Technology Adoption and Multiple Growth Paths: An Intertemporal General Equilibrium Analysis of the Catch-Up Process in Thailand

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Abstract: As opposed to the Veblen–Gerschenkron catching-up hypothesis, the recent literature allows for technological divergence in backward economies. We extend a nonlinear adoption function to include openness and interact with capital accumulation in an intertemporal general equilibrium framework. The threshold gap necessary to catch up is endogenously determined by the economy's absorptive capacity. The model generates multiple transition growth paths depending on whether technological catch-up is achieved, and due to the endogeneity of the threshold gap, endogenous switching between development paths might be observed. Our simulations of the Thailand experience show how lack of investment in education and protectionism generate loss of transition growth and technological divergence. The paper highlights the role of absorptive capacity, and especially its importance for economies on the balance between low growth and high growth paths. JEL no. O41, O53

Keywords: Nonlinear productivity dynamics; intertemporal growth modeling; Thailand

1 Introduction

The catching-up hypothesis, related to Veblen (1915) and Gerschenkron (1962), links productivity growth to the size of the gap to the world technology frontier. The more backward the economy is, the higher the pro-

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Remark: The project is financed by the Norwegian Research Council. I appreciate comments and suggestions at seminars at the University of Amsterdam, the Norwegian University of Science and Technology, and at the European Public Choice Society annual meeting 2002, and in particular from Xinshen Diao, Jørn Rattsø, Ragnar Torvik, and an anonymous referee. Please address correspondence to Hildegunn E. Stokke, Department of Economics, Norwegian University of Science and Technology, N-7491 Trondheim, Norway; e-mail: hildegunnes@svt.ntnu.no ductivity growth rate is. But as observed by Findlay (1978: 2), "of course, the disparity must not be too wide for the thesis to hold." A debate in the literature is related to the existence of a threshold value of the gap, below which the economy is not able to catch up with the frontier, and divergence is observed.

Nelson and Phelps (1966) introduced and formalized an adoption function of technological convergence dependent on human capital. Multiple equilibria with technology adoption is analyzed by Papageorgiou (2002a). We extend the adoption function to include openness and establish an endogenous threshold gap necessary to catch up in a general equilibrium framework. Countries at the same technological level may face different threshold values depending on domestic conditions affecting the ability to absorb and take advantage of technology spillovers from abroad. Since productivity growth influences GDP growth, both directly and indirectly via its effect on capital accumulation, the model generates multiple transition growth paths depending on whether technological catch-up is achieved. The intertemporal model is calibrated to discuss the importance of absorptive capacity for the growth experience in Thailand, where productivity growth mainly has been driven by adoption of foreign technology and with limited importance of domestic innovation and R&D activity.

In the Nelson–Phelps model of technology adoption, the ability to exploit foreign technology is linked to the level of human capital. Findlay (1978) emphasizes the importance of technological contagion to benefit from the technology gap, and relates technology transfer to the degree of foreign direct investments in the domestic economy. Krugman (1979), among others, models international trade as the channel transmitting foreign technology. Diao et al. (2002) integrate both trade and foreign capital as spillover channels in an intertemporal model, and investigate the relevance for Thailand. The present paper focuses on the interaction between technology transfer through trade and domestic human capital to take advantage of its relative backwardness. The more educated workers are and the higher the trade share is, the more backward the economy can be and still be able to catch up towards the frontier.

The analysis assumes exogenous long-run growth and concentrates on transitional dynamics. This is supported in an empirical analysis of productivity dynamics in Thailand, where Rattsø and Stokke (2003) reject endogenous growth rate effects of technology spillovers. Based on the ability to catch up with the frontier through technology adoption, there exist two alternative long-run steady state equilibria with balanced growth and constant technology gap. The high and low equilibria represent different convergence clubs where the long-run growth rate is the same, but different transition growth paths generate large differences with respect to both technological level and overall income level. An important aspect of the model is that due to the endogeneity of the threshold gap, endogenous switching between development paths might be observed. Static multiple equilibria in an intertemporal model raise some questions about what drives the choice of equilibrium. As emphasized by Krugman (1991), the equilibrium may depend on both history and expectations. The present model is built around a representative agent with perfect foresight, and the dynamics of self-fulfilling expectations with many agents are not investigated.

Early evidence on the existence of different convergence clubs is provided by Baumol (1986). Quah (1993, 1997) studies the dynamics of cross-country incomes, and documents a twin-peaked distribution with clusters of rich and poor countries. Using a regression tree analysis, Durlauf and Johnson (1995) also support the existence of different convergence clubs. One theoretical understanding of multiple equilibria in per capita income is linked to the Big-Push literature, where coordinated capital investment is necessary to reach the high equilibrium (Murphy et al. 1989). Azariadis and Drazen (1990) explain club convergence from threshold externalities in accumulation of human capital. A third view, followed up in the present paper, relates multiple convergence clubs to differences in technology acquisition. In a Schumpeterian growth model combining R&D activity and technology adoption, Howitt and Mayer-Foulkes (2002) identify three different convergence clubs, characterized by R&D, technology adoption, and stagnation, respectively. The importance of productivity in explaining large income differences is supported in several empirical studies, for instance Easterly and Levine (2001), Hall and Jones (1999), and Klenow and Rodriguez-Clare (1997). In a recent contribution Feyrer (2003) shows that the twin-peaked distribution of per capita income can be attributed to a twin-peaked distribution of productivity levels rather than differences in physical or human capital accumulation.

As part of the Asian success story Thailand has had an average growth rate of almost 8 percent from 1960 and up until the recent crisis. The economic policy framework with macroeconomic stability, reasonably full utilization of resources, and well-developed institutions is an important explanation behind this remarkable growth record. But as emphasized by Pack (1993: 300), "(...) getting most macroeconomic policies correct without giving explicit attention to technology acquisition will lead to moderate growth, but at rates that will not approach those of the Asian 'miracle' economies." The general equilibrium model is specified and calibrated to discuss the Thailand growth experience from this perspective. It describes an economy characterized by a stable environment for business investment. In this setting, we analyze the marginal impact of technology adoption on economic growth.

The model is calibrated to reproduce Thailand's growth experience during 1960–1998 given the relative backwardness and catch-up possibilities in the early 1960s. Gradual tariff reductions and successive improvements in education stimulate technology adoption, and the interplay between technological catch-up and classical convergence generates prolonged high transition growth above steady state rate. A counterfactual experiment where tariff rates and education are kept constant at the 1960 level shows how the economy might converge to the low equilibrium even though its initial position is above the threshold gap. Further simulations explore the sensitivity of the growth path with respect to the initial technology gap. The results show that starting closer to the frontier cannot compensate for the inability to exploit foreign technology or lack of technology transfer. Starting out below the threshold value for catch-up implies loss of transition growth, but with sufficient improvements of absorptive capacity, the economy becomes capable of exploiting foreign technology and converges towards the high equilibrium. Overall, the paper shows how absorptive capacity can be important for whether relative backward economies develop along a high growth or a low growth path, and might explain the remarkable growth record in Thailand after 1960 and up until the recent crisis.

