related policies. A recipient economy where "FDI-friendly" policies have been adopted would then correspond to multinational firms experiencing a relatively low value of a_M, so that successful adaptation requires relatively less resources. The number of varieties that have been successfully adapted by firm k must then grow over time according to

$$\dot{m}_{Mkt} = \frac{l_{Mkt}}{\frac{a_M}{m_t^\phi}} = m_t^\phi \frac{l_{Mkt}}{a_M}$$

where l_{Mkt} is the southern labor used in adaptive activities by firm k at time t. The aggregate number of adapted varieties changes according to

$$\dot{m}_{Mt} = m_t^\phi \frac{L_{Mt}}{a_M} \tag{2.10}$$

where $\dot{m}_{Mt}$ is the time derivative of m_{Mt} and $L_{Mt} = \sum_k l_{Mkt}$ is the total amount of southern labor employed in adaptation activities.

At this stage it might be of interest to compare this model to the corresponding scale-invariant quality-ladder model in Dinopoulos and Segerstrom (2005). In their model, R&D difficulty necessarily increases over time to rule out explosive growth. In this model this would correspond to the case where $\phi < 0$. In contrast, a variety-expansion model with an amount of industries increasing over time does not need this specific assumption, but will be shown to generate a unique steady-state equilibrium provided intertemporal knowledge spillovers are bounded from above to satisfy $\phi < 1$. For this reason an economy where $0 < \phi < 1$, that is, where R&D difficulty decreases over time, could a priori be expected to exhibit quite different properties compared to an economy experiencing $\phi < 0$.

2.5. R&D incentives. Having successfully innovated a variety, a representative northern firm holding a blueprint on a non-adapted variety earns the profit $\pi_t^N dt$ during the time interval dt. Hiring southern labor at a cost of L_{Mt}, the firm will succeed in adaptation during such an interval with probability $\dot{m}_{Mt}dt$.[5] Successful adaptation implies that owners of the firm earn higher discounted profits, $V_{Mt} - V_{Nt} > 0$, where V_{Mt} and V_{Nt} are the expected discounted profits of a multinational and a northern firm. On the other hand, if a firm is unsuccessful in adapting the variety, owners instead receive the capital gain/loss $\dot{V}_{Nt}dt$ where $\dot{V}_{Nt}$ measures the change over time in the value of a northern firm.

[5] Note that R&D in this model is deterministic in the sense that successful innovation and adaptation is guaranteed once a sufficient amount of resources has been devoted to these activities.

Entry into innovation is financed by an equity offering. Ruling out any arbitrage opportunities for investors then implies that the total expected return on shares in a northern firm must equal the opportunity cost of invested capital, that is, the risk-free market interest rate r_t. Hence no arbitrage ensures

$$\left(\pi_t^N - L_{Mt}\right) dt + \dot{m}_{Mt} dt \left(V_{Mt} - V_{Nt}\right) + \left(1 - \dot{m}_{Mt} dt\right) \dot{V}_{Nt} dt = r_t V_{Nt} dt.$$

In equilibrium, the present discounted value of northern profits must exactly equal the cost of innovation. To see why, suppose that innovation would offer positive profits implying that $V_{Nt} > w_{Nt} \frac{a_D}{m_t^\phi}$. The resulting excess demand for northern labor would have to be met by an increase in the northern wage, eliminating the excess demand and the profits from innovation. Thus, zero profits imply that

$$V_{Nt} = w_{Nt} \frac{a_D}{m_t^\phi}. \tag{2.11}$$

Similar to innovation, if adaptation would offer positive profits, excess demand would push up the southern wage to eliminate profits. The present discounted value of profits associated with successful adaptation must therefore satisfy

$$V_{Mt} - V_{Nt} = \frac{a_M}{m_t^\phi}. \tag{2.12}$$

Dividing both sides of the no-arbitrage condition by $V_{Nt} dt$ and letting $dt \to 0$ then yields

$$\frac{\pi_t^N - L_{Mt}}{V_{Nt}} + \dot{m}_{Mt} \frac{\left(V_{Mt} - V_{Nt}\right)}{V_{Nt}} + \frac{\dot{V}_{Nt}}{V_{Nt}} = r_t.$$

Furthermore, log-differentiating (2.11) and noting that $\dot{m}_{Mt} \left(V_{Mt} - V_{Nt}\right) = L_{Mt}$ having used (2.10) and (2.12), the northern no-arbitrage condition can be written as

$$\frac{\pi_t^N}{r_t + \phi \frac{\dot{m}_t}{m_t}} = w_{Nt} \frac{a_D}{m_t^\phi}. \tag{2.13}$$

The left-hand-side is the profit of a northern firm discounted at the appropriate rate, considering the rate of capital gains/losses. The right-hand-side simply reflects the cost of innovation.

Once a firm has successfully adapted the production process of its northern variety, production shifts to the South and the multinational firm earns an infinite stream of monopoly profits. Owners of the multinational firm collect the profit $\pi_t^M dt$ in a time interval of length dt and realize a capital gain of $\dot{V}_{Mt} dt$, where $\dot{V}_{Mt}$ is the time derivative of the value of a multinational firm. With deterministic adaptation, no arbitrage opportunities ensure that the total expected return on multinational equity claims must equal the opportunity cost r_t of invested capital;

$$\pi_t^M dt + \dot{V}_{Mt} dt = r_t V_{Mt} dt.$$

Dividing by $V_{Mt}dt$ and using (2.11) to log-differentiate (2.12), the multinational no-arbitrage condition can be expressed as

$$\frac{\pi_t^M}{r_t + \phi\frac{\dot{m}_t}{m_t}} - w_{Nt}\frac{a_D}{m_t^\phi} = \frac{a_M}{m_t^\phi} \tag{2.14}$$

where the left-hand-side is the discounted profit of a multinational firm deducting the initial cost of innovation while the right-hand-side is the cost of adaptation.

2.6. Labor market clearing. Considering first the northern labor market, northern workers can move without friction between innovation and production of northern varieties with wages instantaneously adjusting to make labor supply equal labor demand. Successful innovation requires $\frac{a_D}{m_t^\phi}$ units of labor and it can be noted that the labor necessary to maintain a certain rate of innovation changes over time due to intertemporal knowledge spillovers. Labor used to produce a variety for the world market is $\overline{x}_t^N L_t$ per northern firm. Full employment of the northern labor force L_{Nt} thus requires

$$L_{Nt} = \frac{a_D}{m_t^\phi}\dot{m}_t + X_t^N L_t \tag{2.15}$$

where $X_t^N \equiv \overline{x}_t^N m_{Nt}$ is the per capita world demand for all northern varieties.

The corresponding condition for the South is found by noting that southern labor L_{St} is employed in either adaptation or the production of multinational varieties. Adaptation requires $\frac{a_M}{m_t^\phi}$ units of labor and for $\phi > 0$ ($\phi < 0$) the labor necessary to adapt decreases (increases) as the amount of existing varieties, and thus knowledge, increases. Labor used to produce a variety for the world market is $\overline{x}_t^M L_t$ per multinational firm. With free movement between activities and full employment, the southern labor market is described by

$$L_{St} = \frac{a_M}{m_t^\phi}\dot{m}_{Mt} + X_t^M L_t \tag{2.16}$$

where $X_t^M \equiv \overline{x}_t^M m_{Mt}$ is the per capita world demand for varieties produced by multinational firms.

This completes the description of the model.

3. Solving the model

The model is solved for a unique steady-state equilibrium where all endogenous variables grow over time at constant (but not necessarily identical) rates. In each region one condition was found by assuming no arbitrage opportunities on the stock market and another was found by assuming labor market clearing. These four conditions can be narrowed down to three conditions determining the three unknowns; the rate of adaptation ν, the relative R&D difficulty (which remains to be defined) and the North-South wage differential w_N. By carefully studying these conditions, the main properties of the model can be identified.

To solve the model, it is first noted that, by the definition of a steady-state equilibrium, the market interest rate must be constant according to (2.4). As southern labor is used as the numeraire of the model, wages, prices and per capita consumer expenditures are constant as well. Furthermore, as the labor supply in each of the regions grows at the rate $n > 0$ and are divided between production and R&D (adaptation in the South), the steady-state amount of workers in innovative- and adaptive R&D must grow at the rate n as well. Using this information and also denoting the steady-state rate of innovation $g \equiv \frac{\dot{m}_t}{m_t}$, (2.9) can be used to obtain

$$g = \frac{m_t^{\phi-1} L_{Dt}}{a_D}$$

which is constant if

$$g = \frac{n}{1-\phi}. \tag{3.1}$$

Hence, the steady-state rate of innovation is scale-invariant as in Jones (1995).

Next, to derive steady-state conditions governing R&D incentives, a variable capturing the concept of relative R&D difficulty is introduced. To construct this variable, $m_t^{-\phi}$ is understood as the R&D difficulty of the economy whereas $\frac{L_{Nt}}{m_t}$ is seen as a measure of the northern market share of a variety. By taking the ratio of R&D difficulty and the northern market share of a variety[6], relative R&D difficulty is defined as

$$z_{Nt} \equiv \frac{m_t^{-\phi}}{\frac{L_{Nt}}{m_t}} = \frac{m_t^{1-\phi}}{L_{Nt}} \tag{3.2}$$

[6] The relative R&D difficulty-state variable is defined to relate to the size of the northern region in order to isolate comparative static effects from changing the steady-state size of the South. If relative R&D difficulty instead had been defined to relate to the world or the South, changing the size of the South would cause a jump in the chosen state variable, making the comparative static analysis less tractable.

which is constant in steady-state.[7]

First, it can be noted that the absolute measure of R&D difficulty increases if $\phi < 0$ and decreases if $0 < \phi < 1$. From (3.1) it is clear that, in an economy experiencing R&D difficulty increasing over time ($\phi < 0$) the northern market share of a variety increases over time since population growth is higher than innovation growth. For an economy experiencing R&D difficulty decreasing over time ($0 < \phi < 1$), the northern market share instead decreases over time as innovation growth exceeds population growth. In steady-state, the changes in R&D difficulty and the northern market share perfectly outweigh each other, leaving the relative R&D difficulty z_N constant.

The relative R&D difficulty z_N plays an equilibrating role as it ensures zero expected profits from developing and producing a variety. A faster- or slower-than-steady-state growth of m_t affects both R&D difficulty and the northern market share of a variety. This can be contrasted to the role that the rate of innovation plays in a scale-variant model such as the one in Grossman and Helpman (1991a). In their model, policy-induced increases in the rate of innovation permanently decrease the market shares of firms to ensure zero expected profits from innovation. In static trade models the corresponding variable is the number of varieties. The number of varieties introduced in the economy increases until the ex ante benefit of introducing a new variety is zero.

To more clearly see how the northern market share is related to the rewards to innovation and adaptation, (2.5)-(2.8) can be used to rewrite the northern and multinational profits as

$$\pi_t^i = \left(\frac{1}{\sigma - 1}\right) w_i \Phi_i \frac{L_0}{L_{N0}} \frac{L_{Nt}}{m_t}, \; i = N, M$$

where

$$\Phi_i \equiv \left(\frac{\sigma - 1}{\sigma}\right) \left(\frac{w_i^{-\sigma}}{\gamma_{Nt} w_N^{1-\sigma} + \gamma_{Mt}}\right) \bar{c}, \; i = N, M.$$

$0 \leq \gamma_N \equiv \frac{m_{Nt}}{m_t} \leq 1$ and $0 \leq \gamma_M \equiv \frac{m_{Mt}}{m_t} \leq 1$ denote the shares of all varieties produced by northern and multinational firms and are necessarily constant over time in steady-state. Moreover, by log-differentiating $m_t = m_{Nt} + m_{Mt}$, noting that $g \equiv \frac{\dot{m}_t}{m_t} = \frac{\dot{m}_{Nt}}{m_{Nt}} = \frac{\dot{m}_{Mt}}{m_{Mt}}$ and defining the rate of adaptation as $\nu \equiv \frac{\dot{m}_{Mt}}{m_{Nt}}$, these share can be shown to be given by

$$\gamma_N = \frac{g}{g + \nu}$$

and

$$\gamma_M = \frac{\nu}{g + \nu}.$$

[7] This can be seen by log differentiating (3.2), using (3.1) and noting that the northern population grows at the constant rate n.

