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**Productivity growth and organizational learning**

**– Separate appendix**

Date: January 18, 2007

Content



## Appendix A: Necessary conditions for multiple equilibria

The productivity growth rate is defined as:

$$\hat{A} = f(h_i)\frac{A}{A^*} + g(h_a)k(o)\left[\frac{A}{A^*} - \left(\frac{A}{A^*}\right)^2\right] + l(o)\left(1 - \frac{A}{A^*}\right)$$

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

*i*) The optimal level of development is given by a technology gap between 0 and 1.

By differentiating the productivity growth function above, we find that productivity growth is highest when the technology gap is given by:

$$\frac{A}{A^*} = \frac{1}{2} + \frac{f(h_i) - l(o)}{2g(h_a)k(o)}$$

The necessary condition is therefore:

$$-\frac{1}{2} < \frac{f(h_i) - l(o)}{2g(h_a)k(o)} < \frac{1}{2}$$

*ii*) The maximum growth rate exceeds the growth rate at the frontier.

By inserting the expression for the technology gap found under *i*) the highest possible productivity growth rate is found as:

$$\hat{A}_{\max} = f(h_i)\left(\frac{1}{2} + u\right) + g(h_a)k(o)\left(\frac{1}{4} - u^2\right) + l(o)\left(\frac{1}{2-u}\right) > \hat{A}^* \qquad \text{where } u = \frac{f(h_i) - l(o)}{2g(h_a)k(o)}$$

which must be higher than the frontier growth rate.

*iii*) The growth rate for $A/A^* = 0$ and $A/A^* = 1$ cannot exceed the frontier rate.

When $A/A^* = 0$ productivity growth is entirely driven by organizational change:

$$\hat{A}_{A/A^*=0} = l(o) < \hat{A}^*$$

Similar, when $A/A^* = 1$ productivity growth is entirely driven by innovation:

$$\hat{A}_{A/A^*=1} = f(h_i) < \hat{A}^*$$

## Appendix B: Main source of growth during the catch-up process – analytical documentation

Based on the given productivity specification [equation (1) in the paper] the three sources of growth are defined as:

$$\hat{A}_I = f(h_i)\frac{A}{A^*}$$

$$\hat{A}_A = g(h_a)k(o)\left[\frac{A}{A^*} - \left(\frac{A}{A^*}\right)^2\right]$$

$$\hat{A}_S = l(o)\left(1 - \frac{A}{A^*}\right)$$

where $\hat{A}_I$, $\hat{A}_A$ and $\hat{A}_S$ represent the growth contribution from innovation, technology adoption and organizational learning, respectively.

First, we derive how the relative contribution from the three sources of growth varies with the level of development. Second, we show that the main source of growth changes during the development process (from organizational learning to technology adoption and finally innovation).

<u>1. Relative contribution from the three sources of growth during the development process</u>

a) Innovation

The share of productivity growth generated by innovation is given by:

$$\frac{\hat{A}_I}{\hat{A}} = \frac{f(h_i)\frac{A}{A^*}}{f(h_i)\frac{A}{A^*} + g(h_a)k(o)\left[\frac{A}{A^*} - \left(\frac{A}{A^*}\right)^2\right] + l(o)\left(1 - \frac{A}{A^*}\right)}$$

We want to investigate how this share changes during the development process. To ease the analytical calculations, we look at the inverse of the above expression and find the derivative with respect to the technology gap:

$$\frac{\hat{A}}{\hat{A}_I} = 1 + \frac{g(h_a)k(o)\left(1 - \frac{A}{A^*}\right)}{f(h_i)} + \frac{l(o)\left(1 - \frac{A}{A^*}\right)}{\frac{A}{A^*}}$$

$$\Downarrow$$

$$\frac{\partial\left(\hat{A}/\hat{A}_I\right)}{\partial\left(A/A^*\right)} = -\frac{g(h_a)k(o)}{f(h_i)} - \frac{l(o)}{\left(\frac{A}{A^*}\right)^2} < 0$$

$$\Downarrow$$

$$\frac{\partial\left(\hat{A}_I/\hat{A}\right)}{\partial\left(A/A^*\right)} > 0$$

