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**Avoiding the Trap: The Dynamic  
Interaction of North-South Capital  
Mobility and Technology Diffusion**

**by Michael Hübler**

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## **Avoiding the Trap: The Dynamic Interaction of North-South Capital Mobility and Technology Diffusion\***

Michael Hübler

Abstract:

This paper analyzes a stylized model of international capital mobility and diffusion of embodied technologies from North to South. The South can fall behind in terms of technologies or get trapped in a situation, in which it is unable to attract foreign capital and embodied technologies, if its absorptive capacity is too low. The paper reconciles the view that technological catching up is stronger, the larger the technology gap, with the alternative view that technological catching up is strongest at a medium technology gap. The closer the South is to the technology frontier, the more beneficial is a higher income share of foreign capital. The speed of technology diffusion is higher in small economic regions with high population densities.

Keywords: Technology diffusion, technology transfer, capital mobility, human capital, absorptive capacity

JEL classification: F21, O11, O33, O47

### **Michael Hübler**

Kiel Institute for the World Economy

24100 Kiel, Germany

Telephone: +49(431) 8814-401

E-mail: michael.huebler@ifw-kiel.de

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# 1 Introduction

Technology diffusion from industrialized to developing countries is a promising way of economic development (World Bank 2008). Moreover, the potential of international technology diffusion for reducing the energy intensities of economic activities in the developing world and thus for reducing greenhouse gas emissions has become increasingly important. The 2007 Bali conference on climate policy emphasized the responsibility of the industrialized countries to help the developing countries to achieve their emission targets. Most likely, adopting advanced technologies from industrialized countries is much faster and more efficient than inventing own technologies in developing countries. Among the potential channels of international technology transfer - trade, foreign direct investment, migration, patent citations, scientific literature, communication and information technologies and so forth - this paper focuses on international capital movements or in other words foreign direct investment (FDI). Capital flows jointly with embodied technologies to recipient countries, improves their capital and technology endowments and additionally creates technology spillovers to local firms (via imitation of products and machinery, demonstration effects, labor turnover and vertical linkages, increased competition of foreign and domestic firms; compare Saggi 2002).

While some developing countries have been able to converge towards the industrialized countries in terms of technology levels, other developing countries have fallen further behind (World Bank 2008). Herein, the human capital endowment of a recipient developing country is a main determinant of the success of technology adoption via FDI (see for instance World Bank 1993). Additionally, own innovation performed in a developing country might be an effective substitute or support for technology adoption (Lall and Urata 2003).

While there is a broad strand of empirical literature on the effects of capital inflows on productivity and growth, theories on technology diffusion via capital inflows are rare (for example Findlay 1978, Wang and Blomström 1992, Das 1987, Mayer-Foulkes and Nunnenkamp 2008). And there is no common intuitive theory that describes the dynamic interactions of international capital movements, technology diffusion, innovation and absorptive capacity of the recipient country.

Our study investigates the dynamic interaction of North-South capital mobility and technology diffusion building on Nelson and Phelps (1966, in the following denoted by

N&P). Our study deals with the question, whether market forces enable international transfer of capital and embodied technologies in such a way that the technology growth rate a developing country catches up with the growth rate of an industrialized country and that the technology gap narrows. If there is an automatic technology diffusion mechanism that narrows the technology gap, this will be an argument for development and climate policy not to overreact and to let market forces work instead. If, on the other hand, there is a risk that technology diffusion does not occur sufficiently based on market forces, there will be need for policy interventions that actively support technology diffusion processes and that support the absorptive capacities of developing countries. Our consecutive question is, whether own innovation in developing countries can remedy the convergence failure.

The main contribution of this paper is to provide a theoretical explanation for the phenomenon frequently identified in the empirical literature and discussed by the World Bank (2008): The North-South technology gap widens and convergence of technology growth rates might fail in some, but not in all developing countries. This outcome is also a possible explanation for the diverse results of the econometric literature on the impact of FDI on growth and the role of human capital for technology diffusion.

Furthermore, there is the point of view that technology diffusion is strongest at a medium technology gap as described by Benhabib and Spiegel (2005). So far this has been an artificial construction in order to explain the observation that certain countries fall behind in terms of technologies. A contribution of this paper is to derive this outcome theoretically through the introduction of international capital mobility.

We also examine the potential of own innovation in the South for narrowing the technology gap and preventing the convergence failure. Although technology diffusion and own innovation in the South are basically substitutes, they can positively interact as complements in the short run. The reason is that innovations raise total factor productivity, which in turn attracts more foreign capital and embodied technologies. On the other hand, own innovation in the South cannot prevent falling behind in terms of technologies in the long-run, except when the South is as innovative as the North. Different to the original theory by Nelson and Phelps, in our model a higher technology *level* in the North increases the technology gap in the presence of own innovation in the South, since some of the newly arriving technologies are already known.

According to our model, a larger income share of internationally mobile foreign capital is more beneficial for technology diffusion, when the South is close to the technology frontier. Finally, the model favors small economic regions with high population densities concerning the technology diffusion speed in accordance with agglomeration theories and with reality: Asian miracles like Hong Kong and Taiwan, and China's Special Economic Zones have shown extraordinarily high growth rates.

The paper proceeds as follows. Section 2 briefly reviews the related theoretical and empirical literature. Section 3 re-interprets the Nelson and Phelps theory in the context of FDI in general form. Section 4 introduces internationally mobile capital explicitly in a simple myopic market solution approach. Section 5 discusses the results. Section 6 concludes.

## 2 Literature Background

This section at first describes empirical studies on FDI induced productivity gains. This section then presents theoretical approaches dealing with productivity gains via international capital mobility.

There is a broad strand of the empirical literature on international technology diffusion via FDI including cross-country panel analyses as well as case studies for specific countries. Numerous econometric studies examine the effects of FDI inflows on GDP growth of the recipient countries or productivity spillovers from foreign to domestic firms - with diverse results. (Kokko 1992, Blomström and Kokko 1998, OECD 2002, Keller 2004, Saggi 2002 provide detailed literature surveys. Chen and Dunning (1994) also include comprehensive theoretical background information. Concerning East Asian economies see Lall and Urata 2003.) A number of studies confirm the positive effect of human capital on technology diffusion (Benhabib and Spiegel 1994, Crispolti and Marconi 2005, Kneller 2005, Girma 2005, Lai et al. 2006), while others do not confirm it (Sjöholm 1997, Xu and Wang 2000). Some papers additionally find a minimum human capital level which is necessary to enable technological catching up (Borensztein et al. 1998, Crespo et al. 2004, Benhabib and Spiegel 2005, Ciruelos and Wang 2005, also see OECD 2002). Mayer-Foulkes and Nunnenkamp (2008) observe that FDI accelerates eco-

conomic convergence among high-income countries, while it widens the income differential between the USA and low- and middle-income countries.

