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

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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 it is too far away from the technology frontier and 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.

JEL Classifications: F21, O11, O33, O47

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1 Introduction

Technology diffusion from industrialized to developing countries is a promising way of economic development (compare World Bank 2008). Moreover, the potential of international technology diffusion for reducing the energy intensities of economic activities in developing countries 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 diffusion - trade, foreign direct investment, migration, patent citations, scientific literature, communication and information technologies - 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 (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 2009). And there is no common intuitive theory that describes the dynamic interactions of international capital movements, technology diffusion, innovation and absorptive capacities of recipient countries.

Our study therefore 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 of a developing country catches up with the growth rate of an industrialized country so 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 improve the absorptive capacities of developing countries.

The main contribution of this paper is to provide a theoretical explanation for a phenomenon frequently identified in the empirical literature and for example discussed by the World Bank (2008): The North-South technology gap widens and convergence of technology growth rates fails in some developing countries despite increasing global economic integration via international investment and other channels. Our analysis therefore provides one possible explanation (among others for example described by Hanson 2001) for the diverse results of the econometric literature about the impact of FDI on growth and the role of human capital for technology diffusion. A consecutive question is, whether own innovation in developing countries can remedy such a convergence failure.

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 (for the special case of technology diffusion via capital mobility).

We also examine the potential of own innovation in the South for narrowing the technology gap and for preventing a 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 N&P, in our model a higher initial technology *level* (innovative capability) in the North increases the technology gap in the presence of own innovation in the South, because performing own innovation reduces the North-South technology gap and hence the possibility to adopt foreign technologies via international technology diffusion.

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.

The paper proceeds as follows. Section 2 briefly reviews the related theoretical and empirical literature. Section 3 re-interprets the N&P theory in the context of FDI in general form. Section 4 introduces international capital mobility explicitly in a myopic market solution approach. Section 5 critically discusses the results of the paper. Section 6 concludes.

2 Literature Background

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

There is a broad strand of empirical research 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 recipient countries or productivity spillovers from foreign to domestic firms - with diverse results. (Kokko 1992, Blomström and Kokko 1998, OECD 2002, Saggi 2002, Keller 2004 and Hoekman and Javorcik 2006 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 (2009) observe that FDI accelerates economic 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 2007).

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 formalize the so-called Veblen-Gerschenkron effect.[1] Their intuitive approach has been applied in a number of studies.[2]

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 (2009) show which conditions concerning the strength of technology transfer and 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 provides one possible reason (among other reasons) for the mixed empirical evidence described above.

[1] Gerschenkron (1962) studies the phenomenon of economic catching up of countries that have fallen behind.

[2] 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 educational attainment. 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 with a constant relative technology gap.

The N&P theory can be applied to an industrialized country (technological leader, denoted by North) that creates the leading technologies 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). While in N&P the technology diffusion speed only depends on educational attainment, in our re-interpretation technology diffusion additionally depends on the volume of foreign capital in the South, similar to Findlay (1978). In this context, we re-interpret educational attainment as the absorptive capacity, including all factors that determine the ability of host countries to absorb transferred technologies and to benefit from them.

In contrast to the original N&P theory, empirical evidence shows that many developing countries are not able to catch up. For that reason, the original equation by N&P has been artificially modified in the literature so that catching up is fastest at 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 convergence fails so that a country falls further behind in terms of technology levels. 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. Our considerations therefore follow this point of view.

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 technological progress in the North and by the absorptive capacity of the South based on 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. Our extension is the introduction of capital as a determinant of the technology diffusion speed. Throughout the paper, n denotes the North, and s denotes the South.[3]

$$\dot{A}_s = \phi_s(A_n - A_s), \quad \phi_s = \phi_s(H, K) \tag{1}$$

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

A_s is the endogenous technology level 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

[3] A_s and A_n are time dependent variables. Time indices of variables are not shown explicitly. Time derivatives are denoted by dots.

transferred from the North to the South embodies technologies up to this frontier level. A_n and A_s can be interpreted as knowledge capital stocks that are accumulated and that determine total factor productivity. Technology diffusion increases total factor productivity in the South A_s. λ is the exogenous growth rate of the technology frontier. $A_n(0)$ is the level of the frontier at $t = 0$. ϕ_s is the (in this section completely exogenous) spillover strength including the imitation capability of the South and has the following properties:

$$\frac{\partial \phi_s(H, K)}{\partial H} > 0, \qquad \frac{\partial \phi_s(H, K)}{\partial K} > 0$$

ϕ_s is an increasing function of the relative human capital (educational attainment) $H = \frac{Hs}{Hn}$, i.e. the human capital level of the South relative to the human capital level of the North. Throughout the paper, we interpret H in a broader sense as the absorptive capacity including infrastructure, the legal and political framework etc. of the recipient country. A specification in relative terms seems reasonable, because technologies are invented in the North given the North's educational level and absorbed by the South given the South's educational level. The chance to absorb Northern technologies successfully, increases when the South's educational level comes closer to the North's level. H also incorporates naturally given factors that influence technology diffusion. H increases ceteris paribus with the spatial concentration of economic activities, because spatial concentration eases productivity spillovers in accordance with agglomeration theory. China, for example, has established Special Economic Zones in order to concentrate foreign economic activities and to maximize spillovers. Also, small economic areas with high population densities like Hong Kong and Taiwan have shown amazing catching up and economic growth performances. H furthermore captures natural conditions. It decreases if the land is mountainous and landlocked and hence difficult to access, if the climatic conditions are problematic and so forth. We may think of sub-Saharan African countries facing severe detrimental political and natural conditions that prevent the transfer of capital and technologies. H may also increase with the size of the labor force, since the pool of workers suitable for employment in multinational enterprises increases with its size. All kinds of policies that improve technology diffusion can be modeled by raising H. For example, the establishment of China's Special Economic

Zones, the Chinese policy to enforce joint ventures of foreign investors with domestic firms, and the Chinese policy to grant foreign investors privileges of various forms.