This means that the growth contribution from innovation increases as the economy catches-up with the frontier.

b) Technology Adoption

The share of productivity growth generated by technology adoption is given by:

$$\frac{\hat{A}_A}{\hat{A}} = \frac{g(h_a)k(o)\left[\frac{A}{A^*} - \left(\frac{A}{A^*}\right)^2\right]}{f(h_i)\frac{A}{A^*} + g(h_a)k(o)\left[\frac{A}{A^*} - \left(\frac{A}{A^*}\right)^2\right] + l(o)\left(1 - \frac{A}{A^*}\right)}$$

We follow the same procedure as with innovation and find that:

$$\frac{\hat{A}}{\hat{A}_A} = \frac{f(h_i)}{g(h_a)k(o)\left(1 - \frac{A}{A^*}\right)} + 1 + \frac{l(o)}{g(h_a)k(o)\frac{A}{A^*}}$$

$$\Downarrow$$

$$\frac{\partial\left(\hat{A}/\hat{A}_A\right)}{\partial\left(A/A^*\right)} = \frac{f(h_i)}{g(h_a)k(o)\left(1 - \frac{A}{A^*}\right)^2} - \frac{l(o)}{g(h_a)k(o)\left(\frac{A}{A^*}\right)^2}$$

$$= \frac{1}{g(h_a)k(o)}\left[\frac{f(h_i)}{\left(1 - \frac{A}{A^*}\right)^2} - \frac{l(o)}{\left(\frac{A}{A^*}\right)^2}\right]$$

The sign of the derivative depends on the level of development (the technology gap) and the parameters of the productivity specification. We find that:

$$\frac{A}{A^*} \rightarrow 0 \Rightarrow \frac{\partial\left(\hat{A}/\hat{A}_A\right)}{\partial\left(A/A^*\right)} \rightarrow -\infty < 0 \Rightarrow \frac{\partial\left(\hat{A}_A/\hat{A}\right)}{\partial\left(A/A^*\right)} > 0$$

$$\frac{A}{A^*} \rightarrow 1 \Rightarrow \frac{\partial\left(\hat{A}/\hat{A}_A\right)}{\partial\left(A/A^*\right)} \rightarrow \infty > 0 \Rightarrow \frac{\partial\left(\hat{A}_A/\hat{A}\right)}{\partial\left(A/A^*\right)} < 0$$

This means that the growth contribution from technology adoption increases in the early stages of development, reaches a peak, and decreases as the economy approaches the technological frontier. The peak technology gap (where the relative contribution from technology adoption is at its highest) depends on the assumed functional forms and parameter values in the productivity growth equation. Based on the specification applied in section 6 in the paper and Thai data from 1998 the optimal development level for adoption of foreign technology is given by $A/A^* = 0.4$. But in the numerical simulations the peak technology gap for adoption is endogenous since the educational shares and the degree of openness changes over time.

c) Organizational Learning

The share of productivity growth generated by organizational learning is given by:

$$\frac{\hat{A}_S}{\hat{A}} = \frac{l(o)\left(1-\frac{A}{A^*}\right)}{f(h_i)\frac{A}{A^*} + g(h_a)k(o)\left[\frac{A}{A^*} - \left(\frac{A}{A^*}\right)^2\right] + l(o)\left(1-\frac{A}{A^*}\right)}$$

We follow the same procedure as with innovation and technology adoption, and find that:

$$\frac{\hat{A}}{\hat{A}_S} = \frac{f(h_i)\frac{A}{A^*}}{l(o)\left(1-\frac{A}{A^*}\right)} + \frac{g(h_a)k(o)\frac{A}{A^*}}{l(o)} + 1$$

$$\Downarrow$$

$$\frac{\partial\left(\hat{A}/\hat{A}_S\right)}{\partial\left(A/A^*\right)} = \frac{f(h_i)l(o)}{\left[l(o)\left(1-\frac{A}{A^*}\right)\right]^2} + \frac{g(h_a)k(o)}{l(o)} > 0$$

$$\Downarrow$$

$$\frac{\partial\left(\hat{A}_S/\hat{A}\right)}{\partial\left(A/A^*\right)} < 0$$

This means that the growth contribution from organizational learning decreases as the economy catches-up with the frontier.