Moreover, the econometric literature examines the role of the technology gap between the technology in practice in the recipient country and the technology frontier. Some studies find evidence for the hypothesis that the technology diffusion strength increases the larger the technology gap (Griffith et al. 2002, Girma 2005, Griffith et al. 2004, weak evidence by Kokko et al. 1996). Others support the hypothesis of an inverted U-shaped relation of the technology gap and the technology diffusion strength (Benhabib and Spiegel 2005, Girma et al. 2001) or a U-shaped relation (Girma and Görg 2005).

The World Bank (2008) summarizes the effects of technology diffusion to developing countries as follows:

”The level of technological achievement in developing countries has converged with that of high-income countries over the past 15 years. A sustained policy of increased openness to foreign trade and foreign direct investment (FDI), plus increased investments in human capital, have contributed to substantial improvements in technological achievement in developing countries over the past 15 years. And despite rapid progress at the technological frontier, technological achievement in both low- and middle-income countries has increased much more rapidly than in high-income countries. As a result, developing countries have closed the relative gap with high-income countries. However, the gap remains large. Moreover, the strong aggregate performance of low-income countries reflects large improvements in technological achievement by some, but much more modest advances by the majority. As a consequence, many are only maintaining pace with, or even losing ground to, high-income countries.”

An important strand of the theoretical literature deals with endogenous growth via horizontal or vertical product (variety) improvements, for example Krugman (1979), Romer (1990), Grossman and Helpman (1991), Barro and Sala-i-Martin (1997), Aghion and Howitt (2005). Acemoglu, Aghion and Zilibotti (2003a, 2003b) provide full micro founded analyses of imitation and innovation dependent on the distance to the technology frontier.

Our study abstracts from the sources of innovation and economic activities on the micro level and rather examines technology diffusion processes on a macro level in order to understand the large-scale time paths and interactions. We build on Nelson and Phelps (1966, henceforth denoted by N&P). In their macroeconomic model, N&P for-

malize the so-called Veblen-Gerschenkron effect.<sup>1</sup> Their intuitive approach has been applied in a number of studies.<sup>2</sup>

Only few theoretical models specifically deal with FDI as a channel of technology transfer. Findlay (1978) sets up a model of technology diffusion through FDI, where the rate of technical progress in the recipient backward region is a negative function of the technology level in the backward region relative to the level in the advanced region, and a positive function of the stock ratio of foreign to domestic capital within the backward region. Das (1987) examines the optimal dynamic behavior of multinational firms when knowledge spillovers to rivals in the host country occur. He shows that the indigenous firms do not necessarily benefit from the technology transfer to subsidiaries of multinationals firms, while the host economy as a whole always benefits. Wang and Blomström (1992) endogenize technology transfer via capital mobility including costs of transferring technologies and of learning. Building on N&P, Diao et al. (2005) multiply the share of intermediate goods imports in GDP by the share of imported capital in GDP and by the distance to the technology frontier. Their approach takes into account that foreign firms likely import advanced capital goods (from their home countries). Mayer-Foulkes and Nunnenkamp (2008) show which conditions for the strength of technology transfer and for convergence forces must be fulfilled in order to guarantee international convergence of economic growth rates.

Nonetheless, the existing theories do not directly explain the empirical facts described before. Against this background, the contribution of this paper is to provide an intuitive theoretical description of international technology transfer via capital mobility that can explain the empirical evidence described above.

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<sup>1</sup>Gerschenkron (1962) studies the phenomenon of technological catching up of countries that have fallen behind.

<sup>2</sup>Aghion (2007), for instance, applies the N&P approach to examine the effect of education on growth.

### 3 The Nelson and Phelps Theory in the Context of International Capital Mobility

The considerations of N&P are based on the Veblen-Gerschenkron effect (Gerschenkron 1962). According to the N&P theory, technological catching up is faster the larger the gap between the technology in practice and the technology frontier and the better the human capital endowment. When the technology level of the "learning" country is low, most of the newly arriving technologies are not yet known and therefore beneficial. The higher the level, which the "learning" country has reached, the more newly appearing technologies are already known and therefore without an additional benefit. Human capital (educational attainment) enhances the technology diffusion speed for every given technology gap, since it improves the ability to adopt and apply new technologies. In case of exogenous technological progress of the frontier, the technology in practice follows the frontier with the same rate of technological progress and a constant relative technology gap.

The model can be applied to an industrialized country (technological leader, denoted by North) that creates the leading technology and a developing country (technological follower, denoted by South), that adopts technologies from the North and follows with a certain technology gap (compare Benhabib and Spiegel 2005). In this context we replace human capital by the absorptive capacity, including all factors that determine the ability of the host country to benefit from the transferred technologies. While in N&P the technology diffusion speed only depends on the human capital endowment, in our re-interpretation it also depends on the foreign capital intensity following Findlay (1978).

In contrast to the original N&P theory, the empirical evidence shows that many developing countries are not able to catch up. For that reason, the original equation has been artificially modified in the literature so that catching up is fastest for a medium technology gap and decreases the larger the gap and also the smaller the gap (logistic model, e.g. described by Benhabib and Spiegel 2005). As a consequence, it is possible that a country falls technologically further behind. But this assumption seems intuitively not convincing. Why should a country with high educational attainment, a stable political and legal system and good infrastructure not be able to catch up in a certain sector



or field of technology such as solar energy generation where it has completely missed the newest technological development? The inability of developing countries to catch up probably rather lies in the determinants of technology accumulation like education and the legal system, not in the low technology level itself (compare OECD 2002). If these determinants of technology diffusion are sufficiently present, technological catching up is possible even far away from the frontier. Van Meijl and van Tongeren (1999) assume that international spillovers from trade are quantitatively higher when countries are similar in their economic structure. This view is in accordance with our model. Given a high education level, infrastructure etc. in the leading industrialized country, the improvement of these factors in the developing country makes it more similar to the developed country and thus increases the technology spillover strength.