Compared to N&P, we additionally assume that ϕ_s increases with the South-North ratio of internationally mobile (high-tech) capital $K = \frac{K_s}{K_n}$. This approach is a modification of Findlay's (1978) model. The underlying assumption is that high-tech capital is built up in the North and embodies advanced technologies that have been invented in the North. Capital and embodied technologies are simultaneously transferred to the South. But the technologies are not immediately 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.). The quality of the technologies embodied in foreign capital is supposed to rise at the constant rate A_n over time due to Northern innovation activities. We meanwhile assume K to be exogenously given at each certain point of time.

H and K act as complements, i.e. they enhance each other.[4] More foreign investment potentially yields even larger positive spillovers when at the same time the absorptive capacity is higher, in accordance with the empirical findings. Technology diffusion ceases if H or K are zero.

Without technological 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 exponential technological progress of the frontier and reinterpret their results with respect to K. Like N&P, we first solve differential equation (1) and then calculate the relative long-run technology gap. The conclusions of N&P concerning the effect of H on technology diffusion can then be directly transferred to the

[4]This is satisfied in a multiplicative specification that we will use in section 4, but not in an additive specification.

effect of K.[5]

$$\frac{A_n - A_s}{A_s} = \frac{\lambda}{\phi_s} \tag{3}$$

$$A := \frac{A_s}{A_n} = \frac{\phi_s}{\phi_s + \lambda} = \frac{1}{1 + \frac{\lambda}{\phi_s}} < 1 \tag{4}$$

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 and H stay constant. Since ϕ_s is an increasing function of K, a higher foreign capital intensity K and a higher human capital endowment H reduce the relative equilibrium technology gap as shown in equation (4).

The elasticity of the Southern technology level in the steady state with respect to the foreign capital intensity reads:[6]

$$\frac{\partial A_s}{\partial K}\frac{K}{A_s} = \frac{\frac{\partial \phi_s}{\partial K}}{\phi_s}\frac{K\lambda}{\phi_s + \lambda} \tag{5}$$

According to (5), the relative increase in the technology level due to a relative increases in foreign capital is greater the higher the technological progress λ of the frontier. A subsidy on internationally mobile foreign capital can be economically justified because of the positive technology spillover of mobile capital (based on the stylized narrow view of this model). A subsidy increases the foreign capital share. It follows from (5) that the benefit of the subsidy is greater when technological progress in the North is higher.

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 and K 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.[7] We

[5]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.

[6]A_s is given by equation (9) with θ_s set to zero.

[7]Our basic relation implies imperfect technology diffusion. Perfect technology diffusion, i.e. $\phi_s \to \infty$, would make own innovation in the South superfluous. For a further discussion see Grossman and Helpman (1991).

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

$$\dot{A}_s = \phi_s(A_n - A_s) + \theta_s \gamma e^{\gamma t} \tag{6}$$

$$\phi_s = \phi_s(H, K), \quad \theta_s = \theta_s(H_s, R_s), \quad \gamma = \gamma(H_s, R_s) \tag{7}$$

We assume an exogenous Southern innovation rate γ which increases with the input of R&D resources R_s and with H_s.[8] θ_s is the Southern innovation level in $t = 0$, which can be interpreted as the accumulated knowledge up to this point of time. In this sense, it depends on the values of H_s and R_s before $t = 0$. Similar to ϕ_s, θ_s determines how successfully new technologies can be implemented into production processes in the South. Human capital, infrastructure etc. improve ϕ_s, the technology diffusion capability, as well as θ_s which we call in the analog way innovative capability. Herein, we make a simplifying assumption: The time lag between the appearance of new technologies and their full implementation in production is relatively small in case of Southern innovations, because they are directly created for local production and for the local market and fit to the local abilities and circumstances. Foreign technologies on the other hand, often exceed the existing local abilities by far and do not directly fit to the local circumstances. To make the argument more illustrative: Sub-Saharan African countries might develop a new water extraction and storage system through public funding that will be used almost everywhere within a couple of years and that will create a welfare gain. But they will certainly not be able to adopt all relevant chemical know-how from US firms which would be necessary to produce the same advanced pharmaceutics autonomously, although it would certainly boost African welfare.

The solution of differential equation (6) becomes (like in N&P plus the additional source of technological progress):[9]

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

The first term describes the transition process and vanishes as $t \to \infty$. In accordance

[8] Here we write indices s, because the influence of human capital, infrastructure, R&D etc. in the South on Southern innovation is independent of the corresponding Northern values.

