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PRODUCTIVITY GROWTH IN BACKWARD ECONOMIES AND THE ROLE OF BARRIERS TO TECHNOLOGY ADOPTION

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Productivity growth in backward economies and the role of barriers to technology adoption*

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Abstract

We offer a barrier model of growth with a broader understanding of the sources of productivity growth. Organizational change is suggested as an alternative to innovation and technology adoption. Domestic and international barriers (related to the level of human capital and the trade share) determine the timing and pace of technological catch-up, and as opposed to the catching-up hypothesis backward economies may get stuck in a poverty trap. Growth in lagging economies is not driven by adoption of foreign technology due to inappropriateness. The large technological distance forces the economy to rely more on own productivity improvements through organizational change. Trade liberalization in backward economies does not give the expected boost to productivity growth, because of low capability to take advantage of the frontier technology. Economies can escape the poverty trap by reducing trade barriers, but the benefits from an open economy is highest in middle-income economies, which have both the potential and capability to adopt foreign technology.

JEL no. O3, O4
Keywords: Ramsey-model, sources of growth, trade barriers, poverty trap

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1. Introduction

In a recent theoretical investigation of the way out of backwardness, Acemoglu, Aghion and Zilibotti (2002) separate between investment-based growth with adoption of foreign technology and innovation-based growth. They see economic growth as a movement from adoption-oriented early stages to innovation-based growth later on. Similar, Vandenbussche, Aghion and Meghir (2004) develop a model of innovation and technology adoption, where productivity growth increases with the distance to the frontier and economies grow out of backwardness by adopting foreign technology. This is consistent with the catching up hypothesis, where the advantage of relative backwardness gives convergence between rich and poor countries. The profitability of technology adoption increases with the distance to the frontier due to higher learning potential. We offer a model where middle-income economies have the best potential for technology adoption, while backward economies may get stuck in a poverty trap due to high barriers to growth.

The optimistic view of backwardness represented by the catching-up hypothesis lacks empirical support. The data shows large income differences between countries. Recent surveys of empirical analyses of economic growth are offered by Durlauf and Quah (1999) and Temple (1999). Early evidence on multiple convergence clubs is provided by Baumol (1986). Quah (1993, 1997) studies the dynamics of cross-country incomes, and documents a twin-peaked distribution with clusters of rich and poor countries. Using a regression tree analysis Durlauf and Johnson (1995) also support the existence of different convergence clubs. The importance of productivity in explaining large income differences is supported in several empirical studies, for instance Klenow and Rodriguez-Clare (1997), Hall and Jones (1999), and Easterly and Levine (2001). Feyrer (2003) shows that the twin-peaked distribution of per capita income can be attributed to a twin-peaked distribution of productivity levels rather than to differences in physical or human capital accumulation.

The broad understanding of cross-country productivity differences is related to barriers (Parente and Prescott, 2004, Klenow and Rodriguez-Clare, 2004), and a large empirical literature has addressed the importance of barriers in economic growth. In a recent analysis Cole et al. (2004)

find a significant impact of domestic and international competitive barriers on Latin American productivity. Domestic barriers are linked to competitive restrictions like entry barriers, inefficient financial systems and subsidized state-owned enterprises. An alternative understanding of local barriers can be related to the human capital level, which in addition to stimulating own innovative activity, improve the economy's ability to take advantage of foreign technology. The importance of human capital in productivity growth is emphasized by Benhabib and Spiegel (1994). International barriers are typically measured by the degree of openness in the economy. In a study of R&D spillover in 77 developing countries, Coe et al. (1997) conclude that a developing country can boost its productivity by importing a larger variety of intermediate products and capital equipment embodying foreign knowledge. Rodriguez and Rodrik (2001) criticize the empirical trade-growth literature due to methodological problems, and claim that the positive relationship is questionable. In a recent contribution Harding and Rattsø (2005) address the endogeneity problem of openness and concentrate on tariff measures. Lee et al. (2004) utilize a new methodology of identification through heteroskedasticity. Both analyses confirm the positive impact of openness on economic growth.

While the early contribution by Nelson and Phelps (1966) focuses on growth through adoption of foreign technology, Benhabib and Spiegel (1994) extend the model to include innovation as a second channel of growth. But in the developing country context, the domestic research effort is minimal (documented by Cameron, 1998) and the modern technology can be hard to take advantage of due to inappropriateness (formalized by Basu and Weil, 1998). Papageorgiou's (2002a) assumption that backward economies are not able to adopt foreign technology is rationalized with several examples (page 351): "(…) it is doubtful that an Ethiopian farmer will benefit from the latest advances in animal genetics, or an Indian doctor from the latest innovations in laser surgery, or a Nepalese shopkeeper from the latest innovations in computerized inventory control". We share this pessimistic view of the benefit of frontier technology in backward economies.

Motivated by the lack of innovation and technology adoption in backward economies, we offer a broader understanding of productivity growth by suggesting a new specification of the sources of growth. In addition to innovation and adoption we model a third channel of growth related to structural change together with better organization and more discipline in the production process (for simplicity called organizational change). We build this new specification into a Ramsey growth model with domestic and international barriers to technology adoption related to the level of human capital and the trade share, respectively. We apply non-linear productivity dynamics giving multiple convergence clubs and possible technological divergence. Consistent with recent barrier models (Parente and Prescott, 2004, and Ngai, 2004) there exists an endogenous critical value of the technology gap determining whether countries catch-up towards the frontier or diverge. The threshold gap is endogenous and differs between countries and over time depending on the degree of barriers in the economy. The understanding is that countries below the threshold have not yet managed to start modern growth due to high level of barriers.

The model offers new insights on productivity growth in backward economies. As opposed to the catching up hypothesis economies lagging behind do not grow out of backwardness by adopting foreign technology. Lack of technological contact with the frontier makes the new technology inappropriate, and backward economies are forced to rely more heavily on own productivity improvements through organizational change. Productivity growth is positive, but not sufficient to catch-up towards the frontier, and the economy is stuck in a poverty trap with technological divergence. Trade liberalization and investment in human capital affect the threshold gap for catch-up and might get the economy growing. Technology adoption is most profitable in middle-income economies (not in backward economies), but consistent with the catching up hypothesis economies closer to the frontier gradually shift resources into innovation. Numerical simulations of different trade policy scenarios are related to the growth experience in South Africa, and show how barriers can have significant impact on the development path of an economy. An important lesson from the model is that trade liberalization in backward economies may not give the expected boost to productivity growth, because the large technological distance to the frontier makes the new technology inappropriate and hard to take advantage of.