The first section 3.1 explains, how technological catching up of the South is influenced by the rate of technical progress in the North and by the absorptive capacity of the South following N&P. Section 3.2 introduces own innovation in the South and investigates its interaction with technology diffusion. 3.3 briefly explains the allocation of internationally mobile capital in the long-run.

### 3.1 A Re-Interpretation of the Nelson and Phelps Theory

The equations below describe the basic model formulated by N&P. Throughout the paper,  $n$  denotes the North, and  $s$  denotes the South.<sup>3</sup>

$$\dot{A}_s = \phi_s(H_s, k_s)(A_n - A_s) \quad (1)$$

$$A_n = A_n(0)e^{\lambda t} \quad (2)$$

$$\implies \dot{A}_n = \lambda A_n = \lambda A_n(0)e^{\lambda t}$$

$A_s$  is the endogenous technology (total factor productivity) in practice in the destination country, the South.  $A_n$  is the level of the exogenous technology frontier in the North. We assume that capital transferred from the North to the South embodies technologies up to this frontier level. The technologies coming from the North are not immediately

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<sup>3</sup> $A_s$  and  $A_n$  are time dependent variables. Time indices of variables are not shown explicitly. Time derivatives are denoted by dots.

available in all Southern production processes. They rather need time to diffuse into and through the Southern economy (via product and process imitation, learning from foreign managers, engineers or workers, vertical and horizontal linkages between suppliers and customers, productivity gains through increased competition etc.). Technology diffusion increases total factor productivity in the South  $A_s$ .  $\lambda$  is the exogenous growth rate of the technology frontier.  $\phi_s$  is the exogenous spillover strength (including the imitation capability) and has the following properties:

$$\frac{\partial \phi_s(H_s, k_s)}{\partial H_s} > 0, \quad \frac{\partial \phi_s(H_s, k_s)}{\partial k_s} > 0, \quad \frac{\partial^2 \phi_s(H_s, k_s)}{\partial H_s \partial k_s} > 0$$

$\phi_s$  is an increasing function of human capital (educational attainment)  $H_s$ . We interpret  $H_s$  in a broader sense as the absorptive capacity (including infrastructure, legal framework etc.) of the recipient country. Compared to N&P, we additionally assume that  $\phi_s$  increases with the amount of foreign internationally mobile capital  $K_s$  relative to the amount of domestic capital  $D_s$ , denoted by the foreign capital intensity  $k_s = \frac{K_s}{D_s}$ . This specification follows Findlay (1978) and is in accordance with econometric analyses, where FDI is measured in absolute terms or as an intensity (for instance Agosin and Mayer 2000, Ciruelos and Wang 2005).  $H_s$  and  $k_s$  are complements per assumption, because more foreign investment yields even larger positive spillovers when at the same time the absorptive capacity is higher, in accordance with the empirical findings.

Without technical progress of the technological frontier, the technology level of the developing country catches up completely with the frontier. Following N&P, we rather assume exogenous technical progress of the frontier with a constant rate according to N&P and reinterpret their results with respect to  $k_s$ . Like N&P, we first solve differential equation (1) and then calculate the relative technology gap in the long run. The conclusions of N&P concerning the effect of  $H_s$  on technology diffusion can then be directly transferred to the effect of  $k_s$ .<sup>4</sup>

$$\frac{A_n - A_s}{A_s} = \frac{\lambda}{\phi_s(H_s, k_s)} \quad (3)$$

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<sup>4</sup>For more detailed calculations see N&P and our calculations in equations 6 to 10, which are a generalized form of the following basic calculations.

$$A := \frac{A_s}{A_n} = \frac{\phi_s(H_s, k_s)}{\phi_s(H_s, k_s) + \lambda} = \frac{1}{1 + \frac{\lambda}{\phi_s(H_s, k_s)}} < 1 \quad (4)$$

Equation (4) shows that in the long run the technology level of the South has a constant ratio  $A$  to the technology level of the North, when  $k_s$  and  $H_s$  stay constant. Since  $\phi_s$  is an increasing function of  $k_s$ , a higher foreign capital intensity  $k_s$  and a higher human capital endowment  $H_s$  reduce the relative equilibrium technology gap as shown in equation (4).

The elasticity of the Southern technology level with respect to the foreign capital intensity reads:

$$\frac{\partial A_s}{\partial k_s} \frac{k_s}{A_s} = \frac{\frac{\partial \phi_s(H_s, k_s)}{\partial k_s}}{\phi_s(H_s, k_s)} \frac{k_s \lambda}{\phi_s(H_s, k_s) + \lambda} \quad (5)$$

According to (5), the (technological) payoff of a higher capital intensity expressed as the elasticity above is greater, the higher the technological progress  $\lambda$  of the frontier. A subsidy on internationally mobile foreign capital could be economically justified because of the positive technology spillover of mobile capital. It increases the foreign capital share. It follows from (5), that the benefit of the subsidy is greater when technical progress in the industrialized region is higher. When  $\phi_s$  is a concave function of  $H_s$  and of  $k_s$ , the elasticity in (5) decreases in  $H_s$  and in  $k_s$ . This means there is a decreasing marginal benefit of improving the absorptive capacity and of increasing the foreign capital intensity.

### 3.2 Innovation in the South

According to equations (3) and (4), the technology gap cannot be completely closed through technology diffusion as long as  $H_s$  and  $k_s$  are finite. A possible remedy is to add own innovation in the South as described by Benhabib and Spiegel (2005). Our contribution is to solve the differential equation including innovation in the South.<sup>5</sup>

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<sup>5</sup>Our basic relation implies imperfect technology diffusion. Perfect technology diffusion, i.e.  $\phi_s \rightarrow \infty$ , would make own innovation in the South superfluous. For a further discussion see Grossman and Helpman (1991).