[9] Note that the start value $A_s(0)$ includes knowledge gained from technology diffusion as well as from own Southern innovation.

with Benhabib and Spiegel (2005), the leader and the follower still grow at the same *rate* and a certain relative gap in the long-run, when the additional technological 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 innovative capability is (at least) identical to the North's innovation capability, i.e. $\gamma = \lambda$ and additionally $\theta_s = A_n(0)$. But this case occurs unlikely in reality, since the innovative capability is lower in developing countries than in industrialized countries. However, own innovation in the South has the potential to accelerate the convergence process, in other words, it has the potential to lift up the South to a higher transition path.

Different to the literature, we now assume $\gamma = \lambda$, i.e. identical innovation rates in the North and in the South so that θ_s becomes the policy parameter controlling the innovation strength, since in general $\theta_s \neq A_n(0)$.[10] We can then derive the long-run technology level of the South:

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

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

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

This equation clearly shows that complete catching up is possible in two ways: At first, the spillover strength ϕ_s becomes infinitely strong (due to an infinitely large absorptive capacity or an infinitely high foreign capital intensity). At second, the Southern innovative capability θ_s becomes equal to the leading innovative capability $A_n(0)$. Both ways seem not realistic, the latter at least for developing countries. Furthermore, when the rate of technological 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 innovative capability θ_s relative to the North's innovative capability given by $A_n(0)$. According to the original N&P model, the level $A_n(0)$ of the technology frontier does not influence

[10]While in the former analysis a higher technological progress λ of the technological leader made technology adoption more effective, the influence of λ on the technologies used in the South is now ambiguous, because innovation in the South is assumed to grow with λ, too.

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 initial technology *level* of the frontier $A_n(0)$, i.e. a better innovative capability of the North, widens the gap. The intuition is the following: In our model framework a higher level of Northern technologies enlarges the North-South technology gap which in turn enhances the technology diffusion speed. On the other hand, own Southern innovations reduce the North-South technology gap, which in turn reduces international technology diffusion. For this reason, the South cannot fully benefit from a higher Northern technology level in the presence of own Southern innovation. The consequence is, that the North fully benefits from its new innovations, while the South does not. 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 θ_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:

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

According to (11), the relative change in the Southern technology level due to a relative change in the Southern innovative capability (around a certain value of the innovative capability) is higher when ϕ_s and $A_s(0)$ are low. We recall that ϕ_s is an increasing function of the absorptive capacity and of the foreign capital intensity. The intuition is similar to what we considered before: Own Southern innovations increase the Southern technology level and decrease at the same time the North-South technology gap so that international technology diffusion slows down. In this sense, technology diffusion and own innovation act as 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 $A = \frac{A_s}{A_n}$:

$$\hat{A}_s = \phi_s \left(\frac{1}{A} - 1 \right) + \frac{\theta_s \gamma e^{\gamma t}}{A_s} \tag{12}$$

A_s grows with the same rate λ as the technology frontier in case of convergence of growth rates, while own innovations grow at a lower rate γ per plausible assumption. Hence, the last term in the equation above will vanish over time, so that the benefit of Southern innovation vanishes. Nevertheless, innovation in the South accelerates the convergence process to the steady state.

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

3.3 International Factor Allocation in the Steady State

We now turn to the question how technology diffusion affects the allocation of internationally mobile capital between North and South in the long-run steady state when all adjustment processes are completed. Does the international capital allocation still change in the steady state after the catching up process has been completed?[11] 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 λ 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 economically 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

[11] Own innovation in the South may or may not be present at any rate $\gamma \leq \lambda$.

capital allocated to the South relative to the 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 straightforward way: Marginal products of internationally mobile high-tech capital are equalized across North and South.[12] 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 internationally 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.

This section examines these questions. Subsection 4.1 describes the model setup, subsection 4.2 interprets the model.

4.1 The Model

In the following 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, a logistic function approach 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

[12]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.

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, explicitly including the influence of the absorptive capacity and of foreign capital on technology diffusion:

$$\dot{A}_s = \phi_s(A_n - A_s) \tag{13}$$

$$\phi_s = H^{\mu} K^{\nu} \tag{14}$$

H is the absorptive capacity that rises with the Southern human capital endowment, infrastructure, labor endowment and other economically beneficial factors and decreases with economically detrimental factors such as missing access to the sea. H is measured as a South-North ratio, so that a higher similarity between the South and the North enhances the chance to transfer technologies successfully. (Compare section 3.1.) As before, international technology diffusion is driven by *foreign* capital (FDI, multinational enterprises) building on the broad empirical literature. Also as before, a higher South-North ratio of foreign capital K induces a faster technology diffusion when there is a better absorptive capacity H. Therefore, K and H act as complements. This multiplicative specification follows the empirical literature applying interaction terms (e.g. Borensztein et al. 1998, Benhabib and Spiegel 2005, Girma and Görg 2007). It seems reasonable to assume $\mu + \nu \leq 1$ i.e. a decreasing or constant returns to scale specification.