Section 2 documents the importance of trade and education for technology adoption and catch-up, while the assumed productivity dynamics are explained in Section 3. Calibration related to the endogenous productivity specification follows in Section 4, and Section 5 presents the full intertemporal model. Calibration of the high growth reference path is given in Section 6, while Section 7 discusses the importance of absorptive capacity through a counterfactual experiment. Section 8 provides sensitivity analyses of the initial position relative to the frontier to see how this affects previous results. Concluding remarks are offered in Section 9.

2 Empirical Studies of Trade and Education in Technology Adoption

The role of human capital in economic development has been widely discussed in the literature, and is known as the Lucas versus Nelson–Phelps controversy. Lucas (1988) introduces human capital as a factor in the production function, and in this way defines a relationship between human capital level and income level. Nelson and Phelps (1966) on the other hand emphasize the role of human capital in technology adoption, where the level of human capital has a positive impact on technological progress. Utilizing human capital data from Kyriacou (1991), Benhabib and Spiegel (1994) run cross-country growth accounting regressions à la Mankiw et al. (1992), but do not find any significant effect of human capital accumulation on output growth. Motivated by this rejection of the Lucas approach, they focus on the role of human capital in total factor productivity growth, emphasizing two channels: improving technology adoption from abroad and increasing the capability of doing own innovations. Their regression results suggest that the role of human capital in economic growth is in fact through innovation and technology adoption, rather than as separate factor in the production function. In some of the regressions the results seem to favor the catch-up channel over the innovation channel, but as pointed out by the authors, the relative importance of the two channels might change during the development process. Running a regression of the richest third of the nations, the effect of human capital through adoption loses its significance, while the innovation effect is positive and significant. For a sample of poorer countries, on the other hand, the innovation component was found to be unimportant. The role of human capital in the catch-up process is also documented empirically in Dowrick and Rogers (2002), Frantzen (2000), and Baumol et al. (1989).

The importance of trade and openness for technology transfer and spillovers is documented in a wide range of studies. Edwards (1998) investigated the effect of 9 alternative measures of openness on TFP growth in a dataset of 93 countries. He concludes that more open economies indeed have experienced faster productivity growth. Coe et al. (1997) apply a dataset for 77 countries during 1971–1990, and document a substantial spillover effect of foreign R&D and that spillovers are linked to trade. Rattsø and Stokke (2003) apply the method and the disaggregated data of Tinakorn and Sussangkarn (1998) for agriculture and industry in Thailand to investigate more closely the dynamics of productivity and foreign spillover (for the period 1975–1996). Foreign spillovers are assumed to be channeled through foreign trade and foreign direct investment (in industry). They observe a strong and fairly robust long-run relationship between openness and productivity in both domestic sectors during a period of an increasing trade share of GDP and an increasing foreign investment share of investment.

Hansson and Henrekson (1994) study the combined importance of human capital and integration into the world economy for technology diffusion. In a cross-country study of 81 countries they find a significant effect of initial technology gap on labor productivity growth, and the effect is strengthened when the capability to absorb foreign technology is taken into account. Both higher level of human capital and more interaction with the rest of the world stimulate technological catch-up. Applying a dataset for 53 developing countries Mayer (2001) documents a positive and strongly significant effect of the combination of machinery imports and human capital stock on economic growth. Similar results are found in Isaksson (2002), who investigate the role of human capital in the trade-growth link. For countries with sufficient high levels of human capital the trade effect is positive, implying that human capital is important in absorbing and taking advantage of foreign knowledge flows.

3 Productivity Dynamics

The starting point of our productivity specification is the Nelson–Phelps (1966) model of technology adoption and catch-up. They assume exogenous growth of a best practice world technology frontier, and the backward country can catch up by adopting modern technology. In line with the standard Veblen–Gerschenkron catching-up hypothesis productivity growth is increasing with the size of the gap to the world frontier. The further you are from the frontier, the larger the learning and catch-up possibilities are, and thus the higher the growth rate is. In the long run, productivity growth equals the growth rate of the world frontier, and we observe a constant equilibrium technology gap. The relative position to the frontier depends on the country's capability of catching up, measured here by the level of human capital.

The recent literature limits the advantage of relative backwardness and allows for technological divergence in backward economies. Benhabib and Spiegel (2003) offer an alternative formulation of the Veblen–Gerschenkron hypothesis, where low-skilled economies may diverge relative to the frontier.

The relationship between trade and technological progress is analyzed by Xie (1999), and he shows how lack of technological contact may reduce the intensity of cross-country knowledge spillovers as the gap increases. Papageorgiou (2002a) assumes a quadratic (rather than monotonically positive) relationship between the rate of adoption and relative backwardness. As opposed to the catching-up hypothesis there exists a threshold value of the gap, below which economies are not able to adopt modern technology. We apply a similar quadratic relationship between the technology gap and the productivity growth rate, with endogenous determination of the threshold gap as an important extension. This modified Nelson–Phelps specification is consistent with an S-shaped technology diffusion path, where productivity growth first rises and then falls. Griliches (1957) and Gort and Klepper (1982), among others, document the S-curve empirically, while an overview of alternative theoretical explanations is given by Geroski (1999). Our understanding of the concave relationship between technology gap and productivity growth rate is related to learning by doing and decreasing returns to learning, as emphasized by Young (1991). The ability to imitate and benefit from foreign technology improves during the catch-up process (imitation costs decline), and productivity growth rate increases. Over time, less adoption opportunities and decreasing returns to learning generate a falling productivity growth rate.

The literature has focused on the level of human capital as a source of technology adoption. The growth process in Thailand has not been characterized by R&D-intensive high-skilled production, but rather by low-tech industries. The understanding of human capital in the catch-up process is therefore linked to a basic educational level of the labor force. During the period we study (1960–1998), the secondary enrollment ratio in Thailand increased from 13 percent to about 60 percent. Our hypothesis is that this increase in the general level of education has improved the economy's ability to take advantage of its relative backwardness through technology adoption. Trade and interaction with the rest of the world is important for the transfer of new technology to domestic producers, and based on the documentation in Section 2, we extend the adoption function to include the trade share of GDP. The economy's absorptive capacity is hence linked to the degree of openness and the skill level of workers. While the relative gap to the frontier represents the learning potential through imitation and adoption, trade is the channel transmitting the foreign technology and human capital a measure of how well the imported technology can be exploited.