The productivity dynamics of the model is discussed in section 2, while section 3 analyzes the allocation of human capital between different sources of growth. The intertemporal Ramsey model is presented in section 4, and section 5 offers numerical simulations of the impact of trade policy on productivity growth and allocation of resources. Section 6 concludes the paper.

2. Productivity dynamics and sources of growth

Innovation and technology adoption are regarded as the main sources of productivity growth, but in backward economies the R&D activity is limited and the frontier technology can be hard to take advantage of due to inappropriateness (as discussed in the introduction). Motivated by this we suggest a third channel of growth related to organizational change. As a reduced form specification we relate these productivity improvements to human capital and the technology gap. We assume that the growth potential from better organization within the firm increases with the distance to the technological frontier, since backward economies are likely to have more to gain from organizational change than developed economies.

Technology adoption typically combines two elements, the distance to the world technology frontier and the role of barriers. In models consistent with the catching-up hypothesis (Nelson and Phelps, 1966) productivity growth is higher the further from the frontier the economy is, due to higher learning potential. As documented in the introduction, this optimistic view of backwardness lacks empirical support. We follow the formulation in Lau and Wan (1993), where the technology gap has two opposite effects on technology adoption. The learning potential is higher in backward economies, but the capability to adopt foreign technology decreases with the distance to the frontier. The formulation limits the advantage of relative backwardness and gives best potential for technology adoption in middle-income economies. Papageorgiou (2002a) and Stokke (2004) apply similar productivity dynamics in an intertemporal general equilibrium framework. Barriers to technology adoption can be in the form of human capital as in Nelson and Phelps (1966) and Benhabib and Spiegel (2003), investment regulations as in Parente and Prescott (1994), or international barriers as suggested in a broad literature of technology spillovers and formulated by Grossman and Helpman (1991). We focus on the combined role of international and domestic barriers measured by trade and human capital, respectively. While interaction with the rest of the world through trade is important for the transfer of foreign technology, the level of human capital affects the ability to utilize the new technology. Growth generated from innovation depends on the amount of human capital allocated to R&D activities and on the distance to the technological frontier. The higher the level of relative productivity, the higher is the economy's ability to grow through innovation.

Based on this we define productivity growth $(\hat{A})$ as:

$$\hat{A} = \left(\frac{H_I}{H}\right)^{\gamma_1} \frac{A}{T} + b\left(\frac{H_A}{H}\right)^{\gamma_1} \left(\frac{EX+M}{Y}\right)^{\gamma_2} \left[\frac{A}{T} - \left(\frac{A}{T}\right)^2\right] + \left(\frac{H_S}{H}\right)^{\gamma_1} \left(1-\frac{A}{T}\right) \tag{1}$$

where H is the total amount of human capital, EX is exports, M imports, Y gross domestic product, T the productivity level at the technological frontier and b is a positive parameter. The first term on the right hand side is the contribution from innovation, the second term is the technology adoption function and the last term represents productivity improvements from organizational change. The total amount of human capital in the technology sector is allocated between the three sources of productivity growth (H_I, H_A and H_S respectively). The formulation implies decreasing returns to human capital and the trade share with the parameters γ_1 and γ_2 assumed to be less than 1.

The underlying assumption of the productivity specification is that the capability of the economy (broadly understood as level of education, quality of institutions, organization of firms etc.) increases as the economy catches up with the frontier. Consistently the growth potential from organizational change is higher in backward economies. The ability to adopt foreign technology and to grow through innovation increases as the economy catches up, but the profitability of adoption is counteracted by gradual saturation of adoption opportunities. The gap term in the adoption function consists of two factors: $v - v^2 = (1-v)\cdot v$, where $v = A/T$ is the technology gap. The first term ($1-v$) captures the advantage of relative backwardness, while the second term (v) represents the technological capability of the economy. While the learning potential increases with the distance to the frontier, a larger technology gap also makes the modern technology less appropriate and harder to take advantage of for the domestic economy. This can be related to the discussion by Abramovitz (1986), where backwardness represents a potential for catch-up, while the actual realization of the potential depends on the social capability of the economy.

The formulation in equation (1) limits the advantage of relative backwardness and as opposed to the catching up hypothesis middle-income economies have the best growth potential. The non-linear productivity dynamics gives multiple convergence clubs, and there exists a threshold value of the technology gap determining whether economies catch-up or diverge relative to the frontier. The threshold gap for catch-up is endogenously determined by the level of barriers to growth, and varies across economies and over time. Countries at the same level of development may face different threshold values depending on their absorptive and innovative capacity. The higher is the level of human capital and the degree of interaction with the rest of the world through trade, the more backward the economy can be and still be able to catch-up with the frontier. Assuming constant shares of human capital allocated to the different sources of growth and constant trade share the productivity dynamics are illustrated in Figure 1 below. The necessary conditions for multiple equilibria are outlined in Appendix A.

Figure 1 about here.

The horizontal axis shows the relative position to the frontier, while the productivity growth rate is given on the vertical axis. The further to the left the economy is positioned, the larger is the technology gap. Productivity growth at the frontier is set exogenously equal to g. When the domestic productivity growth rate exceeds the growth rate of the frontier, the economy is catching up and the gap decreases. Equivalent, lower productivity growth rate than the frontier increases the gap, as illustrated with arrows in Figure 1. A range of empirical studies of the pattern of economic growth are consistent with the assumed productivity dynamics in the model. Easterly and Levine (1997), Liu and Stengos (1999), Kalaitzidakis et al. (2001), Fiaschi and Lavezzi (2003) and Thorbecke and Wan (2004) all document a non-linear relationship between growth and GDP level with backward economies stuck in a poverty trap. The evidence implies increasing growth rate in the early stages of catching up with highest growth in middle-income economies. A concave productivity growth path generates a S-shaped technology diffusion path, which is empirically documented by Griliches (1957) and Gort and Klepper (1982), among others.

The model generates increasing productivity differences over time, since some countries are catching-up while others are stuck in a poverty trap with technological divergence. The timing and the degree of catch-up vary between countries depending on the level of barriers, consistent with the empirical analysis of Ngai (2004). Economies below the threshold gap have not yet managed to start modern growth because of high barriers to technology adoption (applies to most of Sub-Saharan Africa today). The common understanding in the literature is that increasing productivity differences between countries are a transitional phenomena. Growth miracles (or disasters) cannot last forever, and economies eventually return to world growth normals. Differences in growth rates are transitory, while differences in productivity levels are permanent (as shown by Acemoglu and Ventura, 2002). The model captures this long-run state through the endogenous nature of the threshold gap. Economies lagging behind can escape the poverty trap by investing in human capital or limiting the trade barriers. With a gradual reduction of barriers to growth the threshold gap asymptotically approaches zero, and most countries experience some degree of catch-up and converge to a common growth rate. But a shift from the low to the high convergence club does not necessarily generate a long period of high growth. The degree of catch-up depends on the level of barriers, and the economy may quickly return to the world growth rate with a permanent and large technology gap relative to the frontier.