2. Main source of growth during the development process

So far, we have studied how the relative contribution of the three sources of growth changes as the economy catches up with the frontier. To determine the dominating growth factor at different levels of development we compare the relative contribution from innovation, adoption and organizational learning.

a) Organization learning vs. Innovation:

$$\frac{\hat{A}_I}{\hat{A}} - \frac{\hat{A}_S}{\hat{A}} = \frac{f(h_i)\frac{A}{A^*} - l(o)\left(1-\frac{A}{A^*}\right)}{\hat{A}}$$

From the above expression we find that the growth contribution from innovation exceeds the contribution from organizational learning when the economy is close to the frontier, while the opposite is true in backward economies. The level of development where innovation becomes more important than organizational learning as source of growth depends on the parameters in the productivity specification. It can easily be shown that $\frac{A}{A^*} = \frac{l(o)}{f(h_i)+l(o)}$ represents the turning point.

b) Organizational learning vs. Technology adoption

$$\frac{\hat{A}_A}{\hat{A}} - \frac{\hat{A}_S}{\hat{A}} = \frac{g(h_a)k(o)\left[\frac{A}{A^*} - \left(\frac{A}{A^*}\right)^2\right] - l(o)\left(1 - \frac{A}{A^*}\right)}{\hat{A}}$$

The contribution from technology adoption and organizational learning is equal for two values of the technology gap. The first is at the frontier (when $A/A^* = 1$), where productivity growth is entirely driven by innovation. The second is when $\frac{A}{A^*} = \frac{l(o)}{g(h_a)k(o)}$. The dynamics of the above expression depends on the parameters of the productivity specification, and in particular on whether $\frac{l(o)}{g(h_a)k(o)}$ is larger or smaller than 1. If $l(o) > g(h_a)k(o)$, organizational learning dominates technology adoption as source of growth during the entire catch-up process (for all $A/A^* < 1$). Since this seems unreasonable, we assume that $l(o) < g(h_a)k(o)$. This means that the growth contribution from organizational learning exceeds that from technology adoption when $\frac{A}{A^*} < \frac{l(o)}{g(h_a)k(o)}$, while the opposite is true when $\frac{A}{A^*} > \frac{l(o)}{g(h_a)k(o)}$. Hence, for backward economies organizational learning dominates technology adoption, but as the economy catches up, adoption of foreign technology becomes relatively more important as source of growth than organizational learning.

c) Technology adoption vs. Innovation

$$\frac{\hat{A}_A}{\hat{A}} - \frac{\hat{A}_I}{\hat{A}} = \frac{g(h_a)k(o)\left[\frac{A}{A^*} - \left(\frac{A}{A^*}\right)^2\right] - f(h_i)\frac{A}{A^*}}{\hat{A}}$$

The contribution from technology adoption and innovation is equal for two values of the technology gap. The first is for an infinitely large technology gap (when $A/A^* = 0$), where productivity growth is entirely driven by organizational learning. The second is when $\frac{A}{A^*} = 1 - \frac{f(h_i)}{g(h_a)k(o)}$. The dynamics of the above expression depends on the parameters of the productivity specification, and in particular on whether $1 - \frac{f(h_i)}{g(h_a)k(o)}$ is positive or negative. If $f(h_i) > g(h_a)k(o)$, innovation dominates technology adoption as source of growth during the entire catch-up process (for all $A/A^* \leq 1$). Since this seems unreasonable, we assume that $f(h_i) < g(h_a)k(o)$. This means that the growth contribution from technology adoption exceeds that from innovation when $\frac{A}{A^*} < 1 - \frac{f(h_i)}{g(h_a)k(o)}$, while the opposite is true when $\frac{A}{A^*} > 1 - \frac{f(h_i)}{g(h_a)k(o)}$. Hence, in the first part of the catch-up process technology adoption dominates innovation, but as the economy approaches the frontier, innovation becomes relatively more important as source of growth than adoption of foreign technology.