As γ_N and γ_M are constant in steady-state Φ_N and Φ_M are constant as well, implying that northern and multinational profits are proportional to the northern market share.

Returning to the model, the northern no-arbitrage condition in (2.13) can be rewritten having substituted for profits and the market interest rate using (2.5) and (2.4). This yields

$$\frac{\left(\frac{1}{\sigma-1}\right) w_N \overline{x}_t^N L_t}{\rho + \phi g} = w_{Nt} \frac{a_D}{m_t^{\phi}}.$$

Using (3.2), noting that $\gamma_N = \frac{g}{g+\nu}$ and solving for a steady-state equilibrium where X^N and z_N are constant over time, the *northern innovation condition* is

$$\frac{\left(\frac{1}{\sigma-1}\right) X^N \left(\frac{g+\nu}{g}\right) L_0}{\rho + \phi g} = a_D z_N L_{N0}. \tag{3.3}$$

The left-hand-side of (3.3) is related to the expected discounted profit associated with northern innovation, whereas the right-hand-side is related to the cost of innovation.

First note that an increase in the relative R&D difficulty ($z \uparrow$) increases the cost of innovation. Second, as $\overline{x}_t^N$ decreases over time due to the expansion of the number of varieties, it does not serve as a good measure of how much the average consumer buys of a specific variety. Noting however that X^N is a measure of the demand for northern varieties in general and that $X^N \left(1 + \frac{\nu}{g}\right) = X^N \frac{m_t}{m_{Nt}}$ is constant in steady-state, changes in X^N can also be seen as representing changes in the demand for a specific northern variety as long as the ratio $\frac{m_t}{m_{Nt}}$ remains constant. Hence we can say that any change in $\frac{m_t}{m_{Nt}}$ reflects how much a representative world consumer spends on a specific northern variety given what is spent on northern varieties in general. Using this interpretation, expected discounted profits are higher when the average world consumer buys more of northern varieties in general ($X^N \uparrow$), when the average world consumer spends more on a specific northern variety ($\frac{1}{\gamma_N} = \frac{m_t}{m_{Nt}} \uparrow$) given X^N and when profits are less heavily discounted ($\rho \downarrow$).

For $\phi > 0$, positive intertemporal knowledge spillovers mean that less labor is needed for successful future innovation. Hence, as the cost of innovation decreases over time the number of firms sharing the northern market grows relatively faster than the amount of northern consumers in steady-state which implies that firms experience capital losses. The opposite is true for $\phi < 0$. Negative spillovers causes the cost of innovation to increase over time with firms experiencing capital gains in steady-state as consumer growth exceeds growth in the number of firms sharing the market.

Turning to the South, the multinational no-arbitrage condition in (2.14) can similarly be rewritten as

$$\frac{\pi_t^M}{\rho + \phi g} - w_{Nt} \frac{a_D}{m_t^{\phi}} = \frac{a_M}{m_t^{\phi}},$$

having substituted for profits and the market interest rate using (2.7) and (2.4). Solving for a steady-state equilibrium where X^M and z_N are constant over time using (3.2) and noting that $\gamma_M = \frac{\nu}{g+\nu}$, the *multinational adaptation condition* is

$$\frac{\left(\frac{1-\alpha}{\alpha}\right) X^M \left(\frac{\nu+g}{\nu}\right) L_0}{\rho + \phi g} - w_{Nt} a_D z_N L_{N0} = a_M z_N L_{N0} \tag{3.4}$$

The left hand side of (3.4) is related to the expected discounted profit associated with adaptation performed by multinationals in the South, whereas the right hand side is related to the cost of adaptation. As in the North, an increase in the relative R&D difficulty ($z_N \uparrow$) increases the cost of adaptation. The discounted profit increase when the average consumer buys more of multinational varieties in general ($X^M \uparrow$), when consumer expenditure on a particular variety, given X^M, increases ($\frac{1}{\gamma_M} = \frac{m_t}{m_{Mt}} \uparrow$) and when profits are less heavily discounted ($\rho \downarrow$).

The innovation-, adaptation- and labor market conditions together pin down the unique steady-state of the model. To further simplify the analysis these four conditions can be combined to yield one steady-state condition for each region and one wage condition determining the three unknowns ν, z_N and w_N.

The first steady-state condition is obtained by rewriting the northern labor market condition (2.15) using (3.2) and then substitute for X^N using the northern innovation condition (3.3). As $\gamma_N = \frac{g}{g+\nu}$ this yields the *northern steady-state condition*

$$a_D z_N g + a_D z_N (\rho + \phi g) \left(\frac{g}{g+\nu}\right) (\sigma - 1) = 1 \tag{3.5}$$

where g is given by (3.1). This condition has a simple interpretation. The first term represents the northern labor devoted to innovation while the second term is the northern labor devoted to production of northern varieties. From (3.5) it is also easy to see that any increase in the rate of adaptation ν requires relative R&D difficulty z_N to increase to keep the left-hand-side of (3.5) constant. Hence the northern steady-state condition could be described by an upward-sloping curve in (z_N, ν) space.[8]

The intuition behind the upward-sloping curve is best understood by considering labor market reallocations. An increase in the rate of adaptation implies that more multinational production takes place in the South, decreasing northern labor employed in production of northern varieties. For the northern labor market to clear the relative R&D difficulty has to increase. An increase in the relative R&D difficulty implies that more labor is required in innovative R&D to maintain the rate of innovation. In addition, for a northern firm to break even at a higher level of R&D difficulty, the

[8] By setting $\nu = 0$ in (3.5) the intercept in (z, ν) space is given by $z = \frac{L_{Nt}}{a_D L_t \left[\frac{\alpha}{1-\alpha}(\phi g + \rho) + g\right]} > 0$.

aggregate demand for northern varieties has to increase, effectively implying that more northern labor is employed in the production of northern varieties. Hence, any increase in the rate of adaptation that decreases the amount of labor employed in the production of northern varieties has to be met by an increase in the relative R&D difficulty which increases northern labor in production and innovative R&D.

Next, the southern steady-state condition is derived by using (3.2) to rewrite the southern labor market condition (2.16) and then substitute for X^M using the multinational adaptation condition (3.4). As $\gamma_M = \frac{\nu}{g+\nu}$, the *multinational steady-state condition* can be expressed as

$$a_M z_N \frac{L_{N0}}{L_0}\left(\frac{\nu}{\nu+g}\right) g + (a_M + w_{Nt}a_D)\, z_N \frac{L_{N0}}{L_{S0}} (\rho + \phi g)\left(\frac{\nu}{\nu+g}\right)(\sigma - 1) = 1 \tag{3.6}$$

where g is given by (3.1). This condition has an interpretation similar to that of the northern steady-state condition. The first term represents the southern labor devoted to adaptation while the second term is the southern labor devoted to the production of multinational varieties. Any increase in the rate of adaptation increases the left-hand-side of (3.6). Hence, z_N has to decrease to restore the equality, implying a downward-sloping multinational steady-state condition.

The intuition is as follows. An increase in the rate of adaptation requires more southern labor to be devoted to adaptation. For the southern labor market to clear, relative R&D difficulty must decrease. This implies that less southern labor is needed in adaptation to maintain the adaptation rate. For southern firms to break even with a lower level of relative R&D difficulty and not make positive profits, the aggregate demand for multinational varieties has to decrease, implying that less southern labor is devoted to multinational production. Hence, any increase in the rate of adaptation that increases the southern labor engaged in adaptation must be followed by a decrease in the relative R&D difficulty, decreasing southern employment in adaptation and multinational production.

Finally, the northern relative wage w_N needs to be determined for the steady-state equilibrium to be fully characterized. Combining the innovation- and adaptation conditions in (3.3) and (3.4) yield

$$\frac{\overline{x}_t^N}{\overline{x}_t^S} = \frac{a_D}{a_M + w_{Nt}a_D}.$$

Substituting for per capita world demands $\overline{x}_t^N$ and $\overline{x}_t^S$ using (2.6) and (2.8) yields the *northern relative wage condition*

$$w_N^\sigma - w_N = \frac{a_M}{a_D} \tag{3.7}$$

which is entirely determined by productivity parameters.

Moreover, to verify the existence of a free-trade steady-state equilibrium with adaptation, a_M and a_D must ensure that $w_N > 1$. If this condition is satisfied, the steady-state adaptation rate ν and the relative R&D difficulty z_N are uniquely determined by the intersection of the northern and the multinational steady-state conditions (3.5) and (3.6), taking into account that the northern relative wage is implicitly given by (3.7). The unique steady-state equilibrium is illustrated in Figure 2.

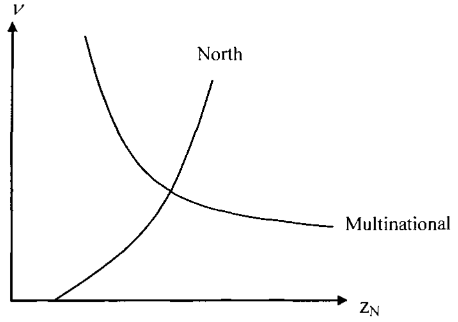

Figure 2. The steady-state equilibrium.

4. Steady-state properties of the model

The steady-state effects from two policy changes are analyzed; (i) a less-developed country adopting a free trade policy and opening up for FDI ($L_{S0} \uparrow$) and (ii) the adoption of a "FDI-friendly" policy in the recipient southern region making northern FDI easier ($a_M \downarrow$). When examining the properties of the model, it is assumed that the North and the South are initially in a steady-state equilibrium determined by (3.5), (3.6) and (3.7) and that at some point in time a policy change ($L_{S0} \uparrow$ or $a_M \downarrow$) takes place.

First, an increase in the size of the South does not affect (3.5) but shifts the multinational curve determined by (3.6) outwards. In the new steady-state, relative R&D difficulty z_N and the rate of adaptation ν have increased to new, higher levels. As an increase in the size of the South does not affect (3.7), the northern relative wage remains unaffected. Thus it has been established

THEOREM 1. *A permanent increase in the size of the South* ($L_{S0} \uparrow$) *leads to a permanent increase in the rate of adaptation* ($\nu \uparrow$), *a temporary increase in the rate of innovation* ($z_N \uparrow$) *but no change in the long-run rate of innovation* $\left(g = \frac{n}{1-\phi}\right)$ *or the North-South wage-differential* (w_N).

An increase in the size of the South implies that more southern labor is devoted to adaptation. Except for increasing the rate of adaptation, more southern consumers also imply a greater world market to which northern firms can sell northern varieties, increasing the incentives to innovate. As northern innovation increases above its steady-state rate, the transition to the new steady-state can take two forms, depending on the evolution of R&D difficulty. For an economy where intertemporal knowledge spillovers are negative ($\phi < 0$), a new innovation not only implies an increase in R&D difficulty, but also a shrinking market share for the northern firms. This increases relative R&D difficulty and reduces the incentive to innovate until the northern rate of innovation has returned to its long-run rate. In an economy where intertemporal knowledge spillovers instead are positive ($\phi > 0$), any innovation implies that the market share of a northern firm decreases relatively faster than the corresponding decrease in R&D difficulty. The incentives to innovate are thus still reduced, decreasing the rate of innovation until the long-run growth rate of innovation is attained.