3. Allocation of resources between different sources of growth

We study how the relative importance of domestic versus foreign sources of productivity growth varies with the level of development and the degree of openness in the economy, and follow the formulation of Romer (1990) assuming static allocation of human capital according to marginal productivities. Within the technology sector human capital is allocated between the three different sources of growth, and based on the first order conditions (see Appendix B) we find that:

$$\frac{H_A}{H_I} = b^{\frac{1}{1-\gamma_1}} \left(\frac{EX+M}{Y} \right)^{\frac{\gamma_2}{1-\gamma_1}} \left(1 - \frac{A}{T} \right)^{\frac{1}{1-\gamma_1}} \tag{2}$$

$$\frac{H_S}{H_I} = \left(\frac{1}{A/T} - 1 \right)^{\frac{1}{1-\gamma_1}} \tag{3}$$

$$\frac{H_A}{H_S} = b^{\frac{1}{1-\gamma_1}} \left(\frac{EX+M}{Y} \right)^{\frac{\gamma_2}{1-\gamma_1}} \left(\frac{A}{T} \right)^{\frac{1}{1-\gamma_1}} \qquad (4)$$

As the economy catches-up with the frontier innovation becomes more important, both relative to technology adoption and organizational change (assuming constant trade share). At the same time, the reliance on foreign technology increases at the cost of organizational factors. To see whether growth is driven primarily by adoption of foreign technology or by domestic factors (including both R&D and organizational change), we combine equations (2), (3) and (4). This gives us the allocation of human capital between domestic and foreign sources of growth as a function of the technology gap and the degree of interaction with the rest of the world through trade:

$$\frac{H_A}{H_I + H_S} = \frac{\left[b \left(\frac{EX+M}{Y} \right)^{\gamma_2} \right]^{\frac{1}{1-\gamma_1}}}{\left(1 - \frac{A}{T} \right)^{-\frac{1}{1-\gamma_1}} + \left(\frac{A}{T} \right)^{-\frac{1}{1-\gamma_1}}} \qquad (5)$$

Assuming constant trade share the allocation dynamics along the two growth paths are illustrated in Figure 2. The horizontal axis shows the relative position to the frontier, while human capital allocated to technology adoption relative to domestic sources of growth is given on the vertical axis. To illustrate the dynamics along the two growth paths, we indicate an assumed position of the threshold gap and the high equilibrium along the horizontal axis. As opposed to the catching up hypothesis backward economies diverge relative to the frontier, and productivity growth is not driven by adoption of foreign technology. Increasing technological distance with the frontier makes the modern technology inappropriate and hard to take advantage of for the domestic economy. Lack of ability to grow through innovation and R&D forces the economy to rely more heavily on productivity improvements through organizational change. This result differs from existing studies of growth (for instance Acemoglu et al., 2002 and Vandenbussche et al., 2004), where backward economies catch-up with the frontier by adopting modern technologies from abroad.

In economies above the threshold gap the importance of domestic versus foreign sources of growth changes during the catch-up process. In the early stages adoption costs decrease as the economy catches up, due to learning by doing and gradually higher degree of technological contact with the frontier. Modern technologies become more appropriate to the local production process, and resources are gradually allocated from domestic activities related to organizational change towards adoption of foreign technologies. As the technology gap decreases, the economy becomes more dependent on foreign technology, and the share of human capital allocated to adoption is not highest in backward economies, but rather in middle-income economies. The analysis by Eaton and Kortum (1997) document that about 80% of post World War II growth in Germany, France, UK and Japan is due to foreign innovations. This supports the high importance of technology adoption in middle-income economies.

Figure 2 about here.

Later in the catch-up process, gradual saturation of adoption opportunities and decreasing returns to learning result in higher dependence on domestic innovation. This is consistent with the econometric analysis of the Japanese growth experience by Cameron (2000), who documents an increasing reliance on R&D as the economy approaches the frontier. During the period of study Japan's productivity level relative to the US increases from about 0.5 in 1955 to 0.9 in 1989, and the shift towards innovation is most significant after the Japanese productivity level has exceeded about 80 percent of the US level. The higher degree of catch-up in the high equilibrium, the more dependent the economy is on innovation versus adoption in generating productivity growth. As documented by Eaton and Kortum (1997) more than 40% of growth in the US since 1950 is due to foreign innovations. This implies that even close to the frontier economies use resources to adopt and learn from others in equivalent positions, since economies develop different varieties of capital goods. Our analysis makes the simplifying assumption that productivity growth at the frontier (when $A = T$) is entirely driven by innovation through R&D activities. But a more realistic specification of the frontier sources of growth would only complicate the analytical solution and not change other results to a large extent.

4. The general equilibrium model

The productivity dynamics is part of a Ramsey growth model with intertemporal consumption and investment decisions. It is an expanding variety model in the tradition of Romer (1990), where productivity improvements result from an increase in the number of capital varieties. The economy consists of a perfectly competitive final good sector, a set of monopolistic producers of differentiated capital goods, and a technology sector producing blueprints for new capital varieties (described in the previous two sections). The economy is open to international trade, but faces a closed capital market. The interest rate is therefore endogenously determined at the domestic market. Investments consist of investment in blueprints and investment in differentiated capital goods, and are fully financed by domestic savings. The representative household is forward looking with rational expectations, and allocates consumption and savings to maximize an intertemporal utility function. We apply the model setup of Diao et al. (1999) as a benchmark with non-linear productivity dynamics and separation between domestic and foreign sources of productivity growth as the main extension. A complete description of the model is given in Appendix B, while the most important equations are presented below.

i) Production of final goods, differentiated capital goods and new blueprints

Output in the final-goods sector (*Y*) is produced from human capital (H_Y) together with a set of differentiated capital goods (X_i):

$$Y = BH_Y^{1-\alpha}\int_0^A X_i^{\alpha}di \qquad (6)$$

where *B* and α are constant parameters. *A* is the number of capital varieties and represents the productivity level in the economy. We make the simplifying assumption that one unit of capital good can be exchanged for one unit of final good, so the marginal cost of producing capital goods equals one. The monopolistic producer of variety *i* chooses the price (Px_i) that maximizes its profit:

$$\max_{Px_i} \pi_x = (Px_i - 1)X_i \qquad (7)$$

which, by applying the demand function for differentiated capital goods from final production, gives:

$$Px_i = \frac{1}{\alpha} \tag{8}$$

Symmetry ($Px_i = Px$ for all *i*) implies that each capital variety is produced at the same amount ($X_i = X$ for all *i*), and the production function in equation (6) can be written as:

$$Y = BH_Y^{1-\alpha} AX^{\alpha} \tag{9}$$

Monopolistic producers have forward looking behavior, and make investment decisions based on intertemporal profit maximization, which gives the following no-arbitrage condition:

$$rP_A = \pi_x + \Delta P_A \tag{10}$$

where P_A is the price of new blueprints and r is the domestic interest rate. At any point in time, the return to a riskless asset of size P_A must equal the expected return from an investment given on the right hand side of equation (10).