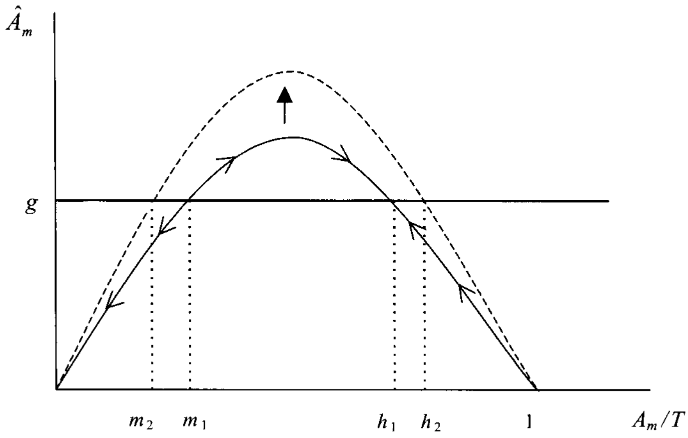
The rate of labor-augmenting technical progress in industry ($\hat{A}_m$) is specified as follows (time subscript omitted):

$$\hat{A}_m = b \cdot (1-u)^{\gamma_1} \left(\frac{EX + IM}{GDP} \right)^{\gamma_2} \left[\frac{A_m}{T} - \left(\frac{A_m}{T} \right)^2 \right], \tag{1}$$

where $(1-u)$ is the share of total labor force engaged in secondary education, EX is exports, IM imports, GDP gross domestic product, T the productivity level of the world frontier, and b is a constant parameter. γ_1 and γ_2 represent the elasticity of productivity growth with respect to education share and trade share, respectively, and is constant over time.

The adoption function in (1) gives a hump-shaped relationship between productivity growth and technology gap, as illustrated in Figure 1. The horizontal axis shows the relative position to the frontier, while productivity growth rate is given on the vertical axis. The further to the left the economy is positioned, the larger the technology gap is. Productivity growth at the frontier is set exogenously equal to g. When the domestic productivity growth rate exceeds the growth rate of the frontier, the economy is catching up and the gap decreases. Equivalently, lower productivity growth rate than the frontier increases the gap, as illustrated with arrows in Figure 1.

Figure 1: *Industrial Productivity Growth Rate as a Function of the Technology Gap*



In the Nelson–Phelps model, the productivity growth rate is a negative and convex function of the technology gap. The further the economy from the frontier is, the larger the catch-up possibilities are. The impact of one unit of larger gap on the productivity growth rate increases with the distance to the frontier (convex relationship). The quadratic formulation of the adoption function limits the advantage of relative backwardness and generates multiple equilibria. There exists a threshold value of the technology gap (m_1), below which the economy is not able to take advantage of foreign technology, and diverges relative to the frontier. The productivity growth rate is positive, but declining, and the gap increases over time. When the technological level is above the threshold value, the economy's capability of adopting and taking advantage of foreign technology is sufficient to catch up towards the frontier (given other conditions like degree of openness and educational level). Learning during the catch-up process generates increasing productivity growth rate, before declining towards the long-run steady state rate due to gradual saturation of adoption opportunities. In the high equilibrium, domestic productivity growth equals the rate at the frontier, and the technology gap is constant (h_1).

In the catch-up model by Nelson and Phelps, the higher level of human capital shifts the adoption function and gives a smaller gap to the frontier in long-run equilibrium. In the present model, the skill level of the labor force and the degree of openness in the economy also influence the threshold value for catch-up, which is endogenous, and may vary across economies and during the development process. The more educated workers are and the higher the trade share is, the more backward the economy can be and still achieve high transition growth and catch up towards the frontier. As illustrated by the dotted curve in Figure 1, improved capacity of absorbing foreign technology (either by higher education or increased trade) shifts the adoption function, and gives lower threshold value for catch-up (m_2) and smaller technology gap in the high equilibrium (h_2). Given the economy is too far from the frontier to benefit from its relative backwardness, more educated workers or increased trade share lower the threshold gap necessary to catch up, and might get the economy growing. For an economy already in the catching-up process, skill level and trade share affect transition growth and the relative position to the frontier in long-run equilibrium. Asymptotically, if the absorptive capacity is sufficiently improved, the threshold gap declines towards zero, and the long-run equilibrium is characterized by complete closing of the gap. The model does take into account potential leapfrogging.

The nonlinear productivity dynamics are combined with capital accumulation in an intertemporal general equilibrium framework. The long-run balanced growth restriction imposed on the model affects the productivity dynamics when the economy is below the threshold value of the gap. The growth rate is lower than the rate at the frontier and the gap increases over time, but in the very long run the productivity growth rate returns to the assumed steady state rate (which equals the exogenous growth rate of the frontier). This means that as the gap widens, the economy reaches a point where the productivity growth rate starts to increase, but is still below the rate at the frontier. A possible understanding of these dynamics is that backward economies produce low-quality products that can easily be improved by copying some basic technologies from the frontier. Even though divergence is observed for a long time, there exists a long-run equilibrium with constant technological gap. The high and low equilibria represent alternative convergence clubs with similar productivity growth rates, but different levels of technology. The focus of the analysis is on the transitional dynamics towards the long-run equilibrium. When the technological level is above the threshold value, the transition path is characterized by high productivity growth exceeding the rate at the frontier during the entire period. An economy below the threshold value converges to the low equilibrium after a period of low productivity growth and increasing technological gap. The model is able to explain both high and low growth paths based on whether technological catch-up is achieved. This follows from the impact of productivity growth on GDP growth, both directly and indirectly via capital accumulation. The possibility of endogenous switching between high and low growth paths due to changes in absorptive capacity is an important part of the model.

4 Calibration of Productivity Dynamics

To capture the impact of openness and skill level on technology adoption and economic growth during transition, import tariffs and education share are calibrated according to data. The elasticities of productivity growth with respect to the level of education and total trade share of GDP (γ_1 and γ_2, respectively) are important for the productivity dynamics explained in the previous section, and are calibrated based on estimates in the literature (documented below).

The share of total labor force in education, defined as the number of pupils in secondary education relative to total population in the group of people 15–64 years old, increased from about 2 percent in 1960 (via 3 percent in 1968 and 6 percent in 1990) to 10 percent in 1996. The data shows a sharp increase in education investment after 1990 (World Bank 2001). The share of total labor force engaged in education is calibrated to increase from about 2 percent in 1960 to 11 percent in 1998, with a relatively larger increase over time, especially after 1990. The education share is assumed to stabilize at 11 percent in the long run. As shown in the IMF study of Kochhar et al. (1996), Thailand did not liberalize trade quickly (partly due to limited public finances), but rather implemented gradual trade liberalization. This is captured in the calibration by a gradual reduction of import tariffs along the transition path based on historical data. Agricultural and industrial tariff rates (relative to import) decrease at a constant annual rate from about 30 percent in 1960 to 10 and 8 percent, respectively, in 1998. In the long run, tariffs remain constant at the 1998 level.