In the next step we derive K from profit maximization of firms under perfect competition and perfect capital mobility, given a Cobb-Douglas type production function. This constant returns to scale production function encompasses total factor productivity A_i, foreign (high-tech) capital K_i, domestic (low-tech) capital D_i and the aggregate input H_i. The additive combination of foreign and domestic capital in the production function implies the co-existence of foreign firms (multinational enterprises) and domestic firms that produce the same output Y_i. H_i encompasses human capital and infrastructure, labor, land and other factors as described before. All factors that enhance (hinder) technology diffusion probably also enhance (hinder) production.

$$Y_i = A_i(K_i^{\alpha} + D_i^{\alpha})H_i^{1-\alpha} = (K_i^{\alpha} + D_i^{\alpha})(\tilde{A}_i H_i)^{1-\alpha} \tag{15}$$

Herein, we use the notation $i = n, s$ and $A_i = \tilde{A}_i^{1-\alpha}$. High-tech capital K_i is built up in the North and perfectly mobile between North and South. It is assumed to stay constant so that $K_n + K_s = 1$. This assumption implies that high-tech capital is a scarce resource.[13] The marginal product of K_i can be derived as follows:

$$\frac{\partial Y_i}{\partial K_i} = \alpha K_i^{\alpha-1}(\tilde{A}_i H_i)^{1-\alpha} \tag{16}$$

Perfect international mobility of high-tech capital equates the marginal products of K_i:

$$\begin{aligned} \alpha K_n^{\alpha-1}(\tilde{A}_n H_n)^{1-\alpha} &= \alpha K_s^{\alpha-1}(\tilde{A}_s H_s)^{1-\alpha} \\ \Leftrightarrow k_n &= k_s \qquad (17) \\ \Rightarrow K &= \tilde{A} H \qquad (18) \end{aligned}$$

In the second equation we write K_i in efficiency units $k_i = \frac{K_i}{\tilde{A}_i H_i}$. In the last equation K, $\tilde{A}$ and H all denote South-North ratios.

Domestic (low-tech) capital is assumed to be internationally immobile and without any influence on international technology diffusion. Different to K_i, D_i is accumulated in the North and in the South via saving and investing part of income Y_i. (More details are presented in the Appendix.) In case of closed economies, K_s is zero. In this case, our model coincides with the standard Solow (or alternatively Ramsey) model of a closed economy, and the South grows due to own (exogenous) innovation and due to accumulation of capital D_s. (Own innovation in the South was discussed in section 3.2.) In the following analysis we basically assume that the South rather follows a purely imitation based strategy, i.e. technological progress in the South is dominated by technology diffusion from the North via the transfer of high-tech capital.

Now we simply insert equation (18) with $\tilde{A} = A^{\frac{1}{1-\alpha}}$ into (13) and (14) to obtain:

$$\dot{A}_s = H^{\mu+\nu} A^{\frac{\nu}{1-\alpha}}(A_n - A_s) \tag{19}$$

[13] Note that in this model the transfer of capital is beneficial both for the North and the South, because in the initial situation the mobile capital earns a higher return in the South than in the North and the return on foreign direct investment is transferred back to the North. Otherwise, no capital would be transferred from North to South.

Equation (21) can be re-written in terms of the growth rate $\hat{A}_s = \frac{\dot{A}_s}{A_s}$:[14]

$$\begin{aligned} \hat{A}_s &= H^{\mu+\nu} \underbrace{A^{\frac{\nu}{1-\alpha}}}_{density} \underbrace{(A^{-1} - 1)}_{distance} && (20) \\ \Leftrightarrow \hat{A}_s &= H^{\mu+\nu} \left(A^{\frac{\alpha+\nu-1}{1-\alpha}} - A^{\frac{\nu}{1-\alpha}} \right) && (21) \end{aligned}$$

4.2 Interpretation

This section interprets equations (20) and (21) derived above. Obviously, a higher H is always beneficial for technology diffusion, since it enhances the diffusion speed as well as output per assumption. Both effects enhance each other in a complementary way. In an analog way, a widespread, unaccessible area with disadvantageous natural and climatic conditions and other economically detrimental factors always impede technology diffusion.

Our main aspect under scrutiny is technological catching up and convergence of technology growth rates. Equation (20) decomposes the impact of the technology gap between A_n and A_s into two opposing parts: The first "A term" means that a lower ratio of A_s to A_n reduces the relative amount of foreign capital in the South. It describes that more foreign capital is allocated to a region if its relative technology level is higher so that technology diffusion is also higher. Let us call this *density effect*. At the same time, the second "A term" in equation (20) states that a larger technology gap increases the possibilities to adopt new technologies so that the technology diffusion speed rises. Let us call this *distance effect*.

It is a priori not clear, which effect dominates. The outcome depends on the values of α and ν. 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, $\hat{A}_s$ steadily decreases with a lower A. In this case, there is no automatic convergence mechanism.

[14]The variable A has a maximal value of one, and the exponent of the first "A term" in parentheses in equation (21) is always smaller than the exponent of the second "A term" in parentheses so that the whole expression never becomes negative.

Without own innovation in the South and without policy intervention, the South falls increasingly behind in terms of technologies, and the amount of foreign high-tech capital allocated to the South asymptotically drops towards zero. - The South is trapped.

In order to find the condition for the possibility of a convergence failure, we note that in (21) 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 situation can only occur when $\nu + \alpha > 1$. This is more likely the case, when α and ν 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. In case of a linear diffusion model with $\nu = 1$, the condition for the possibility of a growth trap is always fulfilled.