Productivity growth results from an increase in the number of capital varieties, which can be generated through technology adoption, innovation or organizational change. Production of new blueprints for capital goods and allocation of resources between domestic and foreign sources of growth are described in the previous two sections. The total supply of human capital, which is exogenous and constant, is applied both in the technology sector and the final good sector, and the wage rate (w) is determined from the market clearing condition:

$$H = H_Y + H_I + H_A + H_S \tag{11}$$

where H_Y, H_I, H_A and H_S are the amount of human capital allocated to final production, innovation, technology adoption and organizational change, respectively.

ii) The foreign sector and commodity equilibrium

The economy faces a closed capital market, and investments are fully financed by domestic savings. International trade is therefore balanced, with the value of imports equal to the value of exports. We assume imperfect substitution between domestic and foreign goods, and the model operates with a composite final good. Total import is endogenously determined through an

Armington composite system, while export is determined through a Constant Elasticity of Transformation (CET) function. Output from the final goods sector is demanded in several ways; consumption demand by households, export demand by foreigners, and investment demand from monopolistic producers.

iii) The household and consumption/saving

The representative household allocates income to consumption and savings to maximize its intertemporal utility. It receives wage income from final production and capital income from the production of differentiated capital goods. There is no independent government sector so public tax revenues from import tariffs are transferred to the household lump sum. We consider an infinite horizon model, and utility is maximized subject to an intertemporal budget constraint, which says that the discounted value of total consumption cannot exceed the discounted value of total income. Assuming intertemporal elasticity of substitution equal to one we have the well-known Euler equation for optimal allocation of total consumption expenditure (E) over time:

$$\frac{E_{t+1}}{E_t} = \frac{1+r_t}{1+\rho} \tag{12}$$

where r_t is the domestic interest rate and ρ the positive rate of time preference. The growth in consumption depends on the interest rate, the time preference rate, and the price path. Higher interest rate or lower time preference rate motivate more savings and thereby higher consumption spending in the future.

iv) Equilibrium

The long-run growth rate is endogenously determined by the productivity dynamics. In the high equilibrium the domestic economy grows at the frontier rate, and the technology gap is constant. Economies diverging to the low equilibrium have constant positive growth, but face an increasing technology gap relative to the frontier. All other quantity variables (like final output, consumption, import, export, household income, savings and investments) grow at the same rate as the productivity level (the growth rate of the number of blueprints). Since the supply of human capital is constant, the wage rate grows at the same growth rate. Other prices are constant in the long run.

In the steady state equilibrium the cost of a new blueprint is constant and equal to the discounted profits from sales of the capital good:

$$P_{A,T} = \frac{\pi_{x,T}}{r_T} \tag{13}$$

To have consumption growth consistent with the economy wide growth rate, the following relationship between interest rate and growth rate has to hold in the long run (derived from the Euler equation in (12) given constant prices):

$$1 + g_T = \frac{1 + r_T}{1 + \rho} \tag{14}$$

The subscript T represents the time periods of the steady state.

5. The impact of trade policy

In a general equilibrium framework Diao et al. (2005) investigate the role of openness for technology adoption, and show how protectionism limits foreign technology spillovers and decreases productivity growth. In the present model trade barriers interact with domestic barriers to growth (measured by human capital) and non-linear gap dynamics, and influence both the growth path and the optimal allocation of resources. A more protectionist trade policy increases the barriers to technology adoption by limiting the transfer of foreign technology, and resources are allocated towards domestically driven productivity improvements. As can be seen from equation (3) in section 3 the relative importance of the two domestic sources of growth is not affected by the degree of openness in the economy. But in absolute terms, increased protectionism in backward economies gives a shift towards organizational change, while economies closer to the frontier compensate the higher barriers to technology adoption by allocating resources towards own innovation.

Since the threshold gap for catch-up is endogenously determined by the level of barriers in the economy, a change in trade policy may generate a shift of convergence club with long run effects on growth and resource allocation. To study the dynamics close to the threshold gap we offer numerical simulations of different trade policy scenarios. The Ramsey model describes an economy with macroeconomic stability, full employment of resources, and flexible allocation of resources according to profitability. The assumptions are certainly heroic, and the labor market adjustments may be faster than in reality. But the model offers insights on important adjustment mechanisms between trade barriers, productivity growth and allocation of human capital along the development process. Calibration of important model parameters and initial values of variables are documented in appendix C.

We consider two backward economies that are at the same level of development (with relative productivity equal to 0.11) and face the same threshold gap. They start out at the high growth path with sufficient capacity to catch-up towards the frontier. Both economies are initially open to international trade with a trade-GDP ratio of about 0.6 and import tariffs at 5%, but we assume that they choose different trade policies over time. While one keeps an open regime with constant low tariffs (at 5%), the other gradually increases the degree of protection to a higher level (around 80%). Productivity growth and the relative importance of technology adoption in the two scenarios are compared in Figures 3a and 3b, respectively.

Figure 3a-b about here.

The more open economy slowly catches up towards the frontier, and adoption of foreign technology gets increasingly important as source of productivity growth. Since the economy still faces a large technology gap at the end of the period studied, it has not yet reached the turning point where resources are allocated towards innovation and R&D. The protectionist economy starts out above the threshold gap for catch-up, but due to increasing trade barriers, the cost of adopting foreign technology increases over time and productivity growth is held back. The ability to absorb foreign technology is reduced and the economy diverges relative to the frontier. While the open economy catches up towards the frontier with a technology gap of 0.16 after 150 years, the protectionist economy diverges and the relative level of productivity decreases to 0.06 during the same period. These dynamics are supported by the empirical analysis of Papageorgiou (2002b) showing that openness can be a source of clustering middle-income economies into high and low groups. The degree of trade barriers also affects the relative importance of domestic versus foreign sources of growth. High adoption costs due to lack of technological contact and increasing barriers to technology adoption forces the diverging economy to rely more heavily on own improvements of technology. The share of human capital allocated to adoption decreases over time, but is still about 50% after 150 years. Hence, given our parameter assumptions technology adoption continues to be the main source of productivity growth, but as the technology gap increases domestic factors like structural change, better organization and more discipline become relatively more important in generating productivity improvements.