Various estimates of the effect of trade or openness on productivity growth rate exist in the literature. As documented in Section 2, Isaksson (2002) emphasizes the important link between trade and human capital, and finds that the impact of total trade share on growth in GDP per capita is positive only when the level of human capital is sufficiently high. According to his results, a 10 percentage points increase in total trade as share of GDP gives a 0.23 percentage points higher GDP per capita growth when average years of schooling is 10 years. Assuming a labor share of 0.35 (consistent with data from Thailand's 1998 SAM), this corresponds to a 0.1 percentage points higher TFP growth rate. In a cross-country study of 16 developed countries during 1950–1986, Alam (1992) estimates a much larger effect of total trade as share of GDP on growth in GDP per worker. He finds that a 10 percentage points increase in total trade share generates about 3 percentage points higher GDP per worker growth rate, corresponding to a 1 percentage point higher TFP growth rate. It seems unreasonable that a 10 percentage points difference in total trade as share of GDP between two countries that are equal in every other respect, should generate productivity growth differences of this magnitude. Even though the mechanisms highlighted and tested in Alam (1992) are certainly important, the econometric analysis faces important challenges. Decreasing returns of the effect of trade share on productivity growth is not taken into account, giving unreasonable high estimates.

In our calibration we assume an elasticity of industrial labor-augmenting technical progress with respect to trade share equal to one ($\gamma_2 = 1$), which lies in the range between the two studies referred to above. Our estimate implies that a 10 percentage points increase in trade share from 0.2 to 0.3

gives a 1.3 percentage points higher productivity growth rate ($\hat{A}_m$) when starting from the assumed steady state rate (2.7 percent). Taking into account the labor share in industry of 0.35, this implies an increase in the TFP growth rate of 0.45 percentage points (see Section 5.1 on the relationship between labor-augmenting technical progress and TFP growth). Similarly, an increase in trade share from 0.7 to 0.8 generates a 0.15 percentage points higher TFP growth rate.

Empirical evidence on the effect of education share (or secondary enrollment ratio) on productivity growth is more limited. Many studies investigate the impact of average years of schooling on growth, but these estimates are hard to translate into education share effects. In a cross-country study, Baumol et al. (1989) estimate the effect of education on GDP per capita growth rate. They document a significant role of secondary education in the catch up process, but the magnitude of the effect seems too high. According to their lowest estimate, a 10 percentage points higher secondary enrollment ratio generates a 2.5 percentage points higher TFP growth rate (assuming a labor share of 0.35). During 1960–1998, Thailand's secondary enrollment ratio increased from 13 to about 60 percent, a development not reflected in increased productivity growth in the magnitude suggested in Baumol et al. (1989). We apply an elasticity of industrial labor-augmenting technical progress with respect to education share equal to 0.33 ($\gamma_1 = 0.33$), which means that a 1 percent increase in the share of total labor force engaged in education generates a 0.33 percent increase in productivity growth. Assuming a constant share of persons in secondary education age relative to total population in the group of people 15–64 years old (equal to 0.18 based on World Bank 2001), the secondary enrollment ratio can easily be calculated from the education share applied in the adoption function in (1). With an elasticity of 0.33 an increase in the enrollment ratio from 20 to 30 percent gives a 0.5 percentage points higher productivity growth when starting from the steady state rate of 2.7 percent (corresponding to a 0.2 percentage points higher TFP growth rate). Similarly, an increase from 30 to 40 percent implies a 0.1 percentage point higher TFP growth rate.

5 The Intertemporal General Equilibrium Model

The intertemporal model describes an economy with macroeconomic stability, full employment of resources, and flexible allocation of resources between sectors according to profitability. The assumptions are heroic, but then Thailand has enjoyed an impressive growth record with the ability of holding macroeconomic balance and reasonably full utilization of resources. We model a small open economy where capital accumulation and technological growth do not influence the world prices and interest rate, which are exogenously given. Exogenous interest rate and no imperfections in the capital market give immediate adjustment of the capital stock to its steady state level if the model is calibrated to an out-of-steady-state path. The economy takes advantage of foreign borrowing to finance the investments to fully exploit the profit opportunities along the steady state. Introducing adjustment costs in investment is a common way of creating interesting dynamics in such a model. Moreover, as shown by Diao et al. (1998), imperfect substitution between domestic and foreign goods through an Armington composite system would also constrain the speed of return to steady state. We choose both approaches in this paper. In addition, the transition paths are affected by the nonlinear productivity dynamics with multiple equilibria. The representative household in the economy allocates consumption and savings to maximize an intertemporal utility function. Since investment can be financed through foreign borrowing, the decisions about savings and investment can be separated. Domestic savings and investments do not have to be equal in each period, but a long-run restriction on foreign debt exists.

We apply the model setup of Diao et al. (2004) as a benchmark, but introduce a nonlinear adoption function allowing for the existence of multiple equilibria. The productivity dynamics are described in Section 3, while other important equations included in the model are presented in the following subsections.[1]

5.1 Production Functions and Balanced Growth

The production functions for agriculture, a, and industry, m, are defined as:

$$X_a = \tilde{A}_a L_a^{\beta_1} LD^{\beta_2} K_a^{1-\beta_1-\beta_2} \tag{2}$$

$$X_m = \tilde{A}_m L_m^{\alpha} K_m^{1-\alpha}, \tag{3}$$

where $0 < \alpha, \beta_1, \beta_2, \beta_1 + \beta_2 < 1$. Further, $\tilde{A}_i$ represents the level of sector TFP, L_i sector labor demand, LD land, and K_i sector capital use, $i = a, m$.

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[1] Complete documentation of the intertemporal general equilibrium model is available from the author upon request.

Labor and capital are mobile across sectors. Due to fixed supply of land together with different capital intensity in the two sectors, we need different growth rates for TFP across sectors in order to have a balanced growth path. Introducing labor-augmenting technical progress, A_i, and land-augmenting technical progress A_D, sector TFP is given as:

$$\tilde{A}_m = A_m^{\alpha} \tag{4}$$

$$\tilde{A}_a = A_a^{\beta_1} A_D^{\beta_2}. \tag{5}$$

It follows that the growth paths of sector TFP are as follows:

$$\frac{\dot{\tilde{A}}_m}{\tilde{A}_m} = \alpha \frac{\dot{A}_m}{A_m} \tag{6}$$

$$\frac{\dot{\tilde{A}}_a}{\tilde{A}_a} = \beta_1 \frac{\dot{A}_a}{A_a} + \beta_2 \frac{\dot{A}_D}{A_D}. \tag{7}$$

Industrial labor-augmenting technical progress is endogenously determined by the economy's relative position to the world technology frontier and its ability to absorb and take advantage of foreign technology (as explained in Section 3). In the long run, technical progress equals the exogenous growth rate of the frontier given as g, implying a constant equilibrium gap. Land- and labor-augmenting technical progress in agriculture are set exogenously consistent with a balanced growth path. The steady state is defined by the exogenous long-term growth rate for the country's overall technical progress g, and the exogenous labor supply growth rate n.