We can now derive another interesting aspect by plotting the function expressed by equations (20) and (21) for different values of α as shown in Figure 2 in the Appendix: The larger the exponent α, which means the income share of foreign capital,[15] 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. Therefore, a higher income share of foreign capital becomes more beneficial the closer the economy is to the technology frontier. Farther away from the technology frontier, a lower income share of foreign capital becomes more beneficial. This outcome stems from the fact, that the demand for foreign capital in the South as a function of A_i described by equation (16) is steeper the higher α. Consequently, when $A = \frac{A_s}{A_n}$ is large, a higher value of α attracts more foreign capital to the South. When A is small so that the South is far away from the technology frontier, a higher value of α attracts less capital to the South. This result is in accordance with what we found before: The likelihood of a convergence failure is higher when α is larger. The reason is that a higher value of α leads to a stronger reaction of the international capital allocation driven by changes in the South-North technology ratio. Thus, the density effect becomes stronger for a higher value of α, and more mobile capital is shifted away from the South when the South falls behind in terms of technologies. Also note that

[15]For reasons of mathematical simplicity, we have also chosen the income share of domestic low-tech capital to be α. But what matters for this outcome is the income share of foreign high-tech capital, not the income share of domestic low-tech capital. Hence, the result would also hold for different exponents of K_i and D_i.

according to Figure 2, increasing α above 0.5 raises $\hat{A}_s$ only slightly. That means, there seems to be a small additional benefit for technology diffusion of an income share of foreign capital higher than 0.5.

We now set $\nu = 1$ and $\alpha = \frac{1}{2}$, which yields an illustrative quadratic form:

$$\hat{A}_s = H^{\mu+\nu} \left(A - A^2 \right) \tag{22}$$

Note that the following considerations qualitatively also hold for other values of α. Figure (1) is the (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 α is chosen as discussed before. Compare Appendix, Figure 2.)

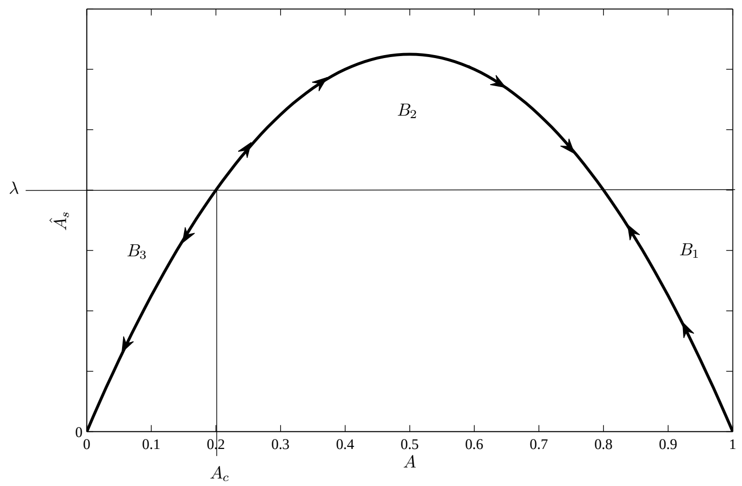

Figure 1: Areas of convergence and divergence of technology growth rates in the North and the South dependent on the distance to frontier

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 technological progress $\hat{A}_s$ increases, while the technology ratio A decreases. (We always move on the parabola.) The technology gap widens. 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 $\lim_{t\to\infty} A = 1$. This case does not occur in this model with exogenous exponential technological progress. It occurs however, if the technology frontier stays constant. (Then λ is zero in equation 4 resulting in $A = 1$.)

We then 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 λ, 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 $A < 1$, which fits to the growth performances of the "Asian Tiger" countries.

Starting on the left hand side of Figure 1 in area B_3 we identify 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. We observe this kind of behavior for example in the case of sub-Saharan African countries.

How can economic policy remedy such a 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 γ, the innovation rate in the South, is smaller than λ, the innovation rate in the North. λ is also the growth rate of A_s in the case of convergence. γ is likely smaller than λ, since the South is probably not as innovative as the North. Thus, at a certain point of time the South will fall back into the divergence area, when the difference between the technology level in the North and the technology level 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 (16). (For a discussion on promoting FDI see Hanson 2001.) The subsidy will be an effective remedy if it is high enough to overcome the critical point of a convergence failure. But again, only in the short-run. We can see from equation (16) that a constant subsidy becomes relatively unimportant when A_i and hence the marginal products of K_i grows in an exponential way. Therefore, the subsidy would have to rise together with technological progress in order too 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 a higher volume of foreign capital 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 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 provide one possible explanation (among other explanations for example given by Hanson 2001) for the mixed findings in the empirical literature on technology spillovers via FDI and the empirical facts, for instance 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 initial level of technological progress in the North, interpreted as a better innovative capability of the North, widens the international technology gap in the presence of own innovation in the South. The reason is that own innovation in the South reduces the North-South technology gap which in turn reduces the possibility to exploit Northern technologies. In this sense, 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.

Our considerations also show that a larger income share of internationally mobile foreign capital is more beneficial for the South in terms of technology diffusion the smaller 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.