The growth and allocation dynamics of the protectionist economy in Figure 3a-b can be related to the experience in South Africa during the international economic sanctions against the Apartheid regime. The country achieved remarkable high growth from 1960 to the mid-1970s with an average of above 6%. Then the economic growth shifted down in the mid-1970s and during the sanctions period. The growth episode followed by stagnation is clearly described by the relative performance of South Africa. GDP per capita relative to the US was about 0.21 in 1960 and reached a peak of 0.25 in 1974. Since the mid 1970s the gap to the technology frontier, here defined as the US, has been steadily rising, and by 2003 relative GDP per capita had declined to 0.13. Dijk (2002) documents a similar pattern of manufacturing labor productivity relative to the US, decreasing from 32% in 1970 to 20% in 1999. Lewis (2001) and Gelb (2004) offer a nice record of the recent economic history.

The dramatic shift in economic growth is partly captured by the general equilibrium model. The economy is initially on the high growth path and catches up towards the frontier. Economic sanctions then increase the barriers to technology adoption and limit the economy’s ability to take advantage of foreign technology. This forced protectionism generates a shift from the high growth path with technological catch-up to low growth and divergence. Technology adoption is still an important source of growth, but since foreign technology is getting increasingly inappropriate to the local production process and foreign spillovers are held back by sanctions, the economy is forced to rely more heavily on own improvements in technology. While South Africa in some aspects has the character of a developing economy, modern parts of the economy have the capacity to generate technological innovations. Productivity growth is therefore generated both through R&D and organizational change. The econometric panel analysis of the South African manufacturing sector during 1970-2002 by Harding and Rattsø (2005) documents how the productivity growth process shifted from the sanctions period to post-sanctions and how domestic factors were more important during sanctions.

The post-apartheid trade liberalization in South Africa has improved the economic performance, but growth has been erratic and low on average. This is consistent with the model proposed here, where trade liberalization in backward economies is less profitable than in models in the Nelson-Phelps tradition. Reduced trade barriers may not give the expected boost to productivity growth because the economy is too far from the frontier to take full advantage of the new technology. Domestic barriers related to the level of human capital also influence the impact of trade liberalization. Backward economies may escape the poverty trap by reducing trade barriers, but the benefits from an open economy are highest in middle-income economies, which have both the potential and capability to adopt foreign technology.

6. Concluding remarks

According to the catching up hypothesis (Nelson and Phelps, 1966) productivity growth increases with the distance to the frontier, and poor economies grow out of backwardness by adopting foreign technology. But this optimistic view of backwardness lacks empirical support. The data shows large income differences with poor countries stuck in a poverty trap. We offer a barrier model of growth with non-linear productivity dynamics giving multiple convergence clubs and possible divergence. The model suggests a broader understanding of productivity growth with organizational change as an alternative to innovation and technology adoption. We build this new specification into a Ramsey growth model with domestic and international barriers related to the level of human capital and the trade share, respectively. Consistent with recent barrier models (Parente and Prescott, 2004, and Ngai, 2004) there exists a critical value of the technology gap determining whether countries catch-up towards the frontier or diverge. The threshold gap varies over time and between countries and is endogenously determined by the degree of barriers in the economy. The understanding is that countries below the threshold have not yet managed to start modern growth due to high level of barriers.

The analysis offers new insights on productivity growth in backward economies. The learning potential increases with the distance to the frontier, but at the same time a large technology gap limits the capability of technology adoption, because the frontier technology is difficult to take advantage of in the local production process. As opposed to the catching-up hypothesis backward economies may get stuck in a poverty trap and growth is not driven by adoption of foreign technology. The large technological distance forces the economy to rely more on own productivity improvements through organizational change. Trade liberalization and investment in human capital affect the threshold gap for catch-up and might get the economy growing. But the benefits from an open economy are highest in middle-income economies, which have both the potential and capability to adopt foreign technology. An important lesson from the model is that trade liberalization in backward economies may not give the expected boost to productivity growth, because the large technological distance to the frontier makes the new technology inappropriate and hard to take advantage of.

In the analysis of human capital allocation between domestic and foreign sources of growth, we have applied the Romer (1990) formulation based on static marginal productivities. Future research must address the full intertemporal modeling of the generation and allocation of human capital. We assume that the total level of human capital is constant during the development process, while in a more full-specified model the human capital level varies with the level of development. But since both domestic and foreign sources of growth are negatively affected by a reduction in the human capital level, this extension of the model is not likely to affect the allocation dynamics, but only further depresses productivity growth in backward economies.

Appendix A: Necessary conditions for multiple equilibria

The productivity growth rate is defined as:

$$\hat{A}=\left(\frac{H_I}{H}\right)^{\gamma_1}\frac{A}{T}+b\left(\frac{H_A}{H}\right)^{\gamma_1}\left(\frac{EX+M}{Y}\right)^{\gamma_2}\left[\frac{A}{T}-\left(\frac{A}{T}\right)^2\right]+\left(\frac{H_S}{H}\right)^{\gamma_1}\left(1-\frac{A}{T}\right)$$

The dynamics is illustrated in Figure 1 in the paper, and necessary conditions for multiple equilibria are:

i) <u>The optimal level of development is given by a technology gap between 0 and 1.</u>
By differentiating the productivity growth function above, we find that productivity growth is highest when the technology gap is given by:

$$\frac{A}{T}=\frac{\left(\frac{H_I}{H}\right)^{\gamma_1}+b\left(\frac{H_A}{H}\right)^{\gamma_1}\left(\frac{EX+M}{Y}\right)^{\gamma_2}-\left(\frac{H_S}{H}\right)^{\gamma_1}}{2b\left(\frac{H_A}{H}\right)^{\gamma_1}\left(\frac{EX+M}{Y}\right)^{\gamma_2}}=\frac{1}{2}+\frac{\left(\frac{H_I}{H}\right)^{\gamma_1}-\left(\frac{H_S}{H}\right)^{\gamma_1}}{2b\left(\frac{H_A}{H}\right)^{\gamma_1}\left(\frac{EX+M}{Y}\right)^{\gamma_2}}$$