d) To sum up:

- Organizational learning is the main source of growth in backward economies.
- Innovation is the main source of growth close to the frontier.
- If $l(o) < g(h_a)k(o)$ and $f(h_i) < g(h_a)k(o)$, there exists an intermediate period during the catch-up process where technology adoption is the main source of growth. Given the productivity specification applied in section 6 of the paper and Thai data from 1998 these two conditions are fulfilled.

**Appendix C: The mathematical documentation of the dynamic general equilibrium model**

**1. Equations**

The following equations are the detailed description of the model. The numerical model is solved by the General Algebraic Modeling System (GAMS).

*The consumer's decision*

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

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

$$s.t.\ \ PC_t \cdot C_t = Y_t - SAV_t$$

where

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

The consumer's income is given as:

$$Y_t = w_t \cdot L_t + Rk_t \cdot K_t + tax \cdot PX_t X_t + tm_t \cdot PWM \cdot M_t - (r - g - n)DEBT_t$$

The first-order condition for the consumer's problem (the Euler equation) is:

$$\frac{Y_t - SAV_t}{Y_{t-1} - SAV_{t-1}} = \frac{1+r}{1+\rho}$$

This equation says that growth in total consumption expenditure depends on the relationship between world market interest rate and consumer time preference rate. The higher interest rate, or the lower time preference rate, the higher consumption growth.

*Production decision*

The value-added production function for the one-sector economy is a Cobb-Douglas function of capital and labor:

$$X_t = A_t^{\alpha} L_t^{\alpha} K_t^{1-\alpha}$$

First order conditions are:

$$\alpha \cdot PV_t X_t = w_t \cdot L_t$$

$$(1-\alpha) PV_t X_t = Rk_t \cdot K_t$$

The value-added price:

$$PV_t = PX_t(1 - tax) - PC_t IO$$

Intermediate goods are employed according to the fixed coefficient:

$$INT_t = IO \cdot X_t$$

GDP at factor price:

$$GDP_t = PV_t \cdot X_t$$

*Investment decision*

Investment decision is made according to intertemporal profit maximization, subject to the accumulation of the capital stock over time:

$$\underset{I,K}{Max} \sum_{t=1}^{T} (1+r)^{-t} \left[ Rk_t \cdot K_t - w_t \cdot L_t - PC_t \cdot I_t - ADJ_t \cdot I_t \right]$$

$$s.t. \;\; K_{t+1} = K_t \cdot (1-\delta) + I_t$$

where

$$ADJ_t = a \cdot PC_t \cdot \frac{I_t}{K_t}$$

is the adjustment cost per unit of investment.

The first order conditions:

$$q_t = PC_t + 2 \cdot PC_t \cdot a \cdot \frac{I_t}{K_t}$$

$$(1+r) \cdot q_{t-1} = Rk_t + a \cdot PC_t \cdot \left( \frac{I_t}{K_t} \right)^2 + q_t \cdot (1-\delta)$$

The second equation is the well-known no-arbitrage condition, which states that marginal return to capital has to equal the interest payments on a perfectly substitutable asset of size $q_{t-1}$.

Total investment demand includes the adjustment cost:

$$TIVD_t = I_t + a \cdot \frac{I_t^2}{K_t}$$

*Exports and Imports*

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

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

where

$PM_t = PWM(1+tm_t)$ is the price of import goods.