It is worth noting that, compared to the models where the scale-effect is present, the introduction of positive population growth and the concept of R&D difficulty play crucial roles in altering innovation incentives, ensuring a return to the long-run rate of innovation during the transition between different steady-state equilibria.

Even though there is a permanent change in the speed at which production is transferred from the North to the South, the northern relative wage nevertheless remains unchanged in the new steady-state. An increase in the size of the southern region increases adaptation efforts, speeding up transfers of technology and production from the North to the South. As firms located in the North are the beneficiaries of the voluntary technology transfer and the cost of adaptation exactly offsets the increase in profits due to the transfer of production, the northern relative wage remains unaffected.

Turning to the examination of FDI-policies, a more FDI-friendly policy adopted by southern decision makers does not affect (3.5) but affects (3.6) both through the direct change in a_M but also through its effect on the northern relative wage. Considering that a decrease in a_M decreases the northern relative wage in (3.7), the southern adoption of a more FDI-friendly policy unambiguously shifts the multinational curve given by (3.6) outwards to a steady-state where relative R&D difficulty and the rate of adaptation has reached higher levels. Thus it has been established

THEOREM 2. *The southern adoption of a permanently more FDI-friendly policy* ($a_M \downarrow$) *leads to a permanent increase in the rate of adaptation* ($\nu \uparrow$), *a temporary increase in the rate of innovation* ($z_N \uparrow$), *a permanent decrease in the North-South wage-differential* ($w_N \downarrow$) *but no change in the long-run rate of innovation* $\left(g = \frac{n}{1-\phi}\right)$.

A more FDI-friendly policy makes adaptation less costly and is therefore associated with a higher rate of adaptation. The multinational firms respond by increasing the demand for southern workers willing to produce the adapted multinational variety, bidding up the southern relative wage. This reduces the cost of hiring northern R&D labor, increasing the rate of innovation above its steady-state rate. Successful innovations ensure that the relative R&D difficulty increases to reduce innovator incentives during the transition to the new steady-state.

The comparative static effects from changing L_{S0} and a_M can be seen in Figure 3.

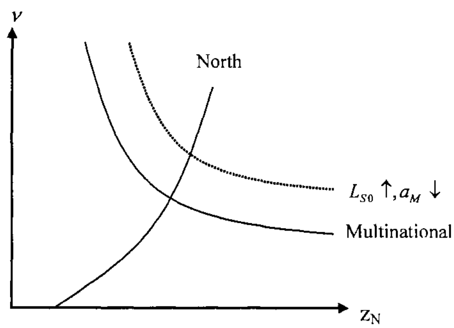

Figure 3. Comparative static effects.

4.1. Variety-expansion and quality-ladders. Having been the two dominant frameworks used for modelling innovation in the North-South trade and growth literature, variety-expansion- and quality-ladder models have often been shown to exhibit different properties, although being structurally similar in several aspects. These differences are particularly evident when comparing the two models developed by Grossman and Helpman (1991a,b). For example, the two models generate different growth- and wage effects from an increase in regional labor resources or stronger protection of intellectual property rights.

Compared to the related quality-ladders model in Dinopoulos and Segerstrom (2005), the variety-expansion framework developed in this paper uses a different definition of R&D difficulty, allowing the model to be solved for a steady-state where R&D difficulty decreases over time. Considering this, there might be a reason to believe that properties of this model will differ from the scale-invariant model developed by Dinopoulos and Segerstrom (2005) where R&D difficulty is assumed to increase over time. In spite of differences in assumptions, the model's implications for the qualitative effects of a larger southern region and FDI-friendly southern policies are however robust to the framework used for modelling innovation. As discussed in Dinopoulos and Segerstrom (2006), the different results found in the two papers by Grossman and Helpman (1991a,b) is explained by the different assumptions made regarding firms price-setting behavior. Whereas firms adopt a limit pricing-strategy in the Grossman and Helpman quality-ladders model they do not in their corresponding variety-expansion model. Limit pricing could be described as firms facing potential competition from the other region (North or South) setting prices just below the marginal cost of potential competitors to deter entry. Modelling firm behavior in this fashion implies that firms who have zero sales exert a dominating influence on pricesetting, which at a first glance seems undesirable. The similarity of results between the two scale-invariant frameworks for modelling innovation should thus in part be explained by the common use of C.E.S. preferences, causing an absence of limit pricing in both this paper and Dinopoulos and Segerstrom (2005).

Whereas the common use of Dixit-Stiglitz preferences remove differences in qualitative results of the model, the difference in assumptions regarding R&D difficulty has an impact on the generality of the model presented in this paper. The Dinopoulos and Segerstrom (2006, 2005) quality-ladder models rely crucially on R&D difficulty growing over time to ensure the existence of a steady-state. The scale-invariant variety-expansion models presented in this paper and Gustafsson (2006) allow R&D difficulty to increase or decrease in steady-state, simply reflecting that intertemporal knowledge spillovers might be positive or negative. As a consequence this model exhibits a somewhat different mechanism governing transitions between steady-states compared to Dinopoulos and Segerstrom (2005). The exact mechanism at work is explained in detail in the section discussing comparative static results of a larger southern region and differs depending on whether intertemporal knowledge spillovers are positive or negative.

In terms of modelling, the scale-invariant variety-expansion framework might appear to require more effort in interpreting some of its key equations. On the other hand, there is a reward of spending time to fully understand the mechanics of the model as the variety-expansion framework has a potential advantage in that it generates similar results as it's quality-ladder counterpart but is mathematically somewhat less complicated. Not having to deal with quality dynamics, the model presented in this paper is bound to be more easily-extended in certain directions.[9]

[9] For example, in the quality-ladder model, industries differ within regions in terms of the quality produced causing demands to be industry-specific. In the variety-expansion model demands are region-specific as varieties do not differ in terms of quality.

5. Concluding remarks

Considering the growing importance and presence of multinationals in the globalized community, a dynamic general equilibrium model of North-South trade have been developed, where multinational firms play a crucial role in voluntarily transferring technology from the developed North to the less-developed South. The model is used to examine how an increase in the size of the South and changes in southern recipient countries attitude towards FDI affect innovation growth, the formation of multinationals and international wage inequality.

The qualitative effects from these southern policies turn out to be similar. Whereas both an increase in the size of the southern region and a FDI-friendly policy increase multinational activity by increasing the rate of adaptation and enhance innovation growth temporarily, the effects on international wage inequality differ. An increase in the size of the South does not affect international wage inequality as the additional profit earned by the northern firm when going multinational is offset by the associated adaptation costs, not altering benefits of adaptation compared to benefits of innovation. In contrast, if southern recipient countries adopt a FDI-friendly policy, adaptation becomes relatively more attractive. This increases the demand for southern labor, pushes up the southern relative wage and thereby decreases the North-South wage inequality.

In removing the scale effect the results in this paper differ from Grossman and Helpman (1991a) and Lai (1998) since policy-induced permanent effects on the rate of innovation in their models become temporary in this model. This property is shared with Dinopoulos and Segerstrom (2005), which generate qualitatively the same predictions as this paper. Due to different modelling assumptions, the steady-state described in Dinopoulos and Segerstrom (2005) relies on R&D difficulty growing over time whereas this model allows for a steady state associated with R&D difficulty increasing or decreasing over time. In addition, the current model is mathematically relatively simple, not having to deal with any quality-dynamics calculations, which is crucial to the models in Dinopoulos and Segerstrom (2005, 2006). This gives the variety-expansion framework a potential advantage when attempting to extend the model in certain directions.

It could also be of interest to compare some of the results to those found in Dinopoulos and Segerstrom (2006) and Gustafsson (2006) where imitation is the channel of technology transfer. Considering an increase in the size of the South, the choice of channel of technology transfer does not matter for growth or the rate at which production shifts to the South, but the reduced North-South wage-gap seen in the models using imitation is not present in the FDI-driven product cycle model. This is explained by the fact that successful imitation reduces the benefits of innovation by shortening the duration of northern profits, whereas the higher rate of adaptation associated with a larger southern region does not alter the rewards of innovation or adaptation.

The modelling framework presented in this paper allows for extensions in several interesting directions. The potential gain from technology transfers in terms of improvements of a recipient country's own R&D capacity is not addressed in this paper. Introducing trade costs complicates the model and any public policy evaluation is likely to involve numerical solutions. This would imply a loss of tractability but a gain in terms of a model environment not relying on the stylized assumption of free trade. Moreover, as the long-run rate of innovation is scale- and policy independent, this strategy could also prove useful in evaluating the long run effects of trade liberalization.

Appendix. Headquarter services

Headquarter services can be introduced into the model by letting the labor necessary to perform headquarter services be given by $L_H = \frac{h}{m^\phi}$, where h is headquarter services at time zero. Hence, with more difficult R&D, reflecting more complex products, more headquarter services is needed for multinational production. The northern labor market condition could then be described by

$$L_{Nt} = \frac{a_D}{m_t^\phi}\dot{m}_t + \frac{h}{m_t^\phi}\dot{m}_t + X_t^N L_t \tag{A.1}$$

where the three terms represent labor in R&D, headquarter services and production of northern varieties. The southern labor market condition is unchanged and is given by

$$L_{St} = \frac{a_M}{m_t^\phi}\dot{m}_{Mt} + X_t^M L_t. \tag{A.2}$$

Since production costs now also involve costs for covering headquarter services, the new innovation and adaptation conditions are given by

$$\frac{\left(\frac{1}{\sigma-1}\right) X^N L_t \left(\frac{g+\nu}{g}\right)}{\rho+\phi g} - \frac{h}{\rho+\phi g} z_N L_{Nt} = a_D z_N L_{Nt} \tag{A.3}$$

and

$$\frac{\left(\frac{1}{\sigma-1}\right) X^M L_t \left(\frac{\nu+g}{\nu}\right)}{\rho+\phi g} - w_N a_D z_N L_{Nt} - w_N \frac{h}{\rho+\phi g} z_N L_{Nt} = a_M z_N L_{Nt}. \tag{A.4}$$

Using (A.3) to substitute for X_t^N in (A.1), the upward-sloping northern steady-state condition can be shown to be given by

$$a_D z_N g + h z_N g + \left(a_D + \frac{h}{\rho+\phi g}\right) z_N (\rho+\phi g)\left(\frac{g}{g+\nu}\right)(\sigma-1) = 1 \tag{A.5}$$

where the first term is the share of labor employed in R&D, the second term is the share of labor in headquarter services and the third term is the share of labor devoted to production of northern varieties. Similarly, using (A.4) to substitute for X_t^M in (A.2), the downward-sloping multinational steady-state condition can be shown to be given by

(A.6)
$$a_M z_N \frac{L_{Nt}}{L_{St}}\left(\frac{\nu}{\nu+g}\right) g + \left(a_M + w_{Nt}\left(a_D + \frac{h}{\rho+\phi g}\right)\right) z_N \frac{L_{Nt}}{L_{St}} (\rho+\phi g)\left(\frac{\nu}{\nu+g}\right)(\sigma-1) = 1$$

where the first term is the share of labor employed in adaptation and the second term is the share of labor devoted to production of multinational varieties. Moreover, by combining (A.3) and (A.4), the northern relative wage can also be shown to be determined by

$$(w_N^{\sigma} - w_N)\left(\frac{h}{\rho + \phi g} + a_D\right) = a_M. \tag{A.7}$$

Hence the unique steady-state equilibrium illustrated in Figure 2 remains valid and the inclusion of headquarter services does not affect the qualitative results presented in the paper.