The necessary condition is therefore:

$$-\frac{1}{2}<\frac{\left(\frac{H_I}{H}\right)^{\gamma_1}-\left(\frac{H_S}{H}\right)^{\gamma_1}}{2b\left(\frac{H_A}{H}\right)^{\gamma_1}\left(\frac{EX+M}{Y}\right)^{\gamma_2}}<\frac{1}{2}$$

ii) <u>The maximum growth rate exceeds the growth rate at the frontier.</u>
By inserting the expression for the technology gap found under *i*) the highest possible productivity growth rate is found as:

$$\hat{A}_{\max}=\frac{\left[\left(\frac{H_I}{H}\right)^{\gamma_1}+b\left(\frac{H_A}{H}\right)^{\gamma_1}\left(\frac{EX+M}{Y}\right)^{\gamma_2}-\left(\frac{H_S}{H}\right)^{\gamma_1}\right]^2}{4b\left(\frac{H_A}{H}\right)^{\gamma_1}\left(\frac{EX+M}{Y}\right)^{\gamma_2}}+\left(\frac{H_S}{H}\right)^{\gamma_1}>\hat{T}$$

which must be higher than the frontier growth rate.

iii) <u>The growth rate for $A/T = 0$ and $A/T = 1$ cannot exceed the frontier rate.</u>
When $A/T = 0$ all human capital in the technology sector is allocated to domestic productivity improvements related to organizational change and the growth rate is given as:

$$\hat{A}_{A/T=0}=\left(\frac{H_S}{H}\right)^{\gamma_1}<\hat{T}$$

Similar, when $A/T = 1$ all human capital in the technology sector is allocated to R&D activities and the growth rate is given as:

$$\hat{A}_{A/T=1}=\left(\frac{H_I}{H}\right)^{\gamma_1}<\hat{T}$$

If the share of total human capital allocated to the technology sector is the same for the two extreme values of the technology gap, the growth rates are also similar.

Appendix B: The full intertemporal model

The model is in the expanding variety tradition of Romer (1990), and consists of three sectors; a final-good sector, a capital-good sector, and a technology sector.

Final-good sector

Final goods are produced from human capital together with a variety of capital goods:

$$Y_t = BH_{Y,t}^{1-\alpha} \int_0^{A_t} X_{i,t}^{\alpha} di \,, \qquad 0 < \alpha < 1$$

The first order conditions following from profit maximization under perfect competition are given as:

$$PY_t \frac{\partial Y_t}{\partial H_{Y,t}} = w_t \quad \Rightarrow \quad PY_t B(1-\alpha) H_{Y,t}^{-\alpha} \int_0^{A_t} X_{i,t}^{\alpha} di = w_t$$

$$PY_t \frac{\partial Y_t}{\partial X_{i,t}} = Px_{i,t} \;\Rightarrow\; X_{i,t} = \left(\frac{PY_t \alpha B}{Px_{i,t}} \right)^{\frac{1}{1-\alpha}} H_{Y,t}$$

Capital-good sector

We make the simplifying assumption that one unit of capital good can be exchanged for one unit of final good, and the marginal cost of manufacturing capital goods therefore equals one. The monopolistic producer of variety *i* chooses the price that maximizes its profit:

$$\max_{Px_i} \pi_{x,t} = (Px_i - 1) X_{i,t}$$

which, by applying the demand function for capital goods gives:

$$Px_i = \frac{1}{\alpha}$$

Symmetry ($Px_i = Px$ for all *i*) implies that each capital variety is produced at the same amount:

$$X_{i,t} = X_t = (PY_t \alpha^2 B)^{\frac{1}{1-\alpha}} H_{Y,t}$$

The production function can then be written as:

$$Y_t = BH_{Y,t}^{1-\alpha} A_t X_t^{\alpha}$$

The first order conditions with respect to human capital and differentiated goods can be simplified to:

$$(1-\alpha) PY_t Y_t = w_t H_{Y,t}$$

$$\alpha PY_t Y_t = Px A_t X_t$$

Monopolistic producers have forward looking behavior, and make investment decisions based on intertemporal profit maximization, which gives the following no-arbitrage condition:

$$(1+r_t) P_{A,t} = \pi_{x,t} + P_{A,t+1}$$

Technology sector

Productivity growth results from an increase in the number of capital varieties, and is determined by a combination of domestic and foreign factors:

$$\hat{A}_t = \left(\frac{H_{I,t}}{H} \right)^{\gamma_1} \frac{A_t}{T_t} + b \left(\frac{H_{A,t}}{H} \right)^{\gamma_1} \left(\frac{EX_t + M_t}{Y_t} \right)^{\gamma_2} \left[\frac{A_t}{T_t} - \left(\frac{A_t}{T_t} \right)^2 \right] + \left(\frac{H_{S,t}}{H} \right)^{\gamma_1} \left(1 - \frac{A_t}{T_t} \right)$$

where the first term on the right hand side is the contribution from innovation through R&D, the second term is the technology adoption function and the last term represents productivity improvements through organizational change. The production function for new varieties of capital goods is hence given as:

$$\hat{A}_t = A_t\left(\frac{H_{I,t}}{H}\right)^{\gamma_1}\frac{A_t}{T_t} + bA_t\left(\frac{H_{A,t}}{H}\right)^{\gamma_1}\left(\frac{EX_t + M_t}{Y_t}\right)^{\gamma_2}\left[\frac{A_t}{T_t} - \left(\frac{A_t}{T_t}\right)^2\right] + A_t\left(\frac{H_{S,t}}{H}\right)^{\gamma_1}\left(1 - \frac{A_t}{T_t}\right)$$

Allocation of human capital within the technology sector is based on marginal productivities:

$$P_{A,t}\frac{\partial \dot{A}_t}{\partial H_{I,t}} = w_t \quad \Rightarrow \quad P_{A,t}A_t\gamma_1 H_{I,t}^{\gamma_1 - 1}H^{-\gamma_1}\frac{A_t}{T_t} = w_t$$

$$P_{A,t}\frac{\partial \dot{A}_t}{\partial H_{A,t}} = w_t \quad \Rightarrow \quad P_{A,t}b\gamma_1 H_{A,t}^{\gamma_1 - 1}H^{-\gamma_1}\left(\frac{EX_t + M_t}{Y_t}\right)^{\gamma_2} A_t\left[\frac{A_t}{T_t} - \left(\frac{A_t}{T_t}\right)^2\right] = w_t$$

$$P_{A,t}\frac{\partial \dot{A}_t}{\partial H_{S,t}} = w_t \quad \Rightarrow \quad P_{A,t}A_t\gamma_1 H_{S,t}^{\gamma_1 - 1}H^{-\gamma_1}\left(1 - \frac{A_t}{T_t}\right) = w_t$$

The total supply of human capital is exogenous and constant, and the wage rate is determined from the market clearing condition:

$$H = H_{Y,t} + H_{I,t} + H_{A,t} + H_{S,t}$$

The consumer's decision

The representative consumer maximizes an intertemporal utility function over time taking into account the current budget constraint for each period:

$$Max\ \ U_1 = \sum_{t=1}^{T}(1+\rho)^{-t}\ln(C_t) + \ln(C_T)\frac{(1+\rho)^{1-T}}{\rho}$$

$$s.t.\ \ PC_t \cdot C_t = Inc_t - Sav_t$$

where U_1 is the value of the intertemporal utility evaluated at time period 1's price.

$$Inc_t = w_t H_{Y,t} + PxA_t X_t + tm_t \cdot PWM \cdot M_t$$

The first-order condition for the consumer's problem is:

$$\frac{E_{t+1}}{E_t} = \frac{1+r_t}{1+\rho}$$

where $E_t = PC_t \cdot C_t$.