The first order conditions:

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

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

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

$$Max \quad PD_t \cdot D_t + PWE \cdot E_t$$

$$s.t. \quad X_t = ac[mc \cdot E_t^{-exc} + (1-mc)D_t^{-exc}]^{1/exc}$$

The first order conditions:

$$\frac{D_t}{X_t} = ac^{\frac{exc}{1-exc}} \cdot \left( (1-mc) \cdot \frac{PX_t}{PD_t} \right)^{\frac{1}{1-exc}}$$
$$\frac{E_t}{X_t} = ac^{\frac{exc}{1-exc}} \cdot \left( mc \cdot \frac{PX_t}{PWE} \right)^{\frac{1}{1-exc}}$$

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

*Foreign borrowing and foreign debt*

$$FSAV_t = PWM \cdot M_t - PWE \cdot E_t$$
$$DEBT_{t+1} = DEBT_t \cdot (1+r) + FSAV_t$$

Foreign debt is accumulated over time from trade deficits and interest payments on outstanding debt.

*Commodity market equilibrium*

$$CC_t = INT_t + C_t + TIVD_t$$

This equation determines the equilibrium price, $PC_t$, for Armington composite goods.

*Endogenous productivity*

$$\hat{A}_t = b_1 h_{i,t}^{\gamma_1} \frac{A_t}{A_t^*} + b_2 h_{a,t}^{\gamma_2} \left(\frac{Trade_t}{GDP_t}\right)^{\gamma_3} \left[\frac{A_t}{A_t^*} - \left(\frac{A_t}{A_t^*}\right)^2\right] + b_3 \left(\frac{Trade_t}{GDP_t}\right)^{\gamma_4} \left(1 - \frac{A_t}{A_t^*}\right)$$

where $Trade_t = E_t + M_t$

*Terminal conditions (steady state constraints)*

The terminal conditions are imposed in the model, such that when the time is beyond T, which is the last period in the model, all endogenous variables have to approach approximately to their steady state situation.

$$FSAV_T = (g + n - r) \cdot DEBT_T$$
$$I_T = (\delta + g + n) \cdot K_T$$
$$Rk_T + a \cdot PC_T \cdot \left(\frac{I_T}{K_T}\right)^2 = (r + \delta) \cdot q_T$$

These conditions state that foreign debt and capital stock grow at a constant rate given by $g + n$, and that marginal return to capital becomes constant.

## 2. Glossary

*Parameters*

| | |
|---|---|
| $\alpha$ | share parameter for labor in industrial value added function |
| $IO$ | input-output coefficient |
| $exa$ | exponent in Armington functions |
| $\sigma_m$ | elasticity of substitution between imported and domestic goods |
| $ma$ | share parameter in Armington function |
| $aa$ | shift parameter in Armington function |
| $exc$ | exponent in CET functions |
| $\sigma_e$ | elasticity of substitution between domestic goods and exports |
| $mc$ | share parameter in CET function |
| $ac$ | shift parameter in CET function |
| $a$ | coefficient in adjustment cost function |
| $\rho$ | rate of consumer's time preference |
| $\delta$ | capital depreciation rate |
| $b_1$ | parameter in productivity specification |

| | |
|---|---|
| $b_2$ | parameter in productivity specification |
| $b_3$ | parameter in productivity specification |
| $\gamma_1$ | elasticity in productivity specification |
| $\gamma_2$ | elasticity in productivity specification |
| $\gamma_3$ | elasticity in productivity specification |
| $\gamma_4$ | elasticity in productivity specification |

*Exogenous variables*

| | |
|---|---|
| $PWM$ | world import price |
| $PWE$ | world export price |
| $tax$ | sales tax rate |
| $tm_t$ | tariff rate |
| $r$ | world interest rate |
| $g+n$ | steady state growth rate |
| $g$ | exogenous technical progress |
| $n$ | exogenous labor supply growth rate |
| $L_t$ | labor supply |
| $A_t^*$ | frontier productivity level |
| $h_{i,t}$ | share of labor force with tertiary education |
| $h_{a,t}$ | share of labor force with secondary education |