We set up a diffusion equation similar to Benhabib and Spiegel (2005):

$$\dot{A}_s = \phi_s(H_s, k_s)(A_n - A_s) + \theta_s(H_s, r_s)N_s \quad (6)$$

$$N_s = \gamma e^{\gamma t} \quad (7)$$

$N_s$  represents own innovations developed in the South. We assume an exogenous innovation rate  $\gamma$  in the South. Its effect on total factor productivity  $A_s$  depends on  $\theta_s$ , the innovative capability of the South, which is an increasing function of the absorptive capacity  $H_s$  and of  $r_s$ .  $r_s$  is the level of R&D resources devoted to improving the innovative capability of the South. Similar to *phi*, *theta* determines how successfully new technologies can be implemented into production processes in the South. Human capital improves the technology diffusion capability as well as the innovative capability. The solution of the differential equation becomes (like in N&P plus the additional source of technical progress):

$$A_s = \left[ A_s(0) \frac{\phi_s A_n(0)}{\phi_s + \lambda} \right] e^{-\phi_s t} + \frac{\phi_s A_n(0)}{\phi_s + \lambda} e^{\lambda t} + \frac{\theta_s \gamma}{\phi_s + \gamma} e^{\gamma t} \quad (8)$$

The first term describes the transition and vanishes as  $t \rightarrow \infty$ . In accordance with Benhabib and Spiegel (2005), the leader and the follower still grow with the same rate and a certain relative gap in the long-run, when the additional technical progress term is added. Complete catching up of the South's technology level to the North's technology level is only possible, if the South's own innovation capability is (at least) identical to the innovation capability of the North, i.e.  $\gamma = \lambda$  and  $\theta_s = A_s(0)$ . But this case occurs very unlikely in reality, since the innovative capability is lower in developing countries than in industrial countries.

Different to the literature so far, we now assume  $\gamma = \lambda$ , i.e. identical innovation rates in the North and in the South, so that  $\theta_s$  becomes the policy parameter controlling the innovation strength, since in general  $\theta_s \neq A_s(0)$ . (While in the former analysis a higher technical progress  $\lambda$  of the technological leader made technology adoption more effective, the influence of  $\lambda$  on the technology of the South is now ambiguous, because innovation in the South is assumed to grow with  $\lambda$ , too.) We can then derive the long-run

technology level of the South:

$$A_s = \frac{\phi_s A_n(0) + \theta_s \lambda}{\phi_s + \lambda} e^{\lambda t} \quad (9)$$

We express the technology ratio  $A$ , now including the South's own innovation level, as:

$$A = \frac{\phi_s A_n(0) + \theta_s \lambda}{\phi_s A_n(0) + A_n(0) \lambda} = \frac{\frac{1}{\lambda} + \frac{\theta_s}{\phi_s A_n(0)}}{\frac{1}{\lambda} + \frac{1}{\phi_s}} < 1 \quad (10)$$

This equation clearly shows that complete catching up is possible in two ways: At first, the spillover strength  $\phi_s$  becomes infinitely strong (due to an infinitely large absorptive capacity or an infinitely high foreign capital intensity). At second, the innovative capability  $\theta_s$  becomes equal to the leading technology level  $A_n(0)$ . Both ways are not realistic, the latter at least for developing countries. Furthermore, when the rate of technical progress (which is assumed to be equal in the North and South) increases, the relative technology gap will mainly be determined by the South's R&D level  $\theta_s$  relative to the North's level  $A_n(0)$ . According to the original N&P model, the level  $A_n(0)$  of the technology frontier does not influence the relative technology gap, while a higher rate of technological progress of the frontier increases the gap. Our model additionally considers own innovation in the South. Now, in the presence of innovation, a higher technology *level* of the frontier  $A_n(0)$  widens the gap. The intuition is the following: The South always benefits from a higher transferred technology level. But some of the newly arriving technologies are already known in the South due to own innovations. This means, the South has made some inventions that are not yet known in the North. The consequence is, that the North fully benefits from its new inventions, while the South does not, because some are already known in the latter region. Thus, the relative gap increases with  $A_n(0)$  in the presence of own innovation in the South.

While both alternatives of complete catching up seem not realistic, we now examine the effectiveness of investing into a higher innovative capability  $\theta_s$ . Technology transfer and innovation are always beneficial from the point of view of the model, but the effectiveness of certain policy measures depends on the other model parameters. Following N&P we derive a technology elasticity, in our case with respect to innovation in the South. This allows us to investigate the effectiveness of enhancing Southern innovation

for narrowing the North-South technology gap:

$$\frac{\partial A_s}{\partial \theta_s} \frac{\theta_s}{A_s} = \frac{1}{\frac{\phi_s A_s(0)}{\lambda \theta_s} + 1} \quad (11)$$

According to (11), increasing the Southern innovative capability pays off more when  $\phi_s$  and  $A_s(0)$  are low. We recall that  $\phi_s$  is an increasing function of the absorptive capacity and of the foreign capital intensity. The intuition is simple: Southern innovation will more likely yield new technologies when the technologies that exist in the industrialized region are less advanced or have not yet been fully exploited through technology diffusion. Thus, technology diffusion and own innovation are substitutes.

Now we relax the assumption that Northern and Southern innovation processes have the same *rate* of progress again. In general, it is plausible to assume that the Southern innovation process has a lower rate than the Northern frontier process, i.e.  $\gamma < \lambda$ . We divide equation (6) by  $A_s$  to obtain the growth rate of the Southern technology level  $\hat{A}_s = \frac{\dot{A}_s}{A_s}$ , where  $A = \frac{A_s}{A_n}$ :

$$\hat{A}_s = \phi_s(H_s, k_s) \left( \frac{1}{A} - 1 \right) + \frac{\theta_s(H_s, r_s) N_s}{A_s} \quad (12)$$

$A_s$  grows with the same rate as the technology frontier  $\lambda$  in case of convergence of growth rates, while  $N_s$  grows with a lower rate per plausible assumption. Hence, the last term in the equation above will vanish over time, so that the benefit of Southern innovation vanishes.

However, the optimal decision on investment in enhancing technology diffusion needs to include the related costs, which is neglected in our analysis.

### 3.3 International Factor Allocation in the Long-Run

We now turn to the question how technology diffusion affects the allocation of internationally mobile capital between North and South in the long-run. Does the international capital allocation still change in the steady state after the catching up process has been completed? The answer is no, which can easily be seen. In the ideal case (neglecting transaction costs) the marginal products of mobile capital and hence their prices are equal in the North and in the South (factor price equalization). If there are transaction

costs, there will be a constant difference between the marginal products. The N&P equation yields equal growth rates  $\lambda$  of the technology of North and the South and a constant relative technology ratio  $A$  in the steady state.

Hence, with or without transaction costs, in the long-run total factor productivities and marginal products of capital in the North and in the South have a constant ratio, which makes any adjustments of mobile capital stocks superfluous (as long as there is no external shock). Moreover, the higher the technology level of the South relative to the technology level of the North, the higher the quantity of mobile capital allocated to the South relative to quantity of capital allocated to the North.