5.2 Education and Labor Market Equilibrium

A constant share of the labor force $(1 - u)$ is at every time engaged in education, acquiring skills that improve the adoption of foreign technology and indirectly affect the economy-wide growth rate. An additional effect of increased investment in education is a reduced labor supply (L), which influences the wage rate through the labor market equilibrium condition:

$$u \cdot L = L_a + L_m, \tag{8}$$

where u is the remaining share of the labor force engaged in production activities.

5.3 The Household and Consumption/Saving

The representative household allocates income to consumption and savings to maximize its intertemporal utility. There is no independent government sector and the tax revenues in the data (including import tariffs and sales taxes) are transferred to the household lump sum. The household receives income from labor, capital, and land, and pays interests on foreign debt. The intertemporal utility function is maximized subject to a budget constraint, which says that discounted value of total consumption cannot exceed discounted value of total income. With the usual restrictions, we have the well-known Euler equation for optimal allocation of consumption:

$$\left(\frac{Q_{t+1}}{Q_t}\right)^{\sigma}\frac{PQ_{t+1}}{PQ_t}=\frac{1+r}{1+\rho}, \tag{9}$$

where r is the exogenous world interest rate, ρ the positive rate of time preference, $1/\sigma$ the intertemporal elasticity of substitution, Q_t total consumption in period t, and PQ_t is the aggregate consumption price. The growth in consumption depends on the relationship between the interest rates, the time preference rates, the elasticity of substitution, and the price path. Higher interest rates and lower time preference rates motivate more savings and thereby higher consumption growth.

5.4 Investment and Capital Stock

The aggregate capital stock is managed by an independent investor who chooses an investment path to maximize the present value of future profits over an infinite horizon, subject to the capital accumulation constraint. With a waste due to the adjustment costs in investment, net profits as returns to capital go to the household. The adjustment costs in real terms, *ADJ*, consumes the industrial good and are specified as:

$$ADJ_t=a\cdot P_{m,t}\cdot\frac{I_t^2}{K_t}, \tag{10}$$

where a is constant, $P_{m,t}$ is the composite price of the industrial good, I_t investment in real terms, and K_t is the stock of capital at time t.

Differentiating the intertemporal profit function of the investor with respect to I_t gives:

$$q_t=PI_t+2\cdot P_{m,t}\cdot a\cdot\frac{I_t}{K_t}, \tag{11}$$

where PI_t is the unit cost of the investment net adjustment costs. This relationship says that the investor equilibrates the marginal cost of investment, which is given on the the right-hand side of (10), and the shadow price of capital, q_t. Differentiating the same function with respect to K_t gives us the well-known no-arbitrage condition:

$$r \cdot q_{t-1} = Rk_t + a \cdot P_{m,t} \cdot \left(\frac{I_t}{K_t}\right)^2 - \delta \cdot q_t + \dot{q}_t, \tag{12}$$

which states that marginal return to capital has to equal the interest payments on a perfectly substitutable asset of size q_{t-1}. The first term on the right-hand side of (12), Rk_t, is the capital rental rate, while the second term is the derivative of capital in the adjustment cost function (10). The marginal return to capital also has to be adjusted by the depreciation rate, δ, and capital gain or loss, $\dot{q}_t$.

5.5 Foreign Sector and Foreign Debt

We assume imperfect substitution between domestic and foreign goods, so the model operates with two composite goods, one agricultural and one industrial. Imports are endogenously determined through the Armington functions, while exports are determined through the constant elasticity of transformation (CET) functions. As discussed earlier, this is a way to create transitional dynamics in a small open economy model facing a perfect international capital market and exogenous interest rate given from the world market. If domestic investments exceed domestic savings, the gap is financed through foreign borrowing. An increase in the foreign capital inflows (i.e., trade deficits) in the current period, together with interest payments on existing debt, augments foreign debt in the next period.

5.6 Equilibrium

In each period (intra-temporal equilibrium), the following conditions must be fulfilled: (1) in each sector, domestic demand plus export demand equal total output; (2) factor demand equals factor supply; (3) investments equal domestic savings plus foreign borrowing.

The steady state equilibrium requires that capital stock and foreign debt ($DEBT$) grow at a constant rate given by $g + n$:

$$I_T = (\delta + g + n)K_T \tag{13}$$

$$FSAV_T = (g + n - r)DEBT_T, \tag{14}$$

where *FSAV* is the trade deficit (surplus if negative). Finally, the shadow price for the capital becomes constant, as does the marginal return to capital:

$$Rk_T + a \cdot P_{m,T}\left(\frac{I_T}{K_T}\right)^2 = (r + \delta)q_T. \tag{15}$$

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

6 Thailand's High Growth Path

The intertemporal model is calibrated to reproduce Thailand's growth experience in 1960–1998, driven by classical convergence and technological catch-up, and taking into account the level of education, the degree of openness, and the gap to the technological frontier. The high growth path is understood as transition growth on its way to steady state growth. The assumed long-run equilibrium growth rate is 5.5 percent (2.7 percent technological progress and 2.8 percent labor growth), but this only serves as a long-run constant, and is not important for the understanding of growth mechanisms along transition. The parameters that support this long-run equilibrium are mainly based on a 1998 social accounting matrix (SAM), as documented in the Appendix.

Starting from the base year 1998, the transition growth serving as reference path is calibrated backwards. To reproduce the actual GDP of 1960, the initial level of the capital stock is reduced to about 4 percent of the base year level. The level of labor supply is scaled down by the constant annual growth rate of n. The balance between the state variables, capital stock and foreign debt, is important for the out-of-steady-state position and foreign debt is adjusted to reproduce the initial year. Industrial and agricultural productivity levels are also scaled down. The scaling back serves as an exogenous shock that takes the economy outside the steady state path. During transition, economic growth is driven by the endogenous mechanisms in the model, while converging to the steady state growth rate in the long run.

A correct reproduction of the actual productivity path during 1960–1998 is more difficult, since data is scarce. Hall and Jones (1999) estimate the productivity level in Thailand to about 50 percent of the level in the

United States in 1988, corresponding to a technology gap of 0.5. Data from Penn World Table (version 6.1) indicates significant catching-up in terms of PPP-adjusted real GDP per capita relative to the United States, increasing from 0.24 in 1960 to 0.45 in 1988. Replicating this development to the productivity level, taking into account the 1988 estimate in Hall and Jones (1999), implies a technology gap of about 0.3 in 1960. Since Thailand's growth process has been characterized by labor-intensive low-tech industry, we do not expect a similar catch-up with regards to technological level. To reproduce the actual growth path we assume an initial technology gap to the frontier of 0.38, so that the economy starts out above the threshold value for catching-up with a productivity growth rate of 2.9 percent.