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PAPER 3

Trade Liberalization and Productivity Growth

ABSTRACT. This paper presents a trade model with firm-level productivity differences and R&D-driven growth. Trade liberalization causes the least productive firms to exit but also slows the development of new products. The overall effect on productivity growth depends on the size of intertemporal knowledge spillovers in R&D. When these spillovers are relatively weak, then trade liberalization promotes productivity growth in the short run and makes consumers better off in the long run. However, when these spillovers are relatively strong, then trade liberalization retards productivity growth in the short run and makes consumers worse off in the long run.

1. Introduction

Empirical research has established that there are large and persistent productivity differences among firms in narrowly defined industries (Bartelsman and Doms 2000). Furthermore, these productivity differences are important for understanding international trade. Even in so-called export sectors, many firms do not export their products and it is the most productive firms that tend to export. Trade liberalization induces the least productive firms to exit and induces more productive non-exporting firms to become exporters, market share reallocations that contribute in a significant way to productivity growth (i.e., Clerides, Lach and Tybout 1998, Bernard and Jensen 1999ab, Aw, Chung and Roberts 2000, Pavcnik 2002; see Tybout 2003 for a survey).

This evidence goes against both old trade theory (the Heckscher-Ohlin and Ricardian trade models) and the so-called new trade theory (Helpman and Krugman 1985). Both classes of trade models have representative firms and assume away any firm-level differences within sectors.

In response to the conflict between old theory and new evidence, a variety of trade models have been developed recently with firm-level productivity differences. Important contributions include Melitz (2003), Bernard, Eaton, Jensen and Kortum (2003), Helpman, Melitz and Yeaple (2004), Melitz and Ottaviano (2005), Yeaple (2005) and Baldwin (2005). These models can account for many of the new firm-level facts and represent significant advances in the theory of international trade. But one thing that

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is missing from all of these models is steady-state productivity growth. For example, in Melitz (2003), trade liberalization causes a permanent increase in productivity but the steady-state rate of productivity growth is zero.

In this paper, we present an improved version of the Melitz (2003) model with steady-state productivity growth. The engine of growth is the introduction of new products, which is modelled in the same way as in Jones (1995b). We find that the main conclusions derived in Melitz (2003) about the effects of trade liberalization on productivity and consumer welfare are not robust. For some parameter values, trade liberalization promotes productivity growth in the short run and makes consumers better off in the long run. But for other parameter values, trade liberalization retards productivity growth in the short run and makes consumers worse off in the long run.

In the model, firms do R&D to develop new products and then learn how costly it is to produce these new products. Once firms have learned what their marginal costs of production are, they decide whether or not to incur the one-time fixed costs of entering the local and foreign markets. The fixed cost of entering the foreign market is assumed to be higher, consistent with the evidence in Roberts and Tybout (1997ab), Bernard and Jensen (2001) and Bernard and Wagner (2001) that potential exporters face significant foreign-market entry costs.

The model has a unique steady-state equilibrium where firms that develop new products with high marginal costs of production immediately exit. Firms that develop new products with intermediate marginal costs incur the fixed cost of entering the local market and only firms with sufficiently low marginal costs choose to also incur the fixed cost of entering the foreign market. Consistent with the empirical evidence, many firms do not export their products and it is the most productive (lowest marginal cost) firms that export in steady-state equilibrium.

We find that trade liberalization always causes the least productive firms to exit, which by itself contributes to productivity growth. In addition, trade liberalization induces the more productive non-exporting firms to incur the fixed cost of entering the foreign market, increases the expected fixed costs of developing profitable new products and causes a temporary slowdown in the development of new products. The overall effect of trade liberalization on productivity growth depends on the size of intertemporal knowledge spillovers in R&D. When these spillovers are relatively weak, then trade liberalization promotes productivity growth in the short run and makes consumers better off in the long run. However, when these spillovers are relatively strong, then trade liberalization retards productivity growth in the short run and makes consumers worse off in the long run.

In another recent paper, Baldwin and Robert-Nicoud (2006) also study the effects of trade liberalization when there are firm-level productivity differences and R&D-driven growth. We build on their analysis but make different assumptions about R&D. Baldwin and Robert-Nicoud study the effects of trade liberalization using first-generation R&D-driven endogenous growth models [building on Romer (1990) and Grossman and Helpman (1991)] where the steady-state rate of productivity growth is an increasing function of population size and the patents-per-researcher ratio increases over time. These basic properties are, however, clearly at odds with empirical evidence. For example, Jones (1995a) shows that there has been no upward trend in productivity growth rates for the U.S., France, Germany and Japan since 1960 in spite of substantial increases in population size and R&D employment. Also Kortum (1993,1997) documents that the patents-per-researcher ratio has decreased significantly over time in many countries and industries.

Motivated by this empirical evidence, we study the effects of trade liberalization using a second-generation R&D-driven endogenous growth model [building on Jones (1995b) and Segerstrom (1998)] where constant productivity growth is consistent with positive population growth and intertemporal knowledge spillovers can be sufficiently weak so that the patents-per-researcher ratio decreases over time. We find that trade liberalization only temporarily changes the rate of productivity growth, in contrast with the permanent growth effects found in Baldwin and Robert-Nicoud (2006). We also find that the direction of the growth effects depends on whether intertemporal knowledge spillovers are relatively weak or relatively strong. Baldwin and Robert-Nicoud do not allow for any variation in the strength of these spillovers and implicitly assume that they are quite strong.

The rest of the paper is organized as follows: in section 2, the dynamic general equilibrium trade model is presented and in section 3, it is solved for a unique steady-state equilibrium. Section 4 studies the implications of trade liberalization and section 5 concludes.

2. The model

2.1. Overview of the model. In the model, there are two symmetric economies (or countries), a single primary factor labor that is inelastically supplied, a single consumption-good sector where there is Dixit-Stiglitz monopolistic competition and a single innovation sector where firms create knowledge through R&D.

Each firm's cost function is linear and involves one-time fixed costs and constant marginal production costs. To produce, a firm must first develop a new variety and this is done in the innovation sector. There is a one-time variety-development fixed cost which represents the sunk cost of developing a new variety. After having incurred this fixed cost, the firm receives a patent to exclusively produce the new variety and learns the unit labor requirement associated with its production. The unit labor requirement is drawn from a probability density function, so different firms have different marginal costs of production.

In addition to the above-mentioned costs, there are also market-entry costs. After having developed a new variety and learned its unit labor requirement, a firm decides whether or not to incur the one-time fixed costs of selling the variety in the local and foreign markets. We think of these market-entry costs as reflecting the costs of adapting the variety to market-specific standards, regulations and norms. A firm needs to draw a sufficiently low unit labor requirement to justify entering the local market and an even more favorable draw to justify entering the foreign market (see Figure 1). Roberts and Tybout (1997a) (for Colombia), Bernard and Jensen (2001) (for the U.S.) and Bernard and Wagner (2001) (for Germany) all find that potential exporters face significant foreign-market entry costs.

For firms that incur the one-time foreign-market entry cost and learn how to export, there are iceberg trade costs associated with shipping their products to the foreign market. The main focus of this paper is on exploring the steady-state equilibrium and welfare implications of trade liberalization, that is, a decrease in these iceberg trade costs and/or the costs of entering foreign markets.

Since the model consists of two trading economies (or countries) that are structurally symmetric, the choices made by agents in both economies can be understood by focusing on one of the two economies. This will be done throughout the rest of the paper.

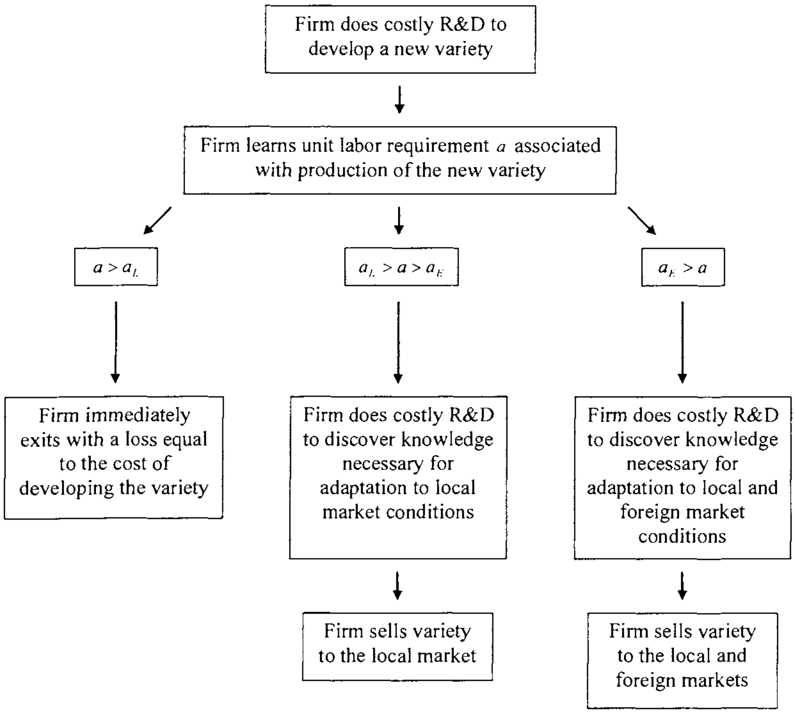

Figure 1. Description of the model.

2.2. Labor. In each economy, there is a fixed measure of households that provide labor services in exchange for wage payments. Each individual member of a household lives forever and is endowed with one unit of labor which is inelastically supplied. The size of each household, measured by the number of its members, grows exponentially at the exogenous population growth rate $n > 0$. Let $L_t = L_0 e^{nt}$ denote the supply of labor in each economy at time t.

The market for labor is perfectly competitive in each economy. Labor is employed either in the production of varieties or in the innovation sector doing R&D. Hence

$$L_t = L_{Pt} + L_{It}$$

where L_{Pt} is the economy-wide amount of labor used to produce varieties and L_{It} is the economy-wide amount of labor used in the innovation sector. Labor is perfectly mobile within an economy and is paid the common wage rate w per unit of labor supplied. The wage rate w is the same in both economies by symmetry and we set $w = 1$, treating labor as the numeraire.

2.3. Consumption. Households share identical preferences. Each household is modelled as a dynastic family that maximizes discounted lifetime utility

$$U = \int_0^\infty e^{-(\rho-n)t} \ln [u_t] \, dt \tag{2.1}$$

where $\rho > n$ is the subjective discount rate and u_t is the instantaneous utility of an individual household member at time t. The representative consumer has a C.E.S. utility function given by

$$u_t = \left[\int_0^{m_t^c} x_t(\omega)^\alpha \, d\omega \right]^{\frac{1}{\alpha}} \qquad 0 < \alpha < 1 \tag{2.2}$$

where $x_t(\omega)$ is the consumer's quantity consumed of a product ω at time t and m_t^c is the number of available varieties in an economy at time t (both domestically produced and imported varieties). The parameter α measures the degree of product differentiation. We assume that products are substitutes, which implies that $0 < \alpha < 1$ and yields an elasticity of substitution between any two products of $\sigma \equiv \frac{1}{1-\alpha} > 1$.