## 4 Endogenous International Capital Mobility

While the foreign capital intensity was exogenous in the last section, it is now endogenized in a simple straight forward way: Marginal products of internationally mobile capital are equalized across North and South.<sup>6</sup> The question is how capital mobility and technology diffusion through capital mobility interact. There is potentially a positive feedback mechanism: A better absorptive capacity and a higher foreign capital intensity enhance the technology diffusion speed. This in turn raises the marginal product of mobile capital and thus attracts more mobile capital and so forth. On the other hand, a situation of a low foreign capital endowment and a low absorptive capacity in the South results in a slow technology diffusion speed. This in turn increases the technology gap, so that even less capital is allocated to the South. Hence, the South might get trapped concerning its technological development and foreign capital accumulation, if the technology diffusion speed does not increase sufficiently far away from the technology frontier. Moreover, we are interested in the influence of the domestic capital endowment on the diffusion speed as an indicator for the effect of the size of an economy (or economic zone) and in the influence of the labor endowment on technology diffusion.

Subsection 4.1 describes the model setup, subsection 4.2 interprets the model.

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<sup>6</sup>The following outcomes also hold when including transaction costs of capital movements. In this case there is a constant difference between the marginal products in the steady state.

## 4.1 The Model

In our stylized model, the international allocation of capital is purely driven by differences in marginal products of capital without perfect foresight and without internalizing the social benefit of technology transfer. Therefore, our model can be called a myopic market solution approach. So far, the logistic function has been used in the literature to model a slower diffusion speed when the technology gap is either small or large (Benhabib and Spiegel 2005). This assumption implies an inverted U-shaped relation between the technology gap and the technology diffusion speed without a direct theoretical explanation. In our model international capital allocation is the explicit mechanism that leads to such a relationship.

We first write the technology diffusion equation (6) without innovation in the South in general form allowing for non-linear influences of the absorptive capacity and the capital intensity on technology diffusion:

$$\dot{A}_s = \phi_s(H_s, k_s)(A_n - A_s)^{\delta_3} \quad (13)$$

$$\phi_s(H_s, k_s) = \mu H_s^{\delta_1} \left( \frac{K_s}{D_s} \right)^{\delta_2} \quad (14)$$

The foreign capital intensity  $k_s = \frac{K_s}{D_s}$  describes the mobile foreign capital stock relative to the stock of immobile domestic capital (following Findlay 1978). Domestic capital indicates the size of the economy and is assumed to be constant. A higher foreign capital intensity induces a higher technology spillover when there is a better absorptive capacity  $H_s$ .  $\mu$  is a constant parameter that determines the "technical" spillover strength which cannot be influenced by economic policy. The multiplicative specification strictly follows the empirical literature applying interaction terms (e.g. Borensztein et al. 1998, Benhabib and Spiegel 2005, Girma and Görg 2005). Choosing the exponents  $\delta_1, \delta_2$  and  $\delta_3$  smaller than one creates decreasing returns to scale concerning the technology diffusion strength when raising the absorptive capacity or the foreign capital intensity or the technology gap. Setting  $\delta_3$  to one leads back to the linear formulation by N&P.

We assume for simplicity that international factor price equalization holds at any



point of time:

$$MPK_n(A_n, K_n) = MPK_s(A_s, K_s) \quad (15)$$

where  $MPK_n$  and  $MPK_s$  are the marginal products of capital in the North and South (the price of the produced commodity set to one). We also assume that the North is a large open economy and the South is a small open economy, i.e. the North determines the world market price for mobile capital. As a consequence, the South attracts more foreign capital, the higher its productivity. In the next step we derive  $MPK_s$  from profit maximization of firms under perfect competition. Herein, we use a Cobb-Douglas production function with the inputs foreign capital  $K_s$ , domestic capital  $D_s$  and labor  $L_s$  and constant returns to scale. The income share of foreign capital is  $\alpha$ , the share of domestic capital is  $\beta$ , the income share of labor is  $1 - \alpha - \beta$ . The technology level  $A_s$  of the developing country determines total factor productivity.

$$Y_s = A_s K_s^\alpha D_s^\beta L_s^{1-\alpha-\beta} \quad (16)$$

$MPK_n$  is equal to the marginal product of internationally mobile capital in the industrialized region and rises with  $A_n$ , because exogenous technical progress permanently increases the marginal product of  $K_n$ , i.e.  $MPK_n(A_n, K_n) = p_n(0)A_n$ .<sup>7</sup> Besides  $A_s$ ,  $K_s$  is now a time dependent variable.

$$\begin{aligned} p_n(0)A_n &= \alpha A_s K_s^{\alpha-1} D_s^\beta L_s^{1-\alpha-\beta} \\ \Leftrightarrow K_s &= \left(\frac{A_s}{A_n}\right)^{\frac{1}{1-\alpha}} \left(\frac{\alpha}{p_n(0)} D_s^\beta L_s^{1-\alpha-\beta}\right)^{\frac{1}{1-\alpha}} \end{aligned} \quad (17)$$

We use the second equation of (17) to replace  $K_s$  in equation (14), and we insert both

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<sup>7</sup> $MPK_n(A_n, K_n)$  can be derived from a Cobb-Douglas production function like in the South. Since the functional form of Northern production is not relevant, we use this general notation. Note that the transfer of capital is beneficial both for the North and the South, if the return on foreign direct investment is transferred back to the North, because in the initial situation the mobile capital earns a higher return in the South than in the North. Otherwise, no capital would be transferred from North to South.

in (13) to obtain:

$$\dot{A}_s = \Omega \left( \frac{A_s}{A_n} \right)^{\frac{\delta_2}{1-\alpha}} (A_n - A_s)^{\delta_3} \quad (18)$$

$$\Omega = \mu H_s^{\delta_1} \left[ D_s^{\frac{\alpha+\beta-1}{1-\alpha}} L_s^{\frac{1-\alpha-\beta}{1-\alpha}} \left( \frac{\alpha}{p_n(0)} \right)^{\frac{1}{1-\alpha}} \right]^{\delta_2} \quad (19)$$

Setting  $\delta_3 = 1$  leads back to the original linear N&P model. Then equation (18) can be re-written in terms of the growth rate  $\hat{A}_s = \frac{\dot{A}_s}{A_s}$ , where  $A = \frac{A_s}{A_n}$ :

$$\hat{A}_s = \Omega \left( A^{\frac{\delta_2+\alpha-1}{1-\alpha}} - A^{\frac{\delta_2}{1-\alpha}} \right) \quad (20)$$

If also  $\delta_3 = 1$ , i.e. there is a linear relationship between the foreign capital intensity and the diffusion speed, the equation reads:

$$e\hat{A}_s = \Omega \left( A^{\frac{\alpha}{1-\alpha}} - A^{\frac{1}{1-\alpha}} \right) \quad (21)$$

Finally, we set for simplicity  $\alpha = \frac{1}{2}$ , which yields an illustrative quadratic form:

$$\hat{A}_s = \Omega (A - A^2) \quad (22)$$

## 4.2 Interpretation

This section interprets the equations derived above. We start with equation (19). Whether raising the absorptive capacity  $H_s$  yields a constant or decreasing marginal effect on the diffusion speed  $\dot{A}_s$  depends on the value of  $\delta_1$  (where  $\delta_1 \leq 1$ , since an increasing marginal benefit of  $H_s$  seems not plausible). However, a higher absorptive capacity is always beneficial for enhancing technology diffusion.