The relationship between productivity growth rate and technology gap is illustrated in Figure 2a. Even though the economy is far from the frontier, the absorptive capacity (measured by the skill level of workers and degree of openness) is sufficient to take advantage of foreign technology. The dynamics are driven by the quadratic formulation of the technology adoption function, with decreasing imitation costs due to learning by doing. Given our calibration, Thailand enjoys an increasing advantage of foreign technology during the whole period of study, implying that the economy is still very far from the frontier. Lower tariffs and higher education over time improve the capability of catching up and generates continuous shifts in the adoption function, further stimulating technology adoption. Productivity growth increases from an initial rate of 2.9 percent to 5.7 percent in the mid-1990s (which equals about 2 percent TFP growth). The growth path corresponds to a movement along the increasing part of the curve in Figure 1, starting out above the threshold gap and increasing towards the maximum point. Exceeding the rate of productivity growth at the frontier, technological catch-up and reduction of the gap is observed. Along the calibrated path the average annual TFP growth in industry equals 1.4 percent, while agricultural TFP growth is set exogenously at 2.6 percent, implying total average TFP growth of 1.7 percent during 1960–1998. This is consistent with conventional TFP calculations for Thailand, documented in Collins and Bosworth (1996), Tinakorn and Sussangkarn (1998), and Young (1994), which tend to identify productivity growth in the order of 2 percent.

The process of catching up is initially slow and no significant reduction of the gap to the frontier is observed the first 10 years (illustrated in Figure 2b). Over time, lower tariffs increases the interaction with the rest of the world and brings with it foreign spillovers. Together with a more educated labor force that is able to take advantage of the new technology, this gen-

Figure 2a: *Industrial Labor-Augmenting Technical Progress along the Calibrated Path as a Function of the Technology Gap*

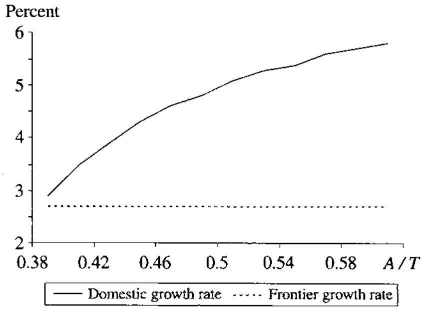
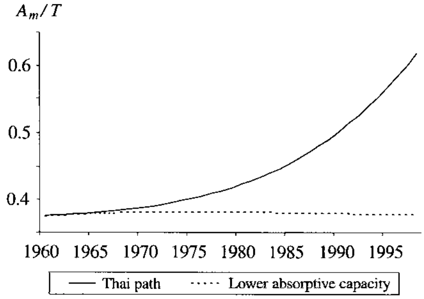


Figure 2b: *Technology Gap to the Frontier along the Calibrated Path and in the Counterfactual Experiment*



erates higher productivity growth increasing the speed of convergence with the frontier. From the mid-1970s the improved capability of technology adoption contributes to a boom in productivity growth and catch-up. The point estimate of 0.5 for 1988 from Hall and Jones (1999) is reproduced, and at the end of the period the technology gap equals 0.62.

We observe a high marginal return to investment in the beginning of the period, with consequent high investment growth and capital accumulation, but due to diminishing returns the rate of accumulation falls over time. Higher productivity growth increases the profitability of investments, and gradually lower tariffs provide less expensive capital goods from abroad. These effects work against the diminishing returns to investment, stimulating further capital accumulation. Even though the increased education share has a negative impact on investment profitability due to reduced labor supply giving higher growth in wages, the initial fall in capital growth rate is counterbalanced, and capital accumulation is kept well above the steady state rate the entire period (Figure 3). Initially capital accumulation is driven by high marginal returns, while the prolonged investment growth in the late 1980s and early 1990s is due to high productivity growth and an open trade regime.

The combination of classical convergence and technological catch-up generates average real GDP growth of 7.1 percent along the calibrated path, as opposed to an average of 7.7 percent in the data (from 1960 till the crisis). The growth rate falls the first 10 years, but as decreasing returns to investment is counteracted and productivity growth increases, we observe an increasing transition growth rate. The paths of real GDP growth for both actual data and the calibrated transition are shown in Figure 4. The model captures the trend growth and does not represent the cyclical factors

Figure 3: *Capital Growth Rate along the Calibrated Path and in the Counterfactual Experiment*

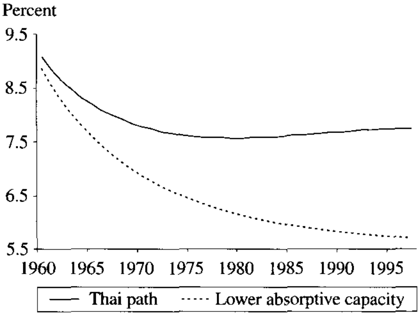
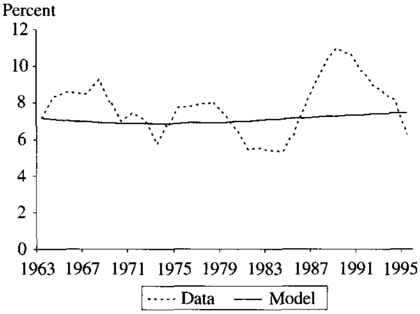


Figure 4: *Real GDP Growth: Calibrated Path of Model vs. Actual Growth (measured as 5-year moving average)*



affecting the actual growth. It is our understanding that the interplay between productivity growth and high investments, together with gradually improved capability of adopting foreign technology, enabled Thailand to avoid a possible low growth path with technological divergence and over time experience extraordinarily high growth rates. The combined importance of classical convergence and technological catch-up for convergence in per capita GDP is supported by Dowrick and Rogers (2002) in a study of 51 developed and developing countries.

High productivity growth makes investments more profitable, and diminishing returns to capital hence can be avoided. Higher investment demand in turn generates more imports, bringing in more foreign spillovers and positively affecting the productivity growth rate. Higher investment in education has two opposite effects on the economy-wide growth rate. First, the absorptive capacity increases due to more skilled workers, improving the technology adoption and giving higher productivity growth. Second, a higher education share implies a reduction in the total supply of labor, with a higher growth rate of wages as result. A reduction in tariff rates gives higher growth due to more technology spillovers and less expensive capital goods from abroad.

7 Counterfactual Analysis

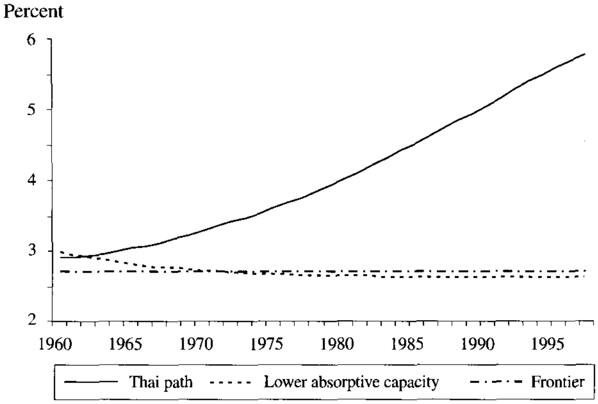
The remarkable high growth experienced in Thailand the past decades is understood as productivity-investment interaction with gradually improved ability to take advantage of foreign technology. The economy's absorptive capacity is linked to the degree of openness and the skill level of workers, and its importance for technology adoption and overall growth is investigated through a counterfactual experiment. Given a favorable initial position to the frontier with good learning and catching-up potential, what are the dynamic consequences of not further improving its absorptive capacity? Is the economy still able to catch up towards the frontier?