On the other hand, a constant subsidy on FDI inflows has only a short-run effect and cannot prevent a convergence failure in the medium-run. The subsidy would have to rise in line with technological progress in order to stay effective. Taking the related fiscal burden into account, this sheds a somewhat critical light on such a policy in line with Hanson (2001). Thus, our outcomes support the need for a critical assessment of potential benefits of subsidizing FDI while considering the specific state of the economy in terms of existing technologies, human capital, infrastructure, the legal system and other country specific circumstances like the spatial distribution of economic activities in the light of agglomeration theory. Supporting FDI inflows in general without such a critical assessment can lead to substantial welfare losses for recipient countries.

Under the assumption of an economy that is closed for FDI inflows the model collapses to the standard Solow (or alternatively Ramsey) model where growth is driven by (exogenous) local innovation and domestic capital accumulation. In this sense the model is in line with success stories of economic growth without allowing significant foreign capital inflows such as in Japan and Korea.

However, the analysis is based on a simple stylized macroeconomic model that neglects endogenous innovation in the North and other channels of technology diffusion besides international capital mobility. It cannot capture other determinants of capital mobility (or FDI) besides returns on capital, either. 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 need to know such costs, which are certainly hard to quantify. However, the previous analysis is not a cost benefit analysis, but rather a qualitative policy assessment.

Moreover, the analysis focusses solely on positive productivity spillover effects through *technology diffusion*. As pointed out by Hanson (2001), the entrance of foreign (multinational) enterprises can have negative effects on domestic enterprises and may lower the welfare of the host country because of several reasons. If the production factors intensively used by foreign enterprises are in inelastic supply, the entrance of foreign enterprises will put upward pressure on the related factor prices and thus increase production costs for domestic and foreign enterprises. Furthermore, in case of horizontal FDI, foreign enterprises may occupy a higher market share from domestic enterprises if the demand for their final products is in inelastic supply. Finally, the entrance of multinational firms likely increases competition in a non-competitive local market. The increased competition on the one hand enhances efficiency, on the other hand diminishes profits of domestic enterprises. Since multinational firms repatriate their profits, host country welfare may decline. Such aspects cast doubt on a purely optimistic point of view of FDI that results in policies of promoting FDI inflows in general. However, such aspects canot be captured by our stylized model.

Empirically, vertical productivity spillovers within the production chain seem to be more significant than horizontal spillovers between competing firms within sectors (for instance Javorcik 2004). In the case of vertical spillovers, negative impacts of FDI on rivaling domestic firms are less likely since these firms operate within the same production chain and not as rivals. Therefore, the distinction between horizontal and vertical linkages is important for economic policy. Furthermore, FDI seeking for the exploration of natural resources has a low potential for creating positive technology spillovers. However, our stylized macroeconomic model is not able to disentangle different kinds of FDI and spillovers within host economies.

Our considerations recommend opening developing countries for FDI inflows and improving the absorptive capacities at the same time in order to benefit from international technology diffusion successfully and to avoid poverty traps. The question remains why this does not happen in reality in many cases, for instance in Sub-Saharan African countries. Some obstacles for international transfer of capital and technologies are naturally given, such as landlockedness. Other factors such as education and infrastructure could be improved, but they are not because governments do not take the responsibilities. But this argument is not directly valid for opening the economy for FDI, because there are no directly related costs like in the case of educational investment. Nevertheless, FDI may create negative effects for host economies as described above. Consequently, certain stakeholders may be worse of due to the entrance of foreign enterprises and therefore lobby against opening the economy for FDI inflows, although such a policy might be beneficial for the economy as a whole (compare Das 1987).

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 international capital mobility. Convergence of growth rates requires a sufficiently high absorptive capacity of the South (via education, infrastructure, legal framework etc.) in order to adopt new technologies successfully (additional to certain preconditions discussed in the paper). Hence, according to the model it is not sufficient to rely on market driven international capital mobility or just to transfer capital and embodied technologies to developing countries. Such policies can be a waste of resources, if development policy does not ensure that the absorptive capacities of the recipient countries determined by education, infrastructure, the legal framework and other factors suffice.

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, at least 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 technological progress over time.

Moreover, the analysis suggests that a larger income share (possibly up to about 0.5) devoted to foreign capital is more beneficial when the technology level is closer to the technology frontier. This means that financial and tax advantages for foreign investors can be ill-designed, when the developing economy lacks in existing basic technologies and in absorptive capacity which are both 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. The distinction of vertical and horizontal FDI as well as vertical and horizontal spillovers seems to be a fruitful avenue for further research. One could also attempt to include the technology diffusion framework of this paper into a general equilibrium framework with factor and product markets. This would allow to contrast the positive external effect of technology spillovers with possible negative effects of FDI for recipient countries. 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.

7 References

Acemoglu, D., P. Aghion and F. Zilibotti, (2003a). Distance to Frontier, Selection, and Economic Growth. Journal of the European Economic Association, 4(1), 37-74.

Acemoglu, D., P. Aghion and F. Zilibotti (2003b). Vertical Integration and Distance to Frontier. Journal of the European Economic Association, 1(2-3), 630-638.

Aghion, P. and P. Howitt (2005). Growth with Quality-Improving Innovations: An Integrated Framework. In: P. Aghion and S. Durlauf, eds., Handbook of Economic Growth, Elsevier, chapter 2.