This equation says that growth in consumption depends on the interest rate, the time preference rate and the price path. Higher interest rate or the lower time preference rate motivates more savings and thereby higher consumption spending in the future.

Exports and Imports

Imports and domestic demand are endogenously determined through an Armington function, and domestic and foreign goods are imperfect substitutes. The demand functions are derived from minimizing current expenditure, subject to the Armington function:

$$Min\ \ PM_t \cdot M_t + PD_t \cdot D_t$$

$$s.t.\ \ CC_t = aa[ma \cdot M_t^{-exa} + (1-ma)D_t^{-exa}]^{-1/exa}$$

where $PM_t = PWM_t(1+tm_t)$ is the price of import goods.
The first order conditions:

$$\frac{M_t}{CC_t} = aa^{\frac{-exa}{exa+1}} \cdot \left(ma \frac{PC_t}{PM_t} \right)^{\frac{1}{exa+1}}$$

$$\frac{D_t}{CC_t} = aa^{\frac{-exa}{exa+1}} \cdot \left((1-ma) \cdot \frac{PC_t}{PD_t} \right)^{\frac{1}{exa+1}}$$

where $exa = \frac{1}{\sigma_m} - 1$.

Sales to export market versus domestic market are endogenously determined through a CET function, and domestic and export goods are imperfect substitutes. The supply functions are derived from maximizing current sales income, subject to the CET function:

$$Max \quad PD_t \cdot D_t + PE \cdot EX_t$$

$$s.t. \;\; Y_t = ac[mc \cdot EX_t^{-exc} + (1-mc)D_t^{-exc}]^{1/exc}$$

where *PE* is the export price.

The first order conditions:

$$\frac{D_t}{Y_t} = ac^{\frac{exc}{1-exc}} \cdot \left((1-mc) \cdot \frac{PY_t}{PD_t} \right)^{\frac{1}{1-exc}}$$

$$\frac{EX_t}{Y_t} = ac^{\frac{exc}{1-exc}} \cdot \left(mc \cdot \frac{PY_t}{PE} \right)^{\frac{1}{1-exc}}$$

where $exc = \frac{1}{\sigma_e} + 1$.

Balanced payment condition

$$PWM_t \cdot M_t = PE \cdot EX_t$$

$$Sav_t = A_t X_t + P_{A,t} \dot{A}_t$$

Commodity market equilibrium

$$CC_t = C_t + A_t X_t + P_{A,t} \dot{A}_t$$

Equilibrium

The long-run growth rate is endogenously determined by the productivity dynamics. All other quantity variables (like final output, consumption, import, export, household income, savings and investments) grow at the same rate as the productivity level (the growth rate of the number of blueprints). Since the supply of human capital is constant, the wage rate grows at the same growth rate. Other prices are constant in the long run.

In the steady state equilibrium the cost of a new blueprint is constant and equal to the discounted profits from sales of the capital good:

$$P_{A,T} = \frac{\pi_{x,T}}{r_T}$$

To have consumption growth consistent with the economy wide growth rate, the following relationship between interest rate and growth rate has to hold in the long run (derived from the Euler equation given constant prices):

$$1 + g_T = \frac{1 + r_T}{1 + \rho}$$

The subscript *T* represents the time periods of the steady state.

<u>Notation</u>

Parameters

α	share parameter for capital goods in final production
exa	exponent in Armington functions
σ_m	elasticity of substitution between imported and domestic goods
ma	share parameter in Armington function
aa	shift parameter in Armington function
exc	exponent in CET functions
σ_e	elasticity of substitution between domestic goods and exports
mc	share parameter in CET function
ac	shift parameter in CET function
ρ	rate of consumer's time preference
γ_1	elasticity wrt human capital in productivity growth function
γ_2	elasticity wrt trade in productivity growth function
b	parameter in productivity growth function
B	parameter in production function final goods

Exogenous variables

PWM	world import price
PE	world export price
tm	tariff rate
H	total supply of human capital
T	productivity level at the frontier
Px	monopolistic price differentiated capital goods

Endogenous variables

r_t	domestic interest rate
Y_t	output of final goods
X_t	amount demanded of each capital good
A_t	number of capital varieties (domestic productivity level)
$\dot{A}_t$	production of new capital varieties (change in productivity level)
$\hat{A}_t$	productivity growth

g_t	endogenous growth rate
$H_{Y,t}$	human capital in final production
$H_{I,t}$	human capital in innovation
$H_{A,t}$	human capital in technology adoption
$H_{S,t}$	human capital in organizational change
D_t	domestic demand and supply of the final good
M_t	imports
CC_t	total absorption of the composite good
EX_t	exports
C_t	consumer's demand for the final good
Inc_t	consumer's income
Sav_t	consumer's savings
w_t	wage rate
PY_t	producer price for final goods
PC_t	Armington composite price for final goods
PD_t	domestic price
PM_t	import price
$P_{A,t}$	price of new blueprints
$\pi_{x,t}$	profit in production of capital goods

Appendix C: Calibration

The model is calibrated as steady-state equilibrium with growth rate of 2%. The calibration assumes a technology gap equal to 0.1, which gives the threshold gap for catch-up (given the initial values of trade and human capital). The representative economy is assumed to be open with total trade as share of GDP of 0.56. The capital market is closed, and the value of imports equals the value of exports. Initial import tariffs are 5% of total imports. Exports account for 27% of total final good production, and total demand consists of 28% imported goods. Total supply of human capital is allocated between final production, technology adoption, innovation and organizational change. Initial calibrated values imply that 79% of total human capital is allocated to the technology sector, while 77% of the human capital within the technology sector is applied on technology adoption, 0.5% on innovation and the remaining 22.5% on organizational change. Factor shares in final production equal 0.53 for human capital and 0.47 for differentiated capital goods. The household saves 26% of its income, while the rest is spent on consumption of the final good. The domestic interest rate is set to 0.1, and the time preference rate is calibrated consistent with the Euler equation. The elasticity of substitution in both the Armington and CET functions are assumed to be equal to 3. These elasticities represent substitution possibilities between domestic and foreign goods (Armington), and between sales to domestic markets versus export markets (CET). The elasticity of growth from innovation, adoption and organizational factors with respect to human capital allocated to the different sources of growth is set to 0.4, while the elasticity of foreign driven growth with respect to the degree of interaction with the rest of the world through trade is assumed to equal 0.3. The parameter *b* is calibrated so that the productivity dynamics generate multiple equilibria.