We investigate the combined effect of keeping the education level and import tariffs at their initial 1960 level, implying an education share of about 2 percent and import tariffs of 30 percent for the entire period. Since we apply an intertemporal model with perfect foresight, higher future tariffs increase the initial trade share compared to the calibrated path. This generates more technology spillovers from abroad and gives an outward shift in the adoption function. Productivity growth rate increases, but even though initial conditions have improved, the economy may converge to the low equilibrium. This follows from the endogeneity of absorptive capacity (working through the trade share), which means that the threshold value for catch-up is not fixed.

Even with a constant rate of tariffs, the trade share is falling over time, mainly due to lower capital accumulation following from decreasing returns to investment. The transfer of foreign technology decreases, and without an increase in the level of education the economy's absorptive capacity is weakened. This generates continuous inward shifts in the adoption function, and the threshold value of the gap necessary to catch up with the frontier increases. The economy is no longer able to take advantage of its relative backwardness, and we observe an endogenous switch from a potential high growth path with technological catch-up to a low growth path. The productivity growth rate decreases from an initial rate of 3 percent, and falls below the rate at the frontier after 15 years (Figure 5). Compared to the calibrated path, the average industrial TFP growth rate falls from 1.4 to 0.9 percent, while the relative gap to the frontier equals 0.38 (as opposed to 0.62) at the end of the period (Figure 2b). Since the ability to exploit foreign technology is gradually improved along the calibrated path, the effects of protection and less investment in education are strengthened over time.

Higher tariffs negatively affect capital accumulation, both directly and indirectly. First, investment costs increase due to more expensive foreign capital goods, and second, the fall in productivity growth implies reduced profitability of investments. The relatively lower education share has two opposite effects on economic growth: Productivity growth is held back due to the lower capability of utilizing foreign spillovers, but less investment

Figure 5: *Industrial Labor-Augmenting Technical Progress along the Calibrated Path and in the Counterfactual Experiment*



in education increases total labor supply, reducing growth in wages and increasing profitability. As illustrated in Figure 3, the classical convergence effect dominates technological catch-up, and the economy is not able to counteract the diminishing returns to investment. Capital growth is initially high due to high marginal returns, but falls quickly towards the steady state rate. Reduced investments imply a fall in imports of capital goods, giving even less technology transfer, and further strengthening the negative effect on productivity growth.

This interplay between investments and productivity generates a falling GDP growth rate over time, with an average rate of 6 percent compared to 7.1 percent along the calibrated path (Figure 6a). High marginal returns to investment generate high growth, but without technological improvements counteracting the diminishing returns, the economy is not able to sustain the high growth rate above steady state for a prolonged period. The cumulated effect of protection and less investment in education on income level is illustrated in Figure 6b, and in the late 1990s we observe an income gap of 30 percent.

The analysis shows the relevance of multiple growth paths linked to technology adoption and catch-up for the growth experience in Thailand during the past four decades. Whether relatively backward economies converge to the long-run equilibrium along a low growth path with technological divergence or along a high growth path with technological catch-up depends on its absorptive capacity. The counterfactual simulation shows how Thailand

Figure 6a: *Real GDP Growth Rate along the Calibrated Path and in the Counterfactual Experiment*

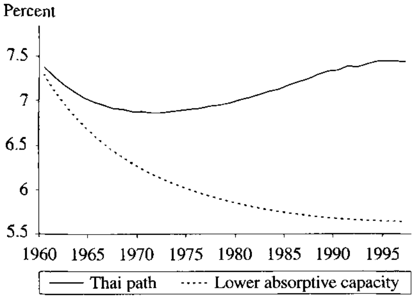
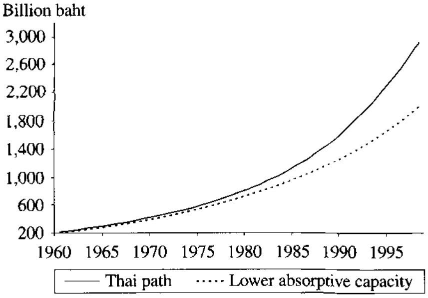


Figure 6b: *Income Gap, Calibrated Path versus Counterfactual Experiment (measured by the level of real GDP in 1988 billion baht)*



without its actual investment in education and opening up of the economy after 1960, might have converged to the low equilibrium even though its initial position is above the threshold gap for catch-up. These dynamics are consistent with the empirical analysis of Papageorgiou (2002b) showing that openness can be a source of clustering middle-income countries into high and low growth groups.

8 Sensitivity Analysis

In the previous section we show that whether a relatively backward economy converges along a low or high growth path depends crucially on its capability of absorbing and utilizing technology spillovers from abroad. In this section we investigate how sensitive these results are upon the initial position relative to the frontier. First, without improving the absorptive capacity over time, how close to the frontier must the economy be initially in order to converge to the high equilibrium? Second, given gradual reduction of tariffs and higher investment in education, how backward can the economy be and still converge to the high equilibrium in the long run? To be able to compare the different scenarios, the capital stock and foreign debt are adjusted to give similar trade share and capital-output ratios initially.

8.1 Impact of Initial Position without Further Investment in Education and Reduction of Tariffs

In the counterfactual experiment in Section 7, we assume an initial gap of 0.38, and show that without further investment in absorptive capacity the economy converges to the low equilibrium with lower transition growth and divergence relative to the technological frontier. We run the same experiment with an initial gap of 0.4 and 0.45, respectively, to study the effect on long-run equilibrium and transition growth rate. A more favorable position relative to the frontier gives higher productivity growth initially, but without stimulating technology transfer (through lower tariffs) or improving the ability to exploit foreign technology (through education), the productivity growth rate falls quickly over time. The mechanism at work is the same as before; falling capital accumulation due to decreasing returns reduces capital imports and limits the transfer of foreign technology. This shifts the adoption function downward, and the economy might eventually fall below the threshold value for catching up with the frontier.