Barro, R. and X. Sala-i-Martin (1997). Technological Diffusion, Convergence, and Growth. Journal of Economic Growth, 2, 127.

Barro, R. J. and X. Sala-i-Martin (2004). Economic Growth. 2nd edition, MIT Press, Cambridge, Mass.

Benhabib, J. and M. Spiegel (1994). The Role of Human Capital in Economic Development: Evidence from Aggregate Cross-Country Data. Journal of Monetary Economics, 34, 143-173.

Benhabib, J. and M. Spiegel (2005). Human capital and technology diffusion. In: P. Aghion and S. Durlauf, eds., Handbook of Economic Growth, Elsevier, chapter 13.

Blomström, M. and A. Kokko (1998). Multinational Corporations and Spillovers. Journal of Economic Surveys, 12(3), 247-277.

Borensztein E., J. De Gregorio and J.W. Lee (1998). How does foreign direct investment affect economic growth? Journal of International Economics, 45(1), 115-135.

Chen, E. K. Y. and J. H. Dunning, eds. (1994). Technology Transfer to Developing Countries. United Nations Conference on Trade and Development Programme on Transnational Corporations. Taylor and Francis.

China Statistical Yearbook (2006). China Statistics Press.

Ciruelos A. and M. Wang (2005). International Technology Diffusion: Effects of Trade and FDI. Atlantic Economic Journal, International Atlantic Economic Society, 33(4).

Crespo J., C. Martin and F. Velazquez, (2004). International technology spillovers from trade: the importance of the technological gap. Investigaciones Economicas, Fundacion SEPI, 28(3), 515-533.

Crispolti, V. and D. Marconi (2005). Technology transfer and economic growth in developing countries: an econometric analysis. Banca d'Italia, Temi di discussione series No. 564.

Das, S. (1987). Externalities, and Technology Transfer through Multinational Corporations: A Theoretical Analysis. Journal of International Economics 22, 171-182.

Diao, X., J. Ratts and H.E. Stokke (2005). International spillovers, productivity growth and openness in Thailand: an intertemporal general equilibrium analysis. Journal of Development Economics 76, 429-450.

Findlay, R. (1978). Relative Backwardness, Direct Foreign Investment, and the Transfer of Technology: A Simple Dynamic Model. The Quarterly Journal of Economics, 92(1) 1-16.

Gerschenkron, A. (1962). Economic Backwardness in Historical Perspective. Harvard University Press.

Girma, S., D. Greenaway and K. Wakelin (2001): Who benefits from Foreign Direct Investment in the UK? Scottish Journal of Political Economy, 48, 119-133.

Girma, S. (2005). Absorptive capacity and productivity spillovers From FDI: a threshold regression analysis, Oxford Bulletin of Economics and Statistics, 67(3), 281-306.

Girma, S. and H. Görg (2007). The role of the efficiency gap for spillovers from FDI: Evidence from quantile regressions. Open Economies Review, 18(2), 215-232.

Grossman, G. and E. Helpman (1991). Innovation and Growth in the Global Economy. The MIT Press.

Griffith, R., S. Redding and H. Simpson (2002). Productivity convergence and foreign ownership at the establishment level. IFS Working Paper WP02/22.

Griffith R., S. Redding and J. van Reenen (2004). Mapping the Two Faces of R&D: Productivity Growth in a Panel of OECD Industries. The Review of Economics and Statistics, MIT Press, 86(4), 883-895.

Hanson, G. H. (2001). Should Countries Promote Foreign Direct Investment? United

Nations Conference on Trade and Development, Center for International Development, Harvard University, G-24 Discussion Paper Series.

Hoekman, B. and B. S. Javorcik, eds. (2006). Global Integration & Technology Transfer. The World Bank, Washington DC.

Javorcik, B. S. (2004). Does Foreign Direct Investment Increase the Productivity of Domestic Firms? In Search of Spillovers through Backward Linkages. American Economic Review 94(3), 605-627.

Keller, W. (2004). International Technology Diffusion. Journal of Economic Literature, American Economic Association, 42(3), 752-782.

Kneller, M. (2005). Frontier technology, Absorptive Capacity and Distance, Oxford Bulletin of Economics and Statistics, 67(1), 1-23.

Kokko, A. (1992). Foreign Direct Investment, Host Country Characteristics, and Spillovers. Stockholm School of Economics.

Kokko A., R. Tansini and M. C. Zejan (1996). Local technological capability and productivity spillovers from FDI in the Uruguayan manufacturing sector. Journal of Development Studies, 32(4), 602-611.

Krugman, P. (1979). A Model of Innovation, Technology Transfer, and the World Distribution of Income. Journal of Political Economy, 87(2), 253-266.

Lai Mingyong, Shuijun Peng and Qun Bao (2006). Technology spillovers, absorptive capacity and economic growth. China Economic Review, 17, 300-320.

Lall, S. and S. Urata (2003). Competitiveness, FDI and Technological Activity in East Asia. Edward Elgar, Cheltenham, Northampton.

Mayer-Foulkes, D. and P. Nunnenkamp (2009). Do Multinational Enterprises Contribute to Convergence or Divergence? A Disaggregated Analysis of US FDI. Forthcoming in: Review of Development Economics, 13(2), 304-318.