Solving the static optimization problem yields the familiar demand function

$$x_t(\omega) = \frac{p_t(\omega)^{-\sigma}}{\int_0^{m_t^c} p_t(\omega)^{1-\sigma} \, d\omega} E_t \tag{2.3}$$

where E_t is individual consumer expenditure and $p_t(\omega)$ is the price charged for product ω at time t. Furthermore, if we let

$$P_t = \left(\int_0^{m_t^c} p_t(\omega)^{1-\sigma} \, d\omega \right)^{\frac{1}{1-\sigma}}$$

denote the aggregate price index and let $c_t \equiv \frac{E_t}{P_t}$ be a measure of real consumption expenditure, then Dixit and Stiglitz (1977) have shown that $u_t = c_t$, that is, each consumer's instantaneous utility coincides with their real consumption expenditure.

Taking prices and expenditure as given, dynamic optimization yields the usual Euler-equation

$$\frac{\dot{E}_t}{E_t} = r_t - \rho. \tag{2.4}$$

Consumer expenditure E_t grows over time if and only if the market interest rate r_t exceeds the subjective discount rate ρ.

2.4. Innovation. In the innovation sector, firms create knowledge by doing R&D. The unit labor requirement associated with creating knowledge is b_{It}, that is, it takes b_{It} units of labor at time t to create one unit of knowledge. Individual firms treat b_{It} as a parameter but it can change over time due to knowledge spillovers.

Following Jones (1995b), we assume that

$$b_{It} = \frac{1}{(m_{Lt} + \lambda m_{Ft})^{\phi}}$$

where $\phi < 1$ and $\lambda \in [0,1]$ are given R&D parameters, m_{Lt} and m_{Ft} are the number of varieties produced in the local and foreign markets, ϕ measures the strength of intertemporal knowledge spillovers and λ measures the international dimension of spillovers. $\lambda = 0$ corresponds to no international spillovers and $\lambda = 1$ corresponds to perfect international spillovers. We allow for all the inbetween possibilities. Given symmetry, $m_{Lt} = m_{Ft} \equiv m_t$ where m_t is the number of varieties produced per economy and hence

$$b_{It} = \frac{1}{(1+\lambda)^{\phi} m_t^{\phi}}. \tag{2.5}$$

The parameter ϕ is a key parameter in the model. We impose the restriction $\phi < 1$ to rule out explosive growth, as in Jones (1995b). Nevertheless, $\phi < 1$ allows for a wide range of values for the degree of intertemporal knowledge spillovers. In particular, these spillovers can be either positive or negative. For $\phi > 0$, researchers become more productive in creating new knowledge as the stock of knowledge measured by m_t increases over time. Researchers experience a "standing on the shoulders" effect. For $\phi < 0$, researchers become less productive in creating new knowledge as the stock of knowledge increases over time. Researchers experience a "fishing out" effect.

To develop a new variety, a firm needs to create F_I units of knowledge in the innovation sector. Thus, the cost of developing a new variety is $b_{It}F_I$ at time t. Knowledge creation is also involved in adapting a variety to market-specific standards, regulations and norms. To sell a new variety in the local market, a firm needs to create F_L units of knowledge at cost $b_{It}F_L$ and to sell a new variety in the foreign market, a firm needs to create F_E units of knowledge at cost $b_{It}F_E$.

Once a firm has developed a new variety, if learns the unit labor requirement a associated with its production. The unit labor requirement a is drawn from a probability density function $g(a)$ with support $[0, \overline{a}]$ and corresponding cumulative distribution function $G(a)$. Once drawn, the unit labor requirement of a firm associated with producing a particular variety does not change over time. We assume that the probability distribution of unit labor requirements is Pareto, that is,

$$G(a) = \int_0^a g(a)da = \left(\frac{a}{\overline{a}}\right)^k, \; a \in [0, \overline{a}]$$

where k and $\overline{a}$ are the shape and scale parameters of the distribution. Melitz (2003) worked with a general probability distribution of unit labor requirements but the model becomes considerably more tractable analytically if a Pareto distribution is assumed. The empirical literature on firm size distribution suggests that a Pareto distribution is a reasonable approximation (Cabral and Mata, 2003).[1]

Because of the heterogeneity in unit labor requirements, the model generates three types of firms: non-producing firms, local firms and exporting firms. Firms that get sufficiently unfavorable draws choose not to produce, firms that get intermediate draws choose to just produce for the local market, and firms that get the most favorable draws choose to produce for both the local and the foreign markets.

For a firm that develops a new variety at time t, let a_{Lt} denote the unit labor requirement (or marginal cost) at which the firm is indifferent between incurring the fixed cost $b_{It}F_L$ of selling in the local market and immediately shutting down production. Similarly, let a_{Et} denote the unit labor requirement (or marginal cost) at which the firm is indifferent between selling in the local market only and incurring the additional fixed cost $b_{It}F_E$ to export its variety. We will solve the model for a steady-state equilibrium where the threshold values a_{Lt} and a_{Et} satisfy

$$0 < a_{Et} < a_{Lt} < \overline{a} \text{ for all } t,$$

that is, not all firms export ($a_{Et} < a_{Lt}$) and not all firms produce ($a_{Lt} < \overline{a}$).

2.5. Product markets. Given a draw of $a \leq a_{Lt}$ from the common density function $g(a)$, a firm's profits from local sales of variety ω are given by

$$\pi_{Lt}(\omega) = \max_{p_{Lt}(\omega)} \left(p_{Lt}(\omega) - a(\omega)\right) x_{Lt}(\omega)$$

where $x_{Lt}(\omega)$ is the demand for a locally sold variety ω and $p_{Lt}(\omega)$ is the corresponding price. $x_{Lt}(\omega)$ is given by (2.3) where E_t is redefined to measure the economy-wide consumer expenditure. Since there exists a continuum of firms, each firm chooses a

[1] Usually the Pareto distribution is defined by $P(X > x) = (x/\overline{x})^{-k}$. Substituting $a = 1/x$ and $\overline{a} = 1/\overline{x}$ yields $G(a) = (a/\overline{a})^k$.

profit-maximizing price taking aggregate expenditure and other firms' prices as given. This yields

$$p_L(\omega) = \frac{\sigma}{\sigma - 1} a(\omega)$$

which is the standard markup of price over marginal cost $a(\omega)$, given that $\sigma > 1$. By substituting for the price, profits of a firm selling locally can be written as

$$\pi_{Lt}(\omega) = (\sigma - 1)^{\sigma - 1} \sigma^{-\sigma} \left(\frac{a(\omega)}{P_t}\right)^{1-\sigma} E_t. \tag{2.6}$$

Similarly, given a draw $a \leq a_{Et}$, additional profits from exports are given by

$$\pi_{Et}(\omega) = \max_{p_{Et}(\omega)} (p_{Et}(\omega) - \tau a(\omega)) x_{Et}(\omega)$$

where $x_{Et}(\omega)$ is the foreign demand for the exported variety ω and $p_{Et}(\omega)$ is the price of the exported variety ω. $\tau > 1$ is an iceberg trade cost such that τ units must be shipped for one unit to reach its destination. The corresponding profit-maximizing price from foreign sales is given by

$$p_{Et}(\omega) = \frac{\sigma}{\sigma - 1} \tau a(\omega).$$

Hence, an exporting firm sets a higher price on varieties sold to foreign consumers to compensate for the trade cost. Substituting for the price, the additional profits earned by an exporting firm are

$$\pi_{Et} = \theta (\sigma - 1)^{\sigma - 1} \sigma^{-\sigma} \left(\frac{a(\omega)}{P_t}\right)^{1-\sigma} E_t, \tag{2.7}$$

where $\theta \equiv \tau^{1-\sigma}$ is a measure of the free-ness of trade ($\theta = 0$ describes the case of autarky, whereas $\theta = 1$ implies free trade).

2.6. Local and foreign market entry. Having solved for the profits that firms earn from selling locally and exporting, we can now determine when firms choose to enter the local and foreign markets.

For the owners of a firm with marginal cost of production equal to either of the two threshold values ($a = a_{it}$, $i = L, E$), profits $\pi_{it}(a_{it})dt$ are earned during the time interval dt and the capital gain $\dot{V}_{it}(a_{it})dt$ is also realized, where $V_{it}(a_{it})$ is the discounted profit associated with the draw $a = a_{it}$. As there is no risk for the owners of a firm once it's a value is known, the total return on equity claims must equal the risk-free market interest rate r_t, that is

$$\pi_{it}(a_{it})dt + \dot{V}_{it}(a_{it})dt = r_t V_{it}(a_{it})dt \qquad i = L, E.$$

Solving for V_{it} yields

$$V_{it}(a_{it}) = \frac{\pi_{it}(a_{it})}{r_t - \frac{\dot{V}_{it}(a_{it})}{V_{it}(a_{it})}} \qquad i = L, E.$$

Note that, unlike in Melitz (2003), firms face no exogenous death rate. Melitz assumes a common exogenous death rate for all firms to enable transitions between steady-states (in response to trade liberalization). We can dispense with this assumption since variety innovation plays the same role of enabling transitions between steady-states.[2] However, all the results in the paper continue to hold when there is a common exogenous death rate for firms.

Given that the firms with threshold values a_{Lt} and a_{Et} are indifferent between entering and not entering the local and foreign markets respectively, the costs of entering must be exactly balanced by the benefits of entering:

$$V_{it}(a_{it}) = b_{It}F_i \qquad i = L, E.$$

Substituting into these two equations using the profit flows (2.6) and (2.7) yields the local market entry condition

$$\text{(2.8)} \qquad \frac{(\sigma-1)^{\sigma-1}\sigma^{-\sigma}\left(\frac{a(\omega)}{P_t}\right)^{1-\sigma}E_t}{r_t - \frac{\dot{b}_{It}}{b_{It}}} = b_{It}F_L$$

and the foreign market entry condition

$$\text{(2.9)} \qquad \frac{(\sigma-1)^{\sigma-1}\sigma^{-\sigma}\left(\frac{a(\omega)}{P_t}\right)^{1-\sigma}E_t}{r_t - \frac{\dot{b}_{It}}{b_{It}}} = \frac{b_{It}F_E}{\theta}.$$

For the model to be consistent with the observation that not all firms export ($a_{Lt} > a_{Et}$), we assume that the costs associated with foreign entry are higher than for local entry, that is, $F_E > F_L$. With this parameter restriction, (2.8) and (2.9) together imply that

$$\text{(2.10)} \qquad \frac{a_{Lt}}{a_{Et}} = \left(\frac{F_E}{F_L\theta}\right)^{\frac{1}{\sigma-1}} > 1$$

for all $\theta \in (0,1)$. Firms that draw $a \leq a_{Lt}$ choose to enter the local market and firms that draw $a \leq a_{Et}$ choose to enter the foreign market as well. Firms that are unlucky and draw $a > a_{Lt}$ choose not to enter either the local or foreign markets.

[2] As the number of varieties produced increases over time, the significance of firms that made entry decisions under the old regime (before trade liberalization) decreases and eventually becomes negligable.

2.7. Innovation incentives. Having solved for when firms choose to sell locally and export, we can now work backwards and determine the incentives to develop new varieties.