Values of selected parameters and variables (initial value for endogenous variables)

Definition	Symbol in the model	Value
Parameters		
Share of capital goods in final production	α	0.47
Parameter in final production function	B	1.97
Parameter in productivity growth function	b	24.9
Elasticity of innovation and adoption wrt. human capital	γ_1	0.4
Elasticity of adoption wrt degree of openness	γ_2	0.3
Distribution parameter Armington function	ma	0.42
Distribution parameter CET function	mc	0.58
Elasticity in Armington function	σ_{m}	3
Elasticity in CET function	σ_{e}	3
Shift parameter in Armington function	aa	1.93
Shift parameter in CET function	ac	2.08
Time preference rate	ρ	0.078
Import tariffs	tm	0.05
Variables		
Output final production	Y	699
Human capital in final production	H_Y	372
Human capital in technology adoption	H_A	1070
Human capital in modern innovation	H_I	8
Human capital in organizational change	H_S	314
Total supply human capital	H	1764
Demand for each capital good	X	76.5
Domestic productivity level	A	2
Frontier productivity level	T	20
Technology gap	A/T	0.1
Household income	Inc	708.5
Consumption	C	520.7
Savings (which equals total investment)	Sav	187.8
Price new blueprints	P_A	870
Profit in capital production	π_x	87
Imports	M	199.5
Exports	EX	190
Import price	PWM	0.95
Export price	PE	1
Wage rate	w	1
Domestic demand	D	509
Total demand	CC	708.5
Overall growth rate	g	0.02
Domestic interest rate	r	0.1

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Figure 1: Productivity dynamics (assuming no allocation dynamics and constant trade share).

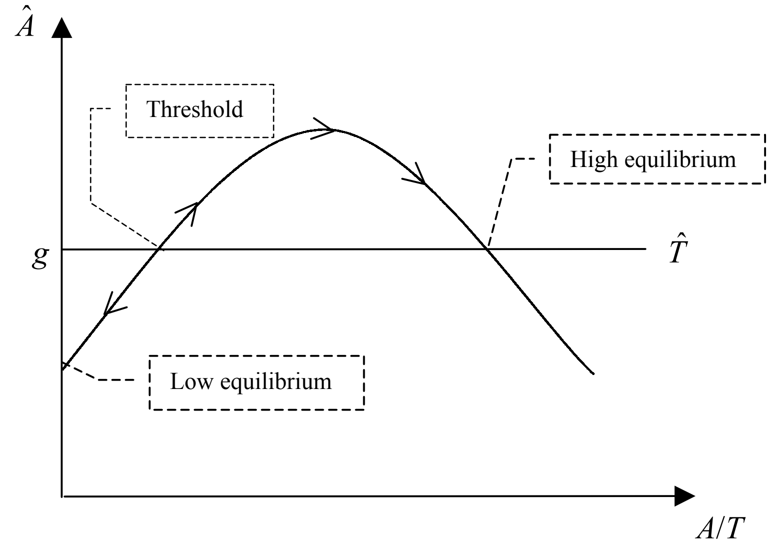

Figure 2: Allocation dynamics along the two growth paths (assuming constant trade share): Foreign relative to domestic sources of growth as a function of the technology gap.

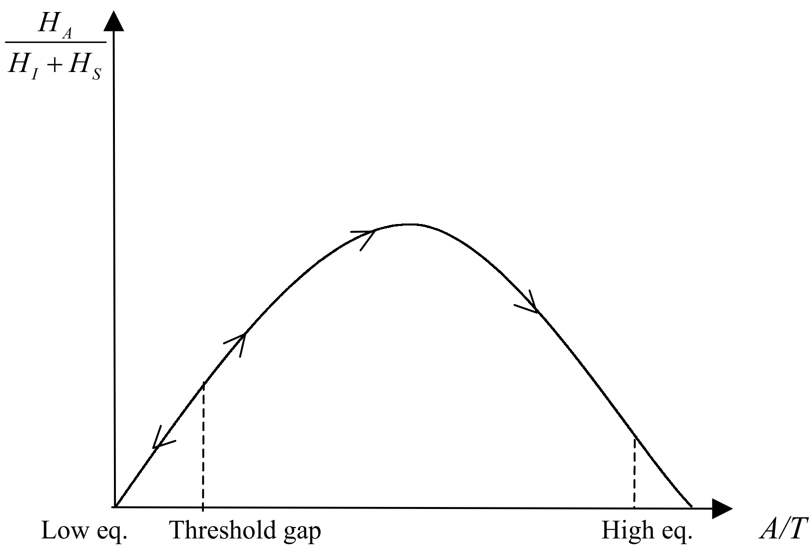

Figure 3a. Comparing productivity growth in two economies that are initially equal, but who choose different trade policies over time.

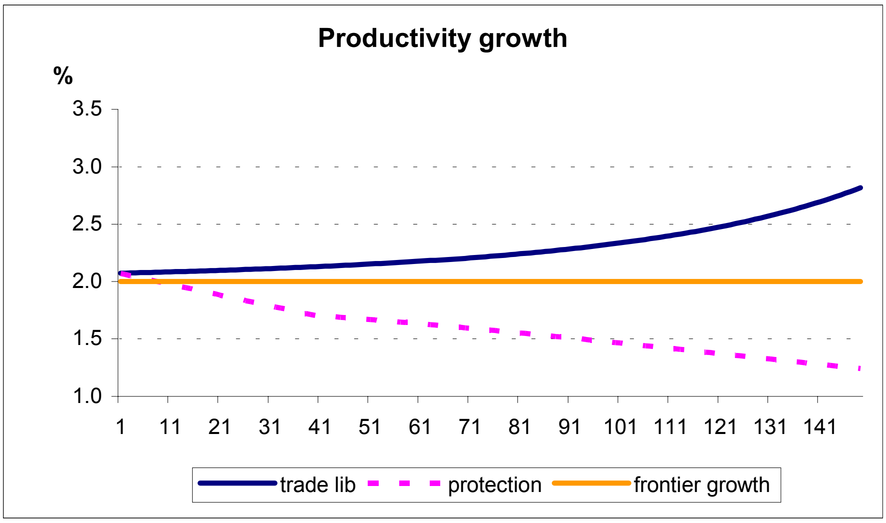

Figure 3b. Comparing the share of human capital in the technology sector allocated to technology adoption in two economies that are initially equal, but who choose different trade policies over time.