We now turn to a crucial outcome: The exponent of domestic capital  $D_s$  is always negative in case of constant or decreasing returns to scale of the Cobb-Douglas production function. (Note that  $\alpha + \beta < 1$ , because the exponent of labor  $L_s$  is  $1 - \alpha - \beta$ .) Consequently, smaller economies or economic regions with less domestic fixed capital have an advantage concerning the technology diffusion speed. The intuition is that on the one hand, more domestic capital raises the marginal product of foreign capital and thus the inflow of foreign capital and embodied technologies. On the other hand, new

technologies need more time to spread over a large economy. If there is a large amount of existing domestic capital, it takes a long time to equip this existing capital with new technologies. Therefore, a larger economy needs more foreign capital in absolute terms to reach the same capital intensity and consequently the same technology diffusion speed as a small economy. The overall outcome depends on which effect dominates. According to equation (19) the latter effect dominates. This result is driven by the standard assumption of a decreasing marginal product of a single production factor, all other production factors kept constant. Note that this result does not depend on the choice of  $\delta_2$ . This result is in accordance with agglomeration theories and with what we observe in reality: China, for example, has established Special Economic Zones in order to concentrate foreign economic activities and to maximize spillovers.

On the contrary, the exponent of domestic labor input  $L_s$  is always positive. This outcome stems from the plausible assumption that the technology diffusion speed is influenced by the amount of existing capital, but not by the number of workers in production (abstracting from skills and education). Hence, a larger number of workers raises the marginal product of foreign capital and attracts more foreign capital, but it does not directly influence the technology diffusion speed in the model. This outcome is backed up by the observation of highly active small economic zones with high population densities like Hong Kong or Taiwan. Their impressive economic growth performances exactly fit to our stylized model.

Our main aspect under scrutiny is technological catching up and convergence of technology growth rates. Equation (18) decomposes the impact of the technology gap between  $A_n$  and  $A_s$  into two opposing parts: The first part shows that a lower ratio of  $A_s$  to  $A_n$  reduces the amount of foreign capital and hence the foreign capital intensity in the South. Let us call this effect *density effect*. It simply stems from the fact that in the optimal case more foreign capital is allocated to a region if its relative technology level is higher. At the same time the second part of equation (18), which is the term in parentheses, means, a larger technology gap increases the possibilities to adopt new technologies so that the technology diffusion speed rises. Let us call this effect *distance effect*. It is a priori not clear, which effect dominates. The outcome depends on the values of  $\alpha$ ,  $\delta_2$  and  $\delta_3$ . Suppose, the technology growth rate of the South,  $\hat{A}_s$ , is lower than the technology growth rate of the North  $\hat{A}_n$  in the initial situation. If the distance effect

dominates, the South will fall behind in terms of the technology level until the distance to the technology frontier is so large (i.e.  $A$  is so small) that the South's technology growth rate becomes equal to the North's growth rate. In other words, the technology gap widens, but growth rates finally converge. If the density effect dominates,  $\hat{A}_s$  clearly decreases with a lower  $A$ . In that case, there is no automatic convergence mechanism. Without policy intervention, the South falls increasingly behind in terms of technologies, and the amount of foreign capital allocated to the South asymptotically drops towards zero. The South is trapped.

Equation (20) uses the simplifying assumption  $\delta_3 = 1$ , which leads back to the original equation formulated by N&P.  $\hat{A}_s$  is at least as high as zero in equation (20) (as well as in equation 21), because the exponent of the first term in parentheses is always smaller than the exponent of the second term in parentheses and  $A$  is between zero and one. The second term in parentheses vanishes, if the technology ratio  $A$  becomes smaller due to a difference in the technology growth rates,  $\hat{A}_s < \hat{A}_n$ . If the first term in parentheses also decreases in  $A$ , the South will be trapped. This trap exactly occurs, when  $\frac{\delta_2 + \alpha - 1}{1 - \alpha} > 0$ . This is more likely the case, when  $\alpha$  and  $\delta_2$  are large, because then the foreign capital endowment in the South reacts more strongly to changes in the technology level  $A_s$ . In this case, lowering  $A_s$  shifts away a relatively large amount of foreign capital.

Equation (21) describes the model, when the impact of the foreign capital intensity on the diffusion speed is also a linear function. Since  $0 < \alpha < 1$ , both exponents are positive, so that a falling technology ratio  $A$  unambiguously lowers  $\hat{A}_s$ . Thus, in the linear model the possibility of a growth trap, i.e. convergence of the technology growth rates of the North and the South fails, always exists. We can derive another interesting aspect by plotting the function in equation (21) for different values of  $\alpha$  as shown in Figure 2 in the Appendix: The larger the exponent  $\alpha$ , which means the income share of foreign capital, the closer the point of maximal diffusion speed is to the technology frontier and the lower the value of  $A_s$  is in the maximum. This outcome stems from the fact, that the demand for foreign capital in the South as a function of  $A = \frac{A_s}{A_n}$ , given by the second equation in (17), is steeper, the higher  $\alpha$ . Consequently, when  $A$  is large, a higher  $\alpha$  attracts more foreign capital to the South. When  $A$  is small, so that the South is far away from the technology frontier, a lower value of  $\alpha$  attracts more capital to the

South. This is in accordance with what we found before: The likelihood of a convergence failure is higher, when  $\alpha$  is larger. The reason is that a higher value of  $\alpha$  leads to a stronger reaction of the international capital allocation driven by changes in the North-South technology ratio. Thus, the density effect becomes stronger for a higher value of  $\alpha$ , and more mobile capital is shifted away from the South when the South falls behind in terms of technologies. Also note that according to Figure 2, increasing  $\alpha$  above 0.5 raises  $\hat{A}_s$  only slightly. That means, there is little additional benefit concerning technology diffusion of having an income share of foreign capital higher than 0.5.