*Endogenous variables*

| | |
|---|---|
| $X_t$ | output |
| $K_t$ | capital stock |
| $D_t$ | goods produced and consumed domestically |
| $M_t$ | imports |
| $CC_t$ | total absorption of the composite good |
| $E_t$ | exports |
| $C_t$ | consumption |
| $INT_t$ | intermediate demand |
| $TIVD_t$ | total investment demand (including adjustment costs) |
| $I_t$ | investment |
| $ADJ_t$ | adjustment costs per unit of investment |
| $Y_t$ | consumer's income |
| $SAV_t$ | consumer's savings |
| $GDP_t$ | GDP |
| $FSAV_t$ | trade deficit |
| $Trade_t$ | total trade |
| $DEBT_t$ | foreign debt |

| | |
|---|---|
| $PV_t$ | value added price |
| $w_t$ | wage rate |
| $Rk_t$ | rate of return to capital |
| $PX_t$ | producer price |
| $PC_t$ | Armington composite price |
| $PD_t$ | price for $D$ |
| $PM_t$ | import price (including tariffs) |
| $q_t$ | shadow price of capital |
| $A_t$ | labor augmenting technical progress |
| $\hat{A}_t$ | productivity growth rate |

## Appendix D: Calibration of the dynamic general equilibrium model

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 developed by the National Economic and Social Development Board (NESDB) in Thailand. The aggregate SAM is illustrated in Appendix Table 1 below.

Appendix Table 1: Thai SAM 1998 (measured in billions of Thai Baht)

| | Act | Comd | Lab | Cap | HH | S-I | RoW | Atax | Mtax | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| Act | | 8 644 | | | | | 2 723 | | | 11 367 |
| Comd | 6 882 | | | | 2 887 | 1 028 | | | | 10 797 |
| Lab | 1 458 | | | | | | | | | 1 458 |
| Cap | 2 702 | | | | | | | | | 2 702 |
| HH | | | 1 458 | 2 702 | | | -721 | 325 | 151 | 3 915 |
| S-I | | | | | 1 028 | | | | | 1 028 |
| RoW | | 2 002 | | | | | | | | 2 002 |
| Atax | 325 | | | | | | | | | 325 |
| Mtax | | 151 | | | | | | | | 151 |
| Total | 11 367 | 10 797 | 1 458 | 2 702 | 3 915 | 1 028 | 2 002 | 325 | 151 | |

*Note*: Act = Activity, Comd = Commodity, Lab = Labor, Cap = Capital, HH = Household, S-I = Savings/Investments, RoW = Rest of world, Atax = Sales taxes, Mtax = Import tariffs.

The calibration assumes long run balanced growth, i.e. the savings-investment balance can support a sustainable growth path, the structure of the economy is stable, and the trade surplus with interest payments balances the projected development of foreign debt. The long run growth path calibrated as supply side response to investment and productivity adjustments must be made consistent with the macroeconomic equilibrium as represented by the Euler equation: $r = (1+\rho)(1+g+n)-1$, where $g + n$ is the exogenous long-run growth rate. With a world market interest rate of 14% and long-run growth rate of 5.2%, the time preference rate is equal to 8%. Then, with the long run assumptions, most parameters of the intertemporal part of the model can be calibrated from the SAM. The value of total investments (including adjustment costs) and capital income is given from the SAM. Together with the calibrated interest rate and the given long-run growth rate, the firm value can be calculated. With the assumed rate of depreciation the capital stock is calibrated. Given the level of capital, the marginal product of capital is calculated based on capital income. Investment is calibrated from the long-run constraint on capital accumulation, for given values of depreciation rate and long run growth rate. The shadow price of capital equals the firm value relative to the capital stock, and follows when we know the level of capital. The initial level of foreign debt is set by the long-run constraint on debt accumulation, given data about trade deficit/surplus together with the long-run growth rate and interest rate. The elasticity of substitution in both the Armington and CET functions are assumed to be 2, broadly consistent with the estimates in the GTAP database (Dimaranan and McDougall, 2002). These elasticities represent substitution possibilities between domestic and foreign goods (Armington), and between sales to domestic markets versus export markets (CET).