With an initial gap of 0.4, divergence relative to the frontier is observed after 37 years, and the economy converges to the low equilibrium, though at a slightly higher transition growth rate than along the original counterfactual growth path. Starting with an initial gap of 0.45, the economy grows faster than the frontier during the entire period, but no significant reduction of the gap is observed (from 0.45 to 0.48). Since technology adoption is not stimulated over time, decreasing returns to capital is not counterbalanced and the productivity growth rate decreases towards the steady state rate. A more favorable initial position generates higher capital accumulation and GDP growth rates in the early years, but due to the falling productivity growth rate and constant tariffs, the rate quickly returns to the steady state level. Without improving its capability of absorbing and taking advantage of foreign technology, the economy is not able to keep the growth rate above the steady state rate for a prolonged period. Starting closer to the technological frontier cannot compensate for the inability to exploit foreign technology or lack of technology transfer.

8.2 Impact of Initial Position with Investment in Education and Reduction of Tariffs

Along the calibrated Thai path we assume an initial gap of 0.38, and show that with gradual reduction of tariffs and increasing education share, the economy converges to the high equilibrium with an increasing transition growth rate and a decreasing gap to the frontier. To investigate the impact of initial position on this outcome, we run two counterfactual experiments with initial gaps equal to 0.3 and 0.25, respectively. In both scenarios the economy initially starts out below its threshold value for catching up, and the distance to the frontier increases. By improving its absorptive capacity a switch from the low growth path to the high growth path with technological catch-up is possible. With an initial gap of 0.3 and 0.25 it takes the economy 6 and 13 years, respectively, to increase productivity growth sufficiently to catch up with the frontier. More interaction with the rest of the world through trade increases technology spillovers, and more skilled workers are able to exploit this new technology. Increasing productivity growth and falling tariff rates in turn stimulate capital accumulation and overall growth rate. Starting out further from the frontier (below its threshold value for catch-up) implies loss of transition growth, but by improving its absorptive capacity the economy eventually becomes able to take advantage of foreign technology and converges towards the high equilibrium.

9 Concluding Remarks

As opposed to the Veblen–Gerschenkron catching-up hypothesis, where productivity growth increases with the distance to the technological frontier, the recent literature allows for technological divergence in backward economies. Papageorgiou (2002a) introduces a quadratic relationship between technology adoption and relative backwardness, with an exogenous threshold gap necessary to catch up with the frontier. We extend the nonlinear productivity specification to include openness, and interact with capital accumulation in an intertemporal general equilibrium model. The threshold gap for catch-up is endogenously determined by the economy's ability to absorb and take advantage of foreign technology, measured by the degree of interaction with the rest of the world through trade and the skill level of workers. Given profitable investments and a market-oriented policy framework, we analyze the marginal impact of technology adoption on the growth experience in Thailand.

The analysis relates to the debate on accumulation versus assimilation as sources of the Asian growth miracle. We understand the high growth experience in Thailand as a combination of capital accumulation and productivity growth through adoption of foreign technology. The counterfactual simulation shows how growth is hampered when the ability to absorb and to take advantage of foreign technology is not stimulated over time. The policy implications of the analysis relates to improving the economy's absorptive capacity through investment in basic education and keeping an open trade regime. High marginal returns to investment generate high growth, but without technological improvements counteracting the diminishing returns, the economy is not able to sustain the high growth rate above steady state for a prolonged period.

Appendix

Calibration

The parameters in the production, demand, and trade functions are set according to the method adopted in most static computable general equilibrium models and are based on a 1998 social accounting matrix (SAM). The original SAM is provided by the National Economic and Social Development Board (NESDB) in Thailand and includes 180 production sectors, which are aggregated into two sectors (agriculture and industry). The domestic savings rate (relative to total income) is 41 percent, and investment accounts for 39 percent of GDP. The economy has a current account surplus of 17 percent of GDP and hence domestic savings fully finance the investments. The agricultural value-added accounts for 16 percent of GDP, while industry represents the remaining 84 percent. The indirect taxes in agriculture and industry are 0.8 and 7 percent of GDP, respectively. The elasticity of substitution in both the Armington and CET functions are assumed to be 3. These elasticities represent substitution possibilities between domestic and foreign goods (Armington), and between sales to domestic markets versus export markets (CET). The productivity levels by sector are also calibrated from the SAM. The elasticity of productivity growth with respect to education share and trade share (γ_1 and γ_2) is based on econometric evidence discussed in Section 4. Long-run technology gap is assumed to be 0.75, and the parameter b in the adoption function is calibrated from equation (1).

The parameters determining the intertemporal equilibrium path follow from the steady state conditions (5.5 percent growth rate) given a few key assumptions. The domestic interest rate is set to 0.11, and the depreciation rate to 0.10. Given marginal product of capital (equal 0.09), the initial capital stock is calculated using capital income from the SAM. Land use in agriculture is assumed to account for 46 percent of total agricultural capital stock. Investment is derived from the steady state condition (13), for given values of the depreciation rate and long-run growth rate. The shadow price of capital, q, equals the firm value relative to the capital stock, and follows when we know the interest rate. The coefficient a in the capital adjustment cost function is determined by the no-arbitrage long-run condition in (15). The initial level of foreign debt is calibrated from (14) given data about trade deficit/surplus together with the long-run growth rate and interest rate. The time preference rate is the residual from the Euler equation (9) and equals 0.023. The intertemporal elasticity of substitution is set to 0.66.

The calibrated parameters and initial values of the intertemporal variables are shown in the Appendix Table 1.

Appendix Table 1: *Values of Selected Parameters and Variables (initial value for endogenous variables)*

Definition	Symbol in the model	Value
Parameters		
Share of labor in agriculture	β_1	0.35
Share of labor in industry	α	0.35
Share of capital in agriculture	$1 - \beta_1 - \beta_2$	0.35
Share of capital in industry	$1 - \alpha$	0.65
Share of land in agriculture	β_2	0.30
Share of imports in agricultural consumption	ma_a	0.28
Share of imports in industrial consumption	ma_m	0.40
Share of exports in agricultural production	mc_a	0.62
Share of exports in industrial production	mc_m	0.59
Coefficient in adjustment cost	a	1.31
Elasticity in Armington function	σ_m	3.00
Elasticity in CET funciton	σ_e	3.00
Intertemporal elasticity of substitution	$1/\sigma$	0.66
Time preference rate	ρ	0.023
Depreciate rate	δ	0.10
Coefficient in technology adoption function	b	0.07
Elasticity of education share in adoption function	γ_1	0.33
Elasticity of trade share in adoption function	γ_2	1.00
Exogenous variables		
Steady state growth rate	$n + g$	5.5
Growth rate of labor	n	2.8
Growth rate of technology	g	2.7
World interest rate	r	0.11
Endogenous variables		
Marginal return to capital	$Rk + a \cdot P_m \, (I/K)^2$	0.12
Marginal product of capital	Rk	0.09
Derivative of adjustment cost w.r.t. capital	$-a \cdot P_m \, (I/K)^2$	−0.03
Shadow price of capital	q	0.58
Adjustment cost per unit of investment	$a \cdot P_m \, (I/K)$	0.20
Total trade as share of GDP (base-year value)	$(EX + IM)/GDP$	0.81

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