We assume that there is free entry by firms into variety innovation. Since any firm can develop a new variety, the ex-ante expected benefit of developing a new variety must equal the cost of variety innovation. This can be stated as

$$\int_0^{a_{Lt}} \left\{ \frac{\pi_{Lt}(a)}{r_t - \frac{\dot{b}_{It}}{b_{It}}} - b_{It}F_L \right\} dG(a) + \int_0^{a_{Et}} \left\{ \frac{\pi_{Et}(a)}{r_t - \frac{\dot{b}_{It}}{b_{It}}} - b_{It}F_E \right\} dG(a) = b_{It}F_I$$

where $G(a)$ is the Pareto cumulative distribution function from which a potential market entrant draws a unit labor requirement. Substituting for profits using (2.6) and (2.7) and integrating, free entry ensures that ex-ante expected discounted profits must equal ex-ante expected fixed costs of developing a profitable variety:

$$\frac{(\sigma-1)^{\sigma-1}\sigma^{-\sigma}E_t\Delta_t}{P_t^{1-\sigma}\left(r_t - \frac{\dot{b}_{It}}{b_{It}}\right)} = b_{It}\overline{F}_t \tag{2.11}$$

where

$$\Delta_t \equiv \int_0^{a_{Lt}} a^{1-\sigma}\frac{g(a)}{G(a_{Lt})}da + \theta\int_0^{a_{Et}} a^{1-\sigma}\frac{g(a)}{G(a_{Lt})}da \tag{2.12}$$

is a weighted average of marginal costs and

$$\overline{F}_t \equiv F_I\frac{1}{G(a_{Lt})} + F_L + F_E\frac{G(a_{Et})}{G(a_{Lt})}.$$

Using the properties of the Pareto distribution, $\overline{F}_t$ can be written as

$$\overline{F}_t = F_I\left(\frac{\overline{a}}{a_{Lt}}\right)^k + F_L + F_E\left(\frac{a_{Et}}{a_{Lt}}\right)^k. \tag{2.13}$$

The first term on the right-hand-side of (2.13) represents the expected cost of innovation, where $\frac{1}{G(a_{Lt})} = \left(\frac{\overline{a}}{a_{Lt}}\right)^k$ can be seen as the number of attempts needed before a profitable variety is discovered. F_L is the fixed cost of local market adaptation paid by all producing firms. The third term is the expected fixed cost associated with adapting a variety to the foreign market. $\left(\frac{a_{Et}}{a_{Lt}}\right)^k = \frac{G(a_{Et})}{G(a_{Lt})}$ represents the likelihood of having developed a variety profitable enough to export, given that local market entry has taken place. Hence, $\overline{F}_t$ is the ex ante expected fixed cost of developing a profitable variety at time t, measured in units of knowledge created.

The flow of new varieties is determined by the labor devoted to R&D divided by the labor units required for successful innovation:

$$\dot{m}_t = \frac{L_{It}}{b_{It}\overline{F}_t}, \tag{2.14}$$

where $L_{It} = \sum_i l_{Iit}$ is the sum of all R&D done by firms in the economy.

This completes the description of the model.

3. Solving the model

In this section, we solve the model for a unique steady-state equilibrium. A steady-state equilibrium is defined as an equilibrium where all endogenous variables grow at constant (not necessarily identical) rates over time. This paper focuses on the steady-state equilibrium implications of the model.

Equation (2.4) implies that the market interest rate r_t must be constant over time in any steady-state equilibrium. It then follows from studying (2.11) that, as the growth rates of the endogenous variables P_t, E_t, Δ_t, and b_{It} are all constant over time, $\overline{F}_t$ must grow at a constant rate. But as F_L is a constant, (2.13) implies that $\overline{F}_t$ cannot grow at a constant rate unless $a_{Lt} = a_L$ and $a_{Et} = a_E$ for all t. Hence $\overline{F}$, a_L and a_E are all constants in any steady-state equilibrium.

Let $g \equiv \frac{\dot{m}_t}{m_t}$ denote the steady-state rate of innovation. Dividing both sides of (2.14) by m_t, and substituting for b_{It} using (2.5) yields

$$g \equiv \frac{\dot{m}_t}{m_t} = \frac{L_{It}\,(1+\lambda)^{\phi}}{\overline{F}m_t^{1-\phi}}.$$

Because labor supply L_t grows at the constant exogenous rate n and consists of workers employed in either production or R&D, R&D labor L_{It} must grow at the rate n as well. It then follows that g can only be constant over time if

$$g = \frac{n}{1-\phi}. \tag{3.1}$$

Equation (3.1) establishes that the steady-state rate of innovation g is proportional to the R&D employment growth rate n. As in Jones (1995b), the parameter restriction $\phi < 1$ is needed to guarantee that the steady-state rate of innovation is positive and finite (given that there is positive population growth).[3]

[3] In Melitz (2003), firms are continually entering with new varieties but because the population growth rate is zero ($n = 0$), productivity growth cannot be sustained in the long run. As Strulik (2005ab) has shown, the assumption of positive population growth is not needed to sustain steady-state economic growth if there is also human capital accumulation. Therefore n should more generally be interpreted as the growth rate of the effective labor force in the economy.

The R&D technology used in this paper differs from the ones used in Baldwin and Robert-Nicoud (2006), who study the implications of five alternative R&D technologies. To facilitate comparison with their paper, we focus on their first model ("the Grossman-Helpman model") although the points that we make apply with appropriate modification to their other models as well. Baldwin and Robert-Nicoud focus on the special case where the intertemporal knowledge spillover parameter ϕ equals one. The assumption $\phi = 1$ implies that the unit labor requirement associated with creating knowledge is

$$\widetilde{b}_{It} = \frac{1}{(1+\lambda)\,\widetilde{m}_t}$$

where $\tilde{}$ is used to distinguish variables in Baldwin and Robert-Nicoud (2006) from corresponding variables in this paper. The number of innovated varieties then increases over time according to

$$\dot{\widetilde{m}}_t = \frac{\widetilde{L}_{It}\,(1+\lambda)\,\widetilde{m}_t}{\overline{F}}$$

and the corresponding rate of innovation is given by

$$\widetilde{g} \equiv \frac{\dot{\widetilde{m}}_t}{\widetilde{m}_t} = \frac{(1+\lambda)}{\overline{F}}\widetilde{L}_{It}.$$

Hence, in contrast to this paper, the choice of R&D technology made by Baldwin and Robert-Nicoud implies that the rate of innovation g is proportional to the R&D employment level L_{It}. Baldwin and Robert-Nicoud then proceed to show that the steady-state economic growth rate is also proportional to the level of R&D employment.

This so-called "scale effect" property is clearly at odds with the available empirical evidence. For example, while the number of U.S. scientists and engineers engaged in R&D grew by more than 500 percent during the period 1950-1993, the rate of economic growth remained fairly constant during this period [See Jones (1995ab)].[4] Furthermore, the data on patenting suggests that, far from intertemporal knowledge spillovers being positive and strong ($\phi = 1$), these spillovers may actually be negative ($\phi < 0$). In contrast with the Baldwin and Robert-Nicoud model where the patents-per-researcher ratio increases over time, Kortum (1993, 1997) documents a decreasing patents-per-researcher ratio in a large set of countries. Looking at industry data, Kortum (1993) finds that the patenting per unit of real R&D ratio has declined in all 20 industries for which data could be obtained. Also Jones (2005) finds evidence of an increasing knowledge burden over time that leads researchers to choose narrower expertise and to

[4] The scale effect property is present in all first generation R&D-driven endogenous growth models, including Romer (1990), Segerstrom, Anant and Dinopoulos (1990), Grossman and Helpman (1991) and Aghion and Howitt (1992).

compensate for their reduced individual capacities by working in larger teams. All of this evidence justifies studying a modified R&D technology where $\phi < 1$.

Returning to the model, we solve next for the steady-state profit rates. We first note that $\Delta_t = \Delta$ for all t according to (2.12) as the unit labor requirement thresholds a_L and a_E are constant in steady-state. To solve for the aggregate price index, we first note that

$$P_t^{1-\sigma} = \int_0^{m_t^c} p(\omega)^{1-\sigma} d\omega = \int_0^{a_L} p_L(a)^{1-\sigma} m_{Lt} \frac{g(a)}{G(a_L)} da + \int_0^{a_E} p_E(a)^{1-\sigma} m_{Ft} \frac{g(a)}{G(a_L)} da$$

where m_{Lt} is the number of locally produced varieties, m_{Ft} is the number of foreign produced varieties and $\frac{g(a)}{G(a_L)}$ is the steady-state density function conditional on entry. Substituting for prices, the aggregate price index is given by

$$P_t = \left(\frac{\sigma}{\sigma - 1}\right)(m_t \Delta)^{\frac{1}{1-\sigma}}. \tag{3.2}$$

This implies that the profits earned from selling locally (2.6) and exporting (2.7) can be rewritten as

$$\pi_{Lt} = s_t(a)\frac{E_t}{\sigma} \tag{3.3}$$

$$\pi_{Et} = \theta s_t(a)\frac{E_t}{\sigma} \tag{3.4}$$

where $s_t(a) \equiv \frac{a^{1-\sigma}}{m_t \Delta}$ is the Dixit-Stiglitz market share at time t.

To solve for a steady-state equilibrium, we need to define the concept of relative R&D difficulty:

$$z_t \equiv \frac{m_t^{-\phi}}{\frac{L_t}{m_t}} = \frac{m_t^{1-\phi}}{L_t}. \tag{3.5}$$

In (3.5), $m_t^{-\phi}$ is a measure of absolute R&D difficulty and $\frac{L_t}{m_t}$ is a measure of the size of the market for each variety. Thus relative R&D difficulty is R&D difficulty relative to the size of the market. By log-differentiating (3.5) and using (3.1), we have that

$$\frac{\dot{z}_t}{z_t} = (1 - \phi) g - n = 0.$$

Hence, relative R&D difficulty z is constant in steady-state equilibrium.[5]

Having defined z, we can state concisely the steady-state market entry conditions. From (2.4), we note that since the growth rate of consumer expenditure must be

[5] The concept of relative R&D difficulty was introduced in Segerstrom (1998). It is defined differently in this paper because the number of varieties increases over time, which decreases the market for each individual variety.

constant in any steady-state equilibrium, the market interest rate must be constant as well, so $r_t = r$ for all t. Taking logs and differentiating (2.5) with respect to time yields $\frac{\dot{b}_{It}}{b_{It}} = -\phi g$. Also using (2.5) to substitute for b_{It}, the local market entry condition (2.8) can now be written as

$$\frac{\frac{a_L^{1-\sigma}}{\Delta}\frac{E_t}{\sigma}}{r+\phi g} = \frac{F_L z L_t}{(1+\lambda)^\phi}. \tag{3.6}$$

The corresponding foreign market entry condition given by (2.9) is

$$\frac{\frac{a_E^{1-\sigma}}{\Delta}\frac{E_t}{\sigma}}{r+\phi g} = \frac{F_E z L_t}{\theta(1+\lambda)^\phi} \tag{3.7}$$

where the left-hand-sides of (3.6) and (3.7) are associated with the discounted benefits of a firm having drawn $a = a_L$ or $a = a_E$, while the corresponding right-hand-sides are associated with the costs of local or foreign market entry.

Using the definition of z and substituting for the aggregate price index P_t, the unit labor requirement for knowledge creation b_{It} and the capital gain term $\frac{\dot{b}_{It}}{b_{It}}$, the free entry into variety innovation condition (2.11) can be written concisely as

$$\frac{\frac{E_t}{\sigma}}{r+\phi g} = \frac{\overline{F} z L_t}{(1+\lambda)^\phi}. \tag{3.8}$$

This condition governs the steady-state incentives for developing new varieties since the left-hand-side is associated with the discounted benefits of developing and producing a profitable variety whereas the right-hand-side is associated with the expected costs of development and market entry.