To make our considerations more illustrative, we additionally set  $\alpha = 0.5$  yielding equation (22). Figure (1) is a qualitative graphical representation of equation (22). On the right hand side of Figure 1 the South's technology level is close to the technology frontier given by the North, i.e.  $A$  is close to one. On the left hand side it is far away from the technology frontier. The vertical axis shows the technology growth rate of the South  $\hat{A}_s$  as a function of the technology ratio  $A$  on the horizontal axis. Obviously, the maximal diffusion speed is reached at half the distance to the technology frontier. (This outcome changes, when another value for the income share of foreign capital  $\alpha$  is chosen as discussed before.)

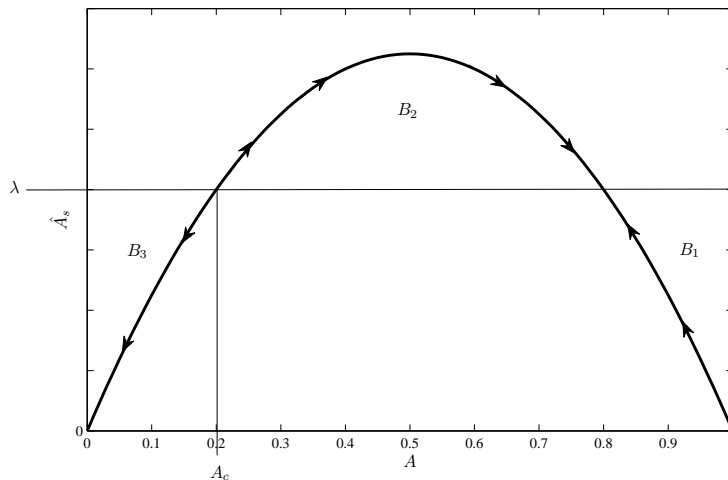


Figure 1: Areas of convergence and divergence of technology growth rates in the North and the South dependent on the distance to frontier

We notice that starting at a high level of  $A$  on the right hand side of Figure 1 in area  $B_1$ , the Southern rate of technical progress  $\hat{A}_s$  increases, while the technology ratio  $A$  decreases. (We always move on the parabola.) The technology gap widens. We observe

this kind of behavior for example concerning Sub-Saharan African countries. In the steady state the technology growth rate of the South has converged to that of the North. Full convergence of growth rates as well as of technology levels implies  $\lim_{t \rightarrow \infty} A = 1$ . This case does not occur in this model with exogenous exponential technical progress. It occurs however, if the technology frontier stays constant. (Then  $\lambda$  is zero in equation 4 resulting in  $A = 1$ .)

We now start at a medium distance to the technology frontier in the middle of Figure 1 in area  $B_2$  above the critical value  $A_c$ .  $A_s$  is larger than  $\lambda$ , so that the technology gap narrows, i.e.  $A$  increases. Economies fulfilling such initial conditions are able to catch up in terms of technologies up to a certain ratio  $A < 1$  as we observe for example concerning the "Asian Tiger" countries.

Starting on the left hand side of Figure 1 in area  $B_3$  we identify again the case of a growth trap.  $A$  is smaller than the critical value of  $A_c$ . We find the situation  $\lambda > \hat{A}_s$  which leads to a movement on the parabola to the lower left hand side. The economy is too far away from the technology frontier. Moreover, the marginal product of capital in the South is too low relative to the marginal product of capital in the North to attract more foreign capital. This means that the developing economy is scarce in foreign capital and the technology diffusion speed is low due to an insufficient absorptive capacity. As a consequence, the South will end up with almost no foreign capital and very low technology diffusion.

How can economic policy remedy the convergence failure? One possibility is to increase the absorptive capacity  $H_s$ , which shifts the parabola in Figure 1 upwards, so that the economy can move from a point in the divergence area to a point in the convergence area. A higher absorptive capacity prevents the convergence failure even in the long-run. The farther the South is away from the technology frontier, the more human capital is necessary to enable catching up.

Another possibility is to introduce own innovation with a certain rate in the follower country which also shifts the parabola upwards. Hence, technology diffusion and innovation positively interact as complements. But recalling equation (12), we notice that the last term steadily decreases over time as long as  $\gamma$ , the innovation rate in the South, is smaller than  $\lambda$ , the innovation rate in the North.  $\lambda$  is also the growth rate of  $A_s$  in the case of convergence.  $\gamma$  is likely smaller than  $\lambda$ , since the South is probably

not as innovative as the North. Thus, at a certain point of time the South will fall back to the divergence area, when the difference between innovation in the North and innovation in the South has become too large. Alternatively, a subsidy on foreign capital gives an additional payoff to the foreign investment, i.e. is added to the marginal product of foreign capital expressed in (15).<sup>8</sup> The subsidy will be an effective remedy if it is high enough to overcome the critical point of convergence failure. But again, only in the short-run. We can see from equation (17) that a constant subsidy becomes relatively unimportant when  $A_n$  and  $A_s$  grow in an exponential way. Therefore, the subsidy would have to rise together with technical progress in order to have a medium- or long-run effect.

## 5 Discussion

Our considerations along the line of the N&P theory describe that a better absorptive capacity as well as higher foreign capital intensity narrow the technology gap between the North and the South until the technology growth rate of the South equals the growth rate of the technology frontier given by the North. In this case, there will be no reallocation of internationally mobile capital in the long-run. If the absorptive capacity of the South is below a certain threshold value, if the South is far away from the technology frontier and if certain preconditions are fulfilled, convergence of technology growth rates fails. As a consequence the South falls further behind in terms of technologies, and foreign capital tends to be completely withdrawn from the South. The South is trapped.