Various estimates of the effect of trade or openness on productivity growth rate exist in the literature. Isaksson (2002) emphasizes the 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, 10 percentage points increase in total trade as share of GDP gives 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 0.1 percentage-points higher TFP growth rate. In a cross-country study of 16 developed countries during 1950-86 Alam (1992) estimates a much larger effect of total trade as share of GDP on growth in GDP per worker. He finds that 10 percentage points increase in total trade share generates about 3 percentage points higher GDP per worker growth rate, corresponding to 1 percentage point higher TFP growth rate. It seems unreasonable that 10 percentage-points difference in total trade as share of GDP between two countries that are equal in every other aspects, 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 the elasticities of technology adoption and organizational change with respect to the trade share ($\gamma_3$ and $\gamma_4$, respectively) are assumed to equal 1. The impact of an increase in the trade share on aggregate productivity growth depends on the growth contribution from technology adoption and organizational change. To get a sense of the magnitude of the effect with the chosen elasticities, assume that 50 % of productivity growth is driven by organizational change, 40 % by technology adoption and the last 10% by innovation, which implies that the long-run growth contribution from the three sources of growth equals 1.35%, 1.08% and 0.27%, respectively (calculated from the long-run productivity growth rate of 2.7%). In this case, our elasticity estimate implies that 10 percentage-points increase in the trade share from 0.2 to 0.3 gives 0.5 percentage-points higher technology adoption driven productivity growth and 0.7 percentage points higher growth from organizational change when starting from the assumed steady state rates of 1.08% and 1.35%, respectively. Aggregate productivity growth increases from 2.7% to 3.9%, which corresponds to an increase in the TFP growth rate from 0.9% to 1.4%. Similarly, an increase in trade share from 0.7 to 0.8 generates 0.15 percentage-points higher TFP growth rate. This means that the model effect of higher trade share on TFP growth lies in the range between the two studies referred to above.

Empirical evidence on the effect of the secondary and tertiary education share in the labor force 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 the model simulations we assume that the elasticity of innovation driven productivity growth with respect to the share of tertiary education in the labor force ($\gamma_1$) and the elasticity of technology adoption with respect to the share of secondary education in the labor force ($\gamma_2$) are equal to 0.5. The impact of an increase in tertiary or secondary education shares on aggregate productivity growth depends on the growth contribution from innovation and technology adoption, respectively. With an elasticity of 0.5 an increase in the share of the labor force with tertiary education from 5% to 10% gives about 0.14 percentage points higher innovation driven productivity growth when starting from the steady state rate of 0.27%. Since an increase in tertiary education does not affect the growth contribution from technology adoption or organizational change, the aggregate productivity growth rate increases from 2.7% to 2.84%. Of course, the impact of increased tertiary education would be higher in an economy closer to the frontier, where innovation accounts for a larger share of aggregate productivity growth. An increase in the share of the labor force with secondary education from 10% to 20% increases the growth contribution from technology adoption with about 0.54 percentage points (starting from the steady state rate of 1.08%), and the aggregate productivity growth rate increases from 2.7% to 3.24% (which corresponds to about 0.2 percentage points increase in the TFP growth rate).

We assume a long-run technology gap equal to 0.6. This is just for calibration purposes, since in the model simulations the technology gap develops endogenously. Based on the long run technological progress rate, initial values of educational and trade shares, the relative level of productivity, elasticities and the parameters $b_1$ and $b_3$, the parameter $b_2$ follows as a residual.

The calibration of import tariffs is based on Social Accounting Matrices from NESDB for 1975 and 1998 together with data from World Bank (1976, 2006). According to World Bank (1976) the tariff rate equals 23% in 1967, which declines to 15% in 1975 (based on the 1975 SAM). Based on this a tariff path is interpolated for the period 1965-75, starting at 25% in 1965. Similarly, the tariff rate of 7% in the 1998 SAM is used to calibrate the tariff path during 1975-98. Import tariffs are assumed to decrease further to about 3% in 2005 (consistent with data from World Bank, 2006).

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