Nelson, R. and E. Phelps (1966). Investment in Humans, Technological Diffusion, and Economic Growth. The American Economic Review, Papers and Proceedings, 61, 69-75.

OECD (2002). Foreign Direct Investment for Development - Maximising Benefits, Minimising Costs. OECD Publications, Paris.

Romer, P. (1990). Endogenous Technological Change. Journal of Political Economy, 98, 71-102.

Saggi, K. (2002). Trade, Foreign Direct Investment, and International Technology Transfer: A Survey. World Bank Research Observer, Oxford University Press, 17(2), 191-235.

Van Meijl, H. and F. van Tongeren (1999). Endogenous International Technology Spillovers And Biased Technical Change In The GTAP Model. GTAP Technical Paper No. 15.

Xu, B., J. Wang J. (2000). Trade, FDI, and International Technology Diffusion. Journal of Economic Integration, 15(4), 585-601.

Wang, J-Y. and M. Blomström (1992). Foreign investment and technological transfer: a simple model, European Economic Review, 36, 137-155.

World Bank (1993). The East Asian Miracle: Economic Growth and Public Policy. World Bank Policy Research Report. Washington DC.

World Bank (2008). Global Economic Perspectives. Technology Diffusion in the Developing World. Washington DC.

8 Appendix

In the following we examine the accumulation of domestic, internationally immobile, domestic (low-tech) capital D_i referring to the model presented in section 4.1. We assume a constant savings rate s a la Solow and a depreciation rate δ.[16]

$$\dot{D}_i = sY_i - \delta D_i \tag{23}$$

The division of this equation by $\tilde{A}_i H_i$ yields a reformulation in efficiency units $k_i = \frac{K_i}{\tilde{A}_i H_i}$ and $d_i = \frac{D_i}{\tilde{A}_i H_i}$:

$$\frac{\dot{D}_i}{\tilde{A}_i H_i} = s(k_i^\alpha + d_i^\alpha) - \delta d_i$$

We transfer this expression following Barrow and Sala-i-Martin (2004):

$$\begin{aligned} \dot{d}_i &= \frac{\dot{D}_i}{\tilde{A}_i H_i} - \hat{\tilde{A}}_i d_i \\ \Rightarrow \dot{d}_i &= s(k_i^\alpha + d_i^\alpha) - (\hat{\tilde{A}}_i + \delta) d_i \end{aligned}$$

[16]Alternatively, capital could be accumulated via an inter-temporarily optimal choice of consumption a la Ramsey.

In the long-run, we find $\lim_{t\to\infty}(k_i^\alpha + d_i^\alpha) = d_i^\alpha$ since D_i is accumulated, while K_i is not. Thus, setting $\dot{d}_i = 0$ implicitly yields the following volume of domestic capital in efficiency units in the asymptotic steady state:

$$s(d_i^*)^\alpha = (\hat{\tilde{A}}_i + \delta)d_i^* \tag{24}$$

Accordingly, D_i asymptotically grows with the same rate as A_i, and Y_i grows with the same rate, too. In case of convergence, the Southern and the Northern economy therefore grow with the same rate A_n which is determined by the technological progress in the North. The steady state value d_i^* rises with the propensity to save and invest and declines with the depreciation rate and with the rate of technological progress. As a consequence, the ratio of domestic capital to the technology level declines when the rate of technological progress becomes higher.

Moreover, we are able to determine the volume of high-tech capital K_s in absolute terms (not only for the steady state but for any point of time) using equation (18) and our initial assumption $K_n + K_s = 1$:

$$\begin{aligned} \frac{K_s}{1-K_s} &= \tilde{A}H \\ \Leftrightarrow K_s &= \frac{\tilde{A}H}{1+\tilde{A}H} \end{aligned} \tag{25}$$

The closer the Southern technology level catches up to the Northern level and the higher the absorptive capacity of the South, the more high-tech capital is obviously allocated to the South.

Finally, Figure 2 plots $\hat{A}_s$ as a function of A for different values of α.

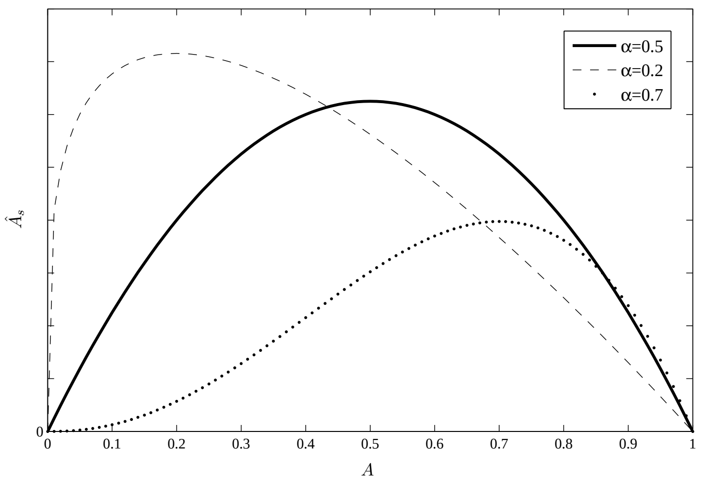

Figure 2: Rate of technological progress in the South dependent on the distance to frontier for different income shares of foreign capital in the South