Different to the literature so far (for example described by Benhabib and Spiegel 2005), we derive this outcome theoretically through the introduction of international capital mobility. A main contribution of our paper is therefore to reconcile the assumption that technological catching up is stronger the farther the distance to frontier with the alternative view that the diffusion speed is strongest at a medium distance to frontier (both discussed by Benhabib and Spiegel 2005) by introducing international capital mobility. As a consequence, we identify the following trade-off: Far away from the technology frontier, there is a high potential for adopting new technologies, but there is

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<sup>8</sup>For a discussion on promoting FDI see Hanson (2001).

also a lack of foreign capital. Close to the technology frontier, more foreign capital is allocated to the South, but there are fewer technologies left that can be adopted. Hence, the optimal technology diffusion speed is achieved somewhere at a medium distance to frontier. Therefore, our model is able to explain the mixed findings in the empirical literature on technology spillovers via FDI and the facts reported by the World Bank (2008): Some developing countries are able to catch up in terms of technologies, others are not, or even fall further behind.

We also examine the role of innovation in the South and its potential to narrow the North-South technology gap. In contrast to N&P, a higher rate of technical progress in the North widens the international technology gap in the presence of own innovation in the South. The reason is that some of the newly arriving technologies are already known in the South due to own innovations and therefore not beneficial. Technology transfer and own innovation in the South are basically substitutes. They become complements in the short-run, since own innovations increase the marginal product of capital, which in turn attracts more foreign capital embodying advanced technologies. But in the long-run, Southern innovation cannot prevent the South falling behind in terms of technologies, except when the South becomes as innovative as the North. This result is in accordance with Acemoglu et al. (2003a), stating that technological leaders follow an innovation-based strategy, while technological followers do not. Our long term outcome, that innovation is not an appropriate option for technological catching up of developing countries that lack in human capital, infrastructure and so forth, is in line with Acemoglu et al. (2003b). They show that imitation activities are more important far away from the technology frontier.

Moreover, our stylized model favors small economies (or economic areas) with high population densities concerning the technology diffusion speed. This outcome is in accordance with agglomeration theories and with what we observe in reality: China, for example, established Special Economic Zones in order to maximize spillovers. Small economic areas with high population densities like Hong Kong and Taiwan have indeed shown amazing catching up and economic growth performances. The model also shows that a larger income share of internationally mobile foreign capital is more beneficial for the South in terms of technology diffusion, the larger the North-South technology gap. Indeed, in China the revenue share of enterprises with Hong Kong, Macao, Taiwan



and foreign funds in the revenue of all enterprises rose from 0.20 in 1998 to 0.24 in 2006 (China Statistical Yearbook 2006). Therefore, according to our stylized model the Chinese policy of relaxing the requirements for FDI in China and supporting FDI inflows has been beneficial for technology diffusion.

However, the analysis is based on a simple stylized macroeconomic model that neglects channels of technology diffusion other than international capital mobility. It cannot capture other determinants of capital mobility (or FDI) besides returns on capital, either. It abstracts from domestic capital accumulation and endogenous technical progress. Furthermore, capital transfer, absorption of technologies and innovation are costly. And keeping the absorptive capacity on a sufficiently high level requires permanent investment. In order to set up the optimal policy mix, policy makers also need to know such costs, which are certainly hard to quantify. Our current analysis is not a cost benefit analysis, but rather a qualitative policy assessment.

## 6 Conclusion

We have analyzed a stylized macroeconomic model of North-South technology diffusion via capital mobility. The results show that one cannot rely on market forces as a guarantee for convergence of the Southern technology growth rate with the Northern technology growth rate via this channel. Convergence of growth rates requires a sufficiently high absorptive capacity of the South (via education, infrastructure, legal framework and so forth) in order to adopt new technologies sufficiently (additional to certain preconditions discussed in the paper). Hence, it is not sufficient to rely on market driven international capital mobility or just to transfer capital and embodied technologies to developing countries according to the model. This can be a waste of resources, if development policy does not ensure that the absorptive capacity suffices.

Furthermore, fostering own innovation in the South positively interacts with technology diffusion in the short-run. But it cannot prevent the South falling behind in terms of technologies in the long-run, except when the South becomes as innovative as the North. This outcome confirms the importance of improving technology diffusion to developing countries rather than trying to create own innovations within developing countries, es-

pecially in early stages of development. Similarly, a subsidy on internationally mobile foreign capital yields a positive short-term effect that vanishes in the long-run. In order to stay effective, the subsidy would have to rise together with technical progress over time, which is probably not optimal.

The model also indicates that technologies need more time to diffuse through economies that encompass more domestic capital. A larger pool of workers, on the other hand, always raises the marginal product of internationally mobile capital and thus attracts more foreign capital and embodied technologies. The model therefore favors small economic zones with high densities of workers and small stocks of domestic capital for enhancing technology diffusion speed. Accordingly, concentrating foreign economic activities in restricted zones with large pools of workers with appropriate skills is a promising way for economic policy to enhance technology diffusion. Moreover, the model suggests that a larger income share (possibly up to 0.5) devoted to foreign capital is more beneficial closer to the technology frontier. This means that financial and tax advantages for foreign investors aiming at increasing the income share of foreign capital can be ill-designed, when the economy lacks in the existing (basic) technology level, which is necessary to attract foreign investment.

Further research could analyze the diffusion mechanism studied in this paper in an inter-temporal optimization framework including costs of capital transfer and innovation. It would yield the optimal allocation of foreign capital to the South along the optimal time path. Moreover, a Computable General Equilibrium (CGE) model analysis could apply the diffusion mechanism to real data and reveal country and sector specific differences in the technology diffusion behavior.

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## 8 Appendix

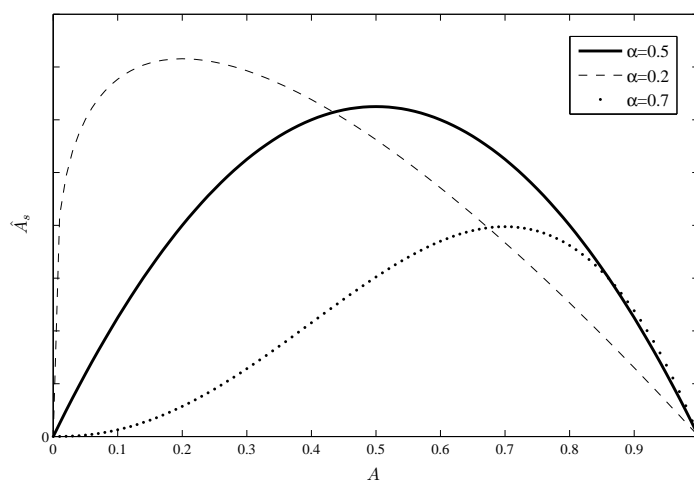


Figure 2: Rate of technical progress in the South dependent on the distance to frontier for different income shares of foreign capital in the South