Next, we turn to labor markets, which are assumed to be perfectly competitive. The total workforce used in industry production is given by the sum of the labor producing for the local market and the labor used to produce goods sold in the foreign market. To produce a variety that will be sold locally, a firm ω needs $a(\omega)x_{Lt}(\omega)$ units of labor. Substituting for demand and prices using (2.3) and (3.2), this corresponds to

$$a(\omega)x_{Lt}(\omega) = \left(\frac{\sigma-1}{\sigma}\right)\frac{a(\omega)^{1-\sigma}}{m_t\Delta_t}E_t.$$

To produce the goods that are exported, a firm ω needs $\tau a(\omega)x_{Et}(\omega)$ units of labor, which can be similarly shown to equal

$$\tau a(\omega)x_{Et}(\omega) = \theta\left(\frac{\sigma-1}{\sigma}\right)\frac{a(\omega)^{1-\sigma}}{m_t\Delta_t}E_t.$$

Summing over firms, the production labor of an economy in steady-state amounts to

$$L_{Pt} = \int_0^{a_L} a(\omega)x_{Lt}(\omega)m_t \frac{g(a)}{G(a_L)} da + \int_0^{a_E} \tau a(\omega)x_{Et}(\omega)m_t \frac{g(a)}{G(a_L)} da$$

where m_t represents the total number of varieties produced per country. Substituting for $a(\omega)x_{Lt}(\omega)$, $\tau a(\omega)x_{Et}(\omega)$ and using (2.12), this simplifies to $L_{Pt} = \left(\frac{\sigma-1}{\sigma}\right) E_t$. The full employment condition $L_t = L_{Pt} + L_{It}$ then implies that

$$E_t = L_t + \frac{E_t}{\sigma} - L_{It}. \tag{3.9}$$

Equation (3.9) has a simple economic interpretation. Aggregate expenditure E_t equals aggregate income, which is given by the sum of aggregate labor income L_t and aggregate profit income $\frac{E_t}{\sigma}$, deducting the wages paid in the innovation sector L_{It}. To see that aggregate profit income is $\frac{E_t}{\sigma}$, it suffices to verify that

$$\int_0^{a_L} \pi_L(a)m_t \frac{g(a)}{G(a_L)} da + \int_0^{a_E} \pi_E(a)m_t \frac{g(a)}{G(a_L)} da = \frac{E_t}{\sigma}$$

using (2.12), (3.3) and (3.4).

To solve for the steady-state interest rate r, we use (3.9) and note that with total labor L_t growing at the rate n, R&D labor L_{It} and aggregate expenditure E_t must grow at the rate n as well. Equation (2.4) then implies that the steady-state interest rate is

$$r = \rho + n.$$

The weighted average of marginal costs Δ_t is constant in steady-state equilibrium and can be written much more simply. Taking into account that the a's are drawn from the Pareto distribution, (2.12) implies that

$$\Delta = \frac{a_L^{1-\sigma}}{1 - \frac{\sigma-1}{k}} \left(1 + \theta \left(\frac{a_E}{a_L}\right)^{1+k-\sigma}\right).$$

We assume that $\beta \equiv \frac{k}{\sigma-1} > 1$ to guarantee that Δ is finite. Then letting $T \equiv \frac{F_E}{F_L}$ and $\Omega \equiv \theta^\beta T^{1-\beta}$ and substituting using (2.10), we obtain that

$$\Delta = \frac{\beta}{\beta - 1} a_L^{1-\sigma} (1 + \Omega). \tag{3.10}$$

The variable Ω measures the degree of openness and depends on both the fixed and the variable trade costs (F_E and τ). Given that the inequality in (2.10) holds and not all firms export, Ω is bounded between zero and one. $\Omega = 0$ corresponds to infinite τ and/or infinite $\frac{F_E}{F_L}$ whereas $\Omega = 1$ corresponds to zero iceberg trade costs ($\tau = 1$) and $F_E = F_L$.

In steady-state equilibrium, the expected fixed cost of developing a profitable variety $\overline{F}$ is constant over time and depends on the degree of openness Ω. Substituting for Δ using (3.10) in the the local market entry condition (3.6) and combining this with the innovation entry condition (3.8), $\overline{F}$ can be explicitly expressed as

$$\overline{F} = F_L \left(\frac{\beta}{\beta - 1}\right)(1 + \Omega). \tag{3.11}$$

In steady-state equilibrium, aggregate expenditure E_t grows over time and we can solve for the exact path. First, (2.5), (2.14) and (3.5) together imply that

$$L_{It} = \frac{\overline{F} z L_t}{(1+\lambda)^{\phi}} g. \tag{3.12}$$

Second, (3.8) can be solved for $\frac{E_t}{\sigma}$. Substituting these results into (3.9) and simplifying using (3.1), steady-state aggregate expenditure is found to be

$$E_t = L_t \left(1 + \rho \frac{\overline{F} z}{(1+\lambda)^{\phi}}\right). \tag{3.13}$$

Free entry ensures that the value of the average producing firm (expected discounted profits) must equal the expected fixed costs of developing a profitable variety

$$b_{It}\overline{F} = \frac{\overline{F}}{(1+\lambda)^{\phi} m_t^{\phi}}.$$

Hence, the value of all the producing firms in the economy is $\frac{\overline{F} m_t^{1-\phi}}{(1+\lambda)^{\phi}} = \frac{\overline{F} z L_t}{(1+\lambda)^{\phi}}$ and equation (3.13) states that aggregate expenditure is equal to the sum of labor income and the returns from the ownership of firms.

All that remains in solving the model is to find steady-state values for a_L, a_E and z. First, we combine (2.10), (2.13) and (3.11) to obtain the steady-state cut-off unit labor requirement for selling locally:

$$a_L = \overline{a}\left(\frac{F_I(\beta - 1)}{F_L(1+\Omega)}\right)^{\frac{1}{k}}. \tag{3.14}$$

Next a_E is determined by using (3.14) to substitute for a_L in (2.10). The steady-state cut-off unit labor requirement for exporting is

$$a_E = \overline{a}\left(\frac{F_I(\beta - 1)\Omega}{F_E(1+\Omega)}\right)^{\frac{1}{k}}. \tag{3.15}$$

Finally, using (3.11) and (3.13) to substitute for $\overline{F}$ and E_t in (3.8), we obtain steady-state relative R&D difficulty

$$z = \frac{(\beta - 1)(1+\lambda)^{\phi}}{\beta \sigma F_L (1+\Omega)\left(\rho - \frac{\rho}{\sigma} + g\right)}. \tag{3.16}$$

We conclude that the model has a unique steady-state equilibrium.

4. Steady-state properties of the model

In this section the steady-state equilibrium implications of trade liberalization are studied. We suppose that the two trading economies are initially in steady-state equilibrium and that at some point in time trade liberalization takes place. By trade liberalization, we mean that Ω increases, which can be due to either a decrease in trade costs ($\tau \downarrow$) or a decrease in the knowledge needed to enter foreign markets ($F_E \downarrow$).

First, we focus on the implications of trade liberalization for market entry. From (3.14), an increase in Ω implies that a_L decreases. A decrease in the cut-off value for local market entry a_L means that fewer firms are willing to incur the fixed cost of local market entry and sell their product varieties in the local market. From (3.15), an increase in Ω also causes a_E to increase. An increase in the cut-off value for foreign market entry a_E means that more firms are willing to incur the fixed cost of foreign market entry and sell their product varieties in the foreign market. Furthermore, it is the least productive (highest marginal cost) local producers that become non-producers as a result of trade liberalization and it is the most productive (lowest marginal cost) non-exporters that become exporters as a result of trade liberalization. We have established

THEOREM 1. *Trade liberalization* ($\Omega \uparrow$) *causes the least productive firms to exit* ($a_L \downarrow$) *and induces more firms to become exporters* ($a_E \uparrow$)

Theorem 1 is the same result as in Melitz (2003) but now it is derived from a model with steady-state productivity growth. In Melitz (2003), the steady-state equilibrium rate of productivity growth is zero.

In support of Theorem 1, several studies have established that exposure to trade opens up new growth opportunities for relatively productive firms. This pattern has been found in the U.S. by Bernard and Jensen (1999a), in Taiwan by Aw, Chung and Roberts (2000) and in Colombia, Mexico and Morocco by Clerides, Lach and Tybout (1998). In addition, the study by Aw, Chung and Roberts (2000) finds that the least productive firms exit as they are exposed to trade. By considering the direct effect from market share allocation on sectoral productivity growth, Pavcnik (2002) finds that the reallocations following trade liberalization in Chile had a significant impact on productivity growth in tradable sectors. In another related study, Bernard and Jensen (1999b) find that market share reallocation towards more productive exporting firms can explain as much as one fifth of U.S. manufacturing productivity growth.

Consider next the steady-state effects of trade liberalization for variety innovation and R&D behavior. From (3.1), an increase in Ω has no effect on $g \equiv \frac{\dot{m}_t}{m_t}$. In the long run, the growth rate of the number of varieties produced does not change as a result of trade liberalization. Turning next to the share of labor employed in R&D, substituting into (3.12) using (3.11) and (3.16) yields

$$\frac{L_{It}}{L_t} = \frac{g}{\sigma\left(\rho - \frac{\rho}{\sigma} + g\right)}.$$

An increase in Ω has no effects on $\frac{L_{It}}{L_t}$ either. In the long run, trade liberalization has no effect on the share of labor employed in R&D. However, trade liberalization does affect z. Equation (3.16) implies that an increase in Ω leads to a lower steady-state z. And from (3.5), the permanent reduction in z can only occur if m_t temporarily grows at lower rates than the steady-state growth rate $g \equiv \frac{\dot{m}_t}{m_t} = \frac{n}{1-\phi}$. Thus trade liberalization leads to a temporary slowdown in variety innovation. We have established

THEOREM 2. *Trade liberalization ($\Omega \uparrow$) has no long-run effect on the growth rate of product variety $\left(g \equiv \frac{\dot{m}_t}{m_t}\right)$ or the share of labor devoted to R&D $\left(\frac{L_{It}}{L_t}\right)$. However, trade liberalization ($\Omega \uparrow$) does cause a temporary slowdown in variety growth ($z \downarrow$) and a permanent decrease in the number of varieties produced ($m_t \downarrow$ for all t).*

The intuition behind Theorem 2 is as follows. Trade liberalization (through a decrease in variable and/or fixed trade costs) makes it more profitable for firms to become exporters. When more firms become exporters, firms on average pay a higher total market entry cost $\overline{F}$ since more firms incur the cost of entering the foreign market ($\overline{F} \uparrow$ when $\Omega \uparrow$). As a result of the increase in the expected cost of innovation (including the market entry costs), the incentives to innovate are reduced and the rate of innovation drops below its steady-state rate g. One aspect of trade liberalization is that it involves a diversion of resources away from a growth-promoting activity: the development of new products.

By itself, Theorem 1 suggests that trade liberalization should promote productivity growth, at least in the short run. Trade liberalization causes the least productive firms to exit ($a_L \downarrow$) and also induces more productive firms to become exporters ($a_E \uparrow$). But Theorem 2 has implications for productivity growth that go in the opposite direction. Trade liberalization leads more firms to become exporters and this diverts resources away from product innovation, an activity that contributes to productivity growth. Thus, the overall effect of trade liberalization on productivity growth is not obvious.

To determine the overall effect of trade liberalization on productivity growth, we need to measure productivity and solve for how it evolves over time. Since $\frac{E_t}{P_t}$ is real output at time t and labor is the only factor of production, we use real output per worker $\frac{E_t}{P_t L_t}$ as our measure of productivity. Real output per worker coincides with per capita real consumption in the model and from section 2.3, this measure of productivity also coincides with consumer instantaneous utility ($u_t = c_t = \frac{E_t}{P_t L_t}$ where E_t is aggregate expenditure). Thus, the measure of productivity c_t is also a measure of consumer welfare.

Substituting for P_t using (3.2) and for $\frac{E_t}{L_t}$ using (3.13), productivity at time t can be written as

$$c_t = \left(1 + \rho \frac{\overline{F} z}{(1+\lambda)^{\phi}}\right) \left(\frac{\sigma - 1}{\sigma}\right) (m_t \Delta)^{\frac{1}{\sigma - 1}} . \tag{4.1}$$

In the model's steady-state equilibrium, $\overline{F}$, z and Δ are all constants over time. Thus productivity c_t grows over time only because the number of varieties m_t grows over time. Using (3.1), it immediately follows from (4.1) that

$$\frac{\dot{c}_t}{c_t} = \frac{1}{\sigma - 1} \frac{\dot{m}_t}{m_t} = \frac{n}{(\sigma - 1)(1 - \phi)} . \tag{4.2}$$

The steady-state growth rate of productivity $\frac{\dot{c}_t}{c_t}$ is proportional to the steady-state rate of innovation $\frac{\dot{m}_t}{m_t}$. Just as trade liberalization has no effect on the steady-state rate of innovation (Theorem 2), it is clear from (4.2) that trade liberalization has no effect on the steady-state rate of productivity growth.

Although trade liberalization does not have any long-run growth effects, it does have level effects on productivity and consumer welfare. To determine the direction of these level effects, we compare two steady-state equilibrium paths: one associated with an economy experiencing less restricted trade (Ω) and the other associated with an economy experiencing more restricted trade ($\Omega^* < \Omega$). To facilitate this comparison of steady-state paths, all variables associated with the more restricted trade path have the asterisk * attached, so in particular, c_t represents per capita real consumption on the steady-state path with less restricted trade (Ω) and c_t^* represents per capita real consumption on the steady-state path with more restricted trade ($\Omega^* < \Omega$). We solve for the ratio $\frac{c_t}{c_t^*}$. This ratio is constant over time since trade liberalization does not affect steady-state productivity growth. If $\frac{c_t}{c_t^*} > 1$, then we can conclude that trade liberalization ($\Omega^* \rightarrow \Omega$) promotes productivity growth in the short run and makes consumers better off in the long run. If instead $\frac{c_t}{c_t^*} < 1$, then we can conclude that trade liberalization retards productivity growth in the short run and makes consumers worse off in the long run.

To solve for $\frac{c_t}{c_t^*}$, first note that $\overline{F}z = \overline{F}^* z^*$ follows from (3.11) and (3.16). Equation (4.1) then implies that

$$\frac{c_t}{c_t^*} = \left(\frac{m_t \Delta}{m_t^* \Delta^*}\right)^{\frac{1}{\sigma-1}}.$$

Now (3.10) and (3.14) together imply that

$$\frac{\Delta}{\Delta^*} = \left(\frac{a_L}{a_L^*}\right)^{1-\sigma} \frac{1+\Omega}{1+\Omega^*} = \left(\frac{1+\Omega}{1+\Omega^*}\right)^{1+\frac{\sigma-1}{k}}$$

and (3.5) and (3.16) together imply that

$$\frac{m_t}{m_t^*} = \left(\frac{z}{z^*}\right)^{\frac{1}{1-\phi}} = \left(\frac{1+\Omega^*}{1+\Omega}\right)^{\frac{1}{1-\phi}}$$

Putting these results together yields

$$\left(\frac{c_t}{c_t^*}\right)^{\sigma-1} = \left(\frac{1+\Omega}{1+\Omega^*}\right)^{1+\frac{\sigma-1}{k}-\frac{1}{1-\phi}}$$

and $\frac{c_t}{c_t^*} > 1$ if and only if $1 + \frac{\sigma-1}{k} - \frac{1}{1-\phi} > 0$. This parameter condition simplifies to $\phi < \overline{\phi} \equiv \frac{1}{1+\beta}$ and thus we have established

THEOREM 3. *If* $\phi < \overline{\phi} \equiv \frac{1}{1+\beta}$, *then trade liberalization promotes productivity growth in the short run and makes consumers better off in the long run* $\left(\Omega > \Omega^* \Rightarrow \frac{c_t}{c_t^*} > 1\right)$. *However, if* $\phi > \overline{\phi} \equiv \frac{1}{1+\beta}$, *then trade liberalization retards productivity growth in the short-run and makes consumers worse off in the long run* $\left(\Omega > \Omega^* \Rightarrow \frac{c_t}{c_t^*} < 1\right)$.

Theorem 3 is the main result in the paper and it is surprising. Melitz (2003) finds that trade liberalization unambiguously promotes productivity growth in the short run and makes consumers better off in the long run. We find that this unambiguous conclusion is not robust and in a setting with steady-state productivity growth, trade liberalization sometimes makes consumers worse off in the long run.

Different possible effects from trade liberalization are illustrated in Figures 2, 3 and 4.

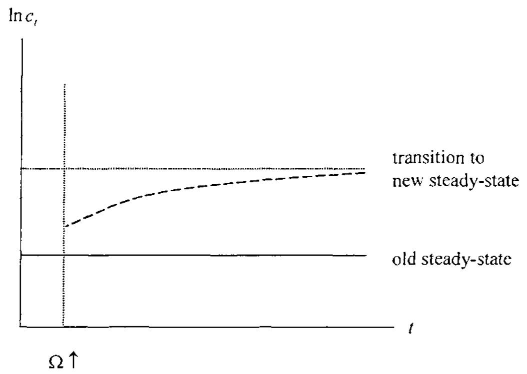

Figure 2. The effects of trade liberalization: the Melitz (2003) "zero growth" case.

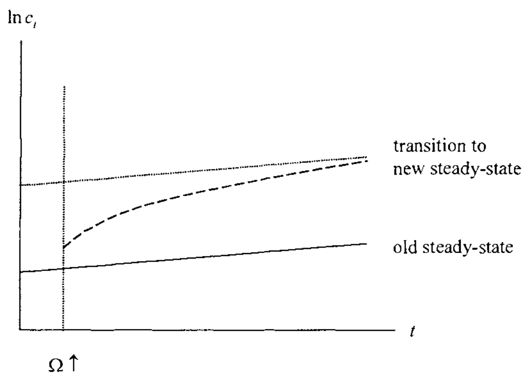

Figure 3. The effects of trade liberalization: the $\phi < \overline{\phi}$ "low growth" case.

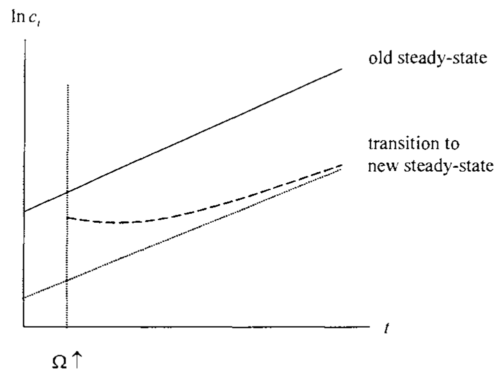

Figure 4. The effects of trade liberalization: the $\phi > \overline{\phi}$ "high growth" case.

Figure 2 illustrates the Melitz (2003) "zero growth" case. The horizontal line represents an old steady-state with a zero rate of productivity growth. When trade liberalization occurs ($\Omega \uparrow$), per capita real consumption c_t jumps up and then there is gradual convergence to a new steady-state with zero productivity growth but higher consumer welfare at each point in time t. Figure 3 illustrates the $\phi < \overline{\phi}$ "low growth" case. The slightly upward sloping line represents an old steady-state equilibrium with a low rate of productivity growth. When trade liberalization occurs ($\Omega \uparrow$), per capita real consumption c_t jumps up and then there is gradual convergence to a new steady-state equilibrium with the same low rate of productivity growth but higher consumer welfare at each point in time t. Figure 4 illustrates the $\phi > \overline{\phi}$ "high growth" case. The significantly upward-sloping line represents an old steady-state equilibrium with a high rate of productivity growth. When trade liberalization occurs ($\Omega \uparrow$), per capita real consumption c_t jumps down and then there is gradual convergence to a new steady-state equilibrium with the same high rate of productivity growth but lower consumer welfare at each point in time t.

The intuition behind Theorem 3 is as follows. When knowledge spillovers are relatively weak ($\phi < \overline{\phi}$) and the steady-state rate of productivity growth $\frac{\dot{c}_t}{c_t}$ given by (4.2) is relatively low, then the fact that trade liberalization causes the least productive firms to exit (Theorem 1) is more important for productivity growth than the fact that trade liberalization temporarily lowers the variety growth rate $g \equiv \frac{\dot{m}_t}{m_t}$ (Theorem 2). In the "low growth" case, trade liberalization promotes productivity growth in the short run and makes consumers better off in the long run. However, when knowledge spillovers are relatively strong ($\phi > \overline{\phi}$) and the steady-state rate of productivity growth $\frac{\dot{c}_t}{c_t}$ given by (4.2) is relatively high, then the fact that trade liberalization causes the least productive firms to exit (Theorem 1) is less important for productivity growth than the fact that trade liberalization temporarily lowers the variety growth rate $g \equiv \frac{\dot{m}_t}{m_t}$ (Theorem 2). In the "high growth" case, trade liberalization retards productivity growth in the short run and makes consumers worse off in the long run.

This intuition is helpful for understanding otherwise puzzling results in the earlier literature. In Melitz (2003), trade liberalization has the first effect of causing the least productive firms to exit but the second effect of causing a slowdown in variety growth is absent since there is no variety growth ($g = 0$). Thus the first effect must dominate and Melitz (2003) finds that trade liberalization unambiguously makes consumers better off in the long run. In “the Grossman-Helpman model” in Baldwin and Robert-Nicoud (2006), attention is restricted to the special case where knowledge spillovers are quite strong ($\phi = 1 > \overline{\phi} \equiv \frac{1}{1+\beta}$). Trade liberalization causes a permanent decrease in the variety growth rate ($g \downarrow$) and because this effect must eventually dominate the temporary effect on productivity of the least productive firms exiting ($a_L \downarrow$), Baldwin and Robert-Nicoud find that trade liberalization unambiguously makes consumers worse off in the long run. In our model, the effect of trade liberalization in slowing variety growth is temporary in nature (Theorem 2) and thus the overall effect of trade liberalization on long run welfare can go either way (Theorem 3).

5. Concluding remarks

This paper explores the implications of trade liberalization when firms are heterogeneous in terms of productivity and there is R&D-driven productivity growth.

Trade liberalization causes the least productive firms to exit and induces more firms to become exporters (Theorem 1). By itself, this market share reallocation from less to more productive firms contributes to productivity growth. But trade liberalization also causes a temporary slowdown in the development of new products (Theorem 2). When more firms choose to incur the fixed costs of becoming exporters, the expected costs of developing profitable new products increase, and it is profit-maximizing for firms to cut back on the development of new products.

The overall effect of trade liberalization on productivity growth depends on the size of intertemporal knowledge spillovers in R&D, the extent to which researchers become more productive in developing new products as the stock of knowledge increases over time (Theorem 3). When these spillovers are relatively weak and the steady-state rate of productivity growth is relatively low, then trade liberalization promotes productivity growth in the short run and makes consumers better off in the long run. However, the reverse holds when knowledge spillovers are relatively strong and the steady-state rate of productivity growth is relatively high. Then trade liberalization retards productivity growth in the short run and makes consumers worse off in the long run.

To keep the analysis as streamlined as possible, this paper has focused on the symmetric country case. It would be interesting to explore how things change when countries differ in terms of resources or trade policies. Then the analysis becomes more complicated because asymmetries in resources or trade policies can produce asymmetric cut-off values for entering local and foreign markets. We have also restricted attention to the case where all innovations are new product varieties. It would be interesting to explore how the model's properties change when firms also do R&D to improve the quality of existing products. Trade liberalization could possibly stimulate R&D effort in that case. These are possible directions for future research.

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