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CAPITAL GOODS IMPORTS, KNOWLEDGE DIFFUSION AND ECONOMIC GROWTH

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Abstract: The present paper considers the role of capital goods imports in knowledge diffusion and economic growth. I construct an endogenous growth model assuming a small open economy. One important finding of the model is that capital goods incorporating a more advanced technology than domestic goods, contribute to human capital accumulation and long run growth rate *via* the generated learning effects and technological spillovers. I show that foreign capital goods are an increasing function of the productivity gap between imported and domestic capital goods. In the comparative statics, I find that the more important the learning parameter is, the higher the growth rate is. Moreover, export promotion improves growth by allowing more imports. During the transitional dynamics, I find that the use of imported capital goods decreases when the productivity gap falls and the economy has accumulated enough human capital.

Keywords: growth, imports, knowledge, diffusion, human capital.

JEL classification: O41, O30, O11.

1. INTRODUCTION

Paul Romer (1993) highlighted the role of idea gap and technological differences in explaining the growth rate differences between countries. Romer and Rivera Batiz (1991a, 1991b), using the framework of the endogenous innovation model developed by Romer (1990), showed that international trade has positive dynamic effects only in the presence of flows of idea and knowledge diffusion between countries. The same conclusion was highlighted by Grossman and Helpman (1991a, 1991b). Trade of goods without flows of ideas has only static effects and does not affect growth rate. However, those models are concerned with trade between developed countries. They also dissociate between trade in goods and free circulation of ideas.

International trade, through imports of capital goods incorporating advanced technology, is dynamically beneficial for a country in that it stimulates the accumulation of sources of growth. Trade in goods allows a country to access the international stock of knowledge, adopt foreign technology incorporated in capital goods and improve its rate of growth through technological spillovers.

Many North-South models have investigated technological diffusion using an endogenous innovation framework. In this regard, Grossman and Helpman (1991a) developed different model variants where the North introduces new goods and the South imitates. The South is supposed to have free access to all goods newly produced by the North. Imitators compete with creators of new goods in the North. As a result, productivity in all sectors other than research and development (R&D) tends to equalize in both regions. In a similar setting, inspired from Romer (1990), Barro and Sala-i-Martin (1995) developed a model where growth in the North is determined by the introduction of new varieties of equipment while that of the South is mainly explained by the imitation and adaptation of these varieties to its local conditions of production. The rhythm of invention is determined in the North.

In a framework inspired from the *AK* model of Rebelo (1991), Lee (1995) developed an endogenous growth model with two sectors each producing a good (consumption good and capital good). Domestic firms producing capital goods invest in domestic and foreign equipment, assuming that both types of goods are imperfectly substitutable. Trade, in capital goods, between countries that differ by their level of development and industrialization, leads to a change in the volume and structure of investment, increases the production of capital goods and improves the rate of growth. The model verifies the convergence of growth rates and the assumption of technological catch-up. The imposition of an import tariff reduces the rate of growth. The model does not impose constraints on technological adoption.

On the empirical side, according to Keller (2004), much empirical research confirms technological externalities generated from imports. Spillover effects may be due to intermediate goods or other kind of imports. For most countries, 90% of productivity growth is due to foreign technology. Investment in R&D is more important in rich countries than in developing countries where it is almost absent. This conclusion is not far from the findings of Coe and Helpman (1995), who argued that 96% of international R&D is done in developed countries. Therefore, international trade is considered as an important source of technological diffusion. One should distinguish between studies using macroeconomic data and those using microeconomic data (in particular those concerned with the heterogeneity of firms). In this regard, Keller and Acharya (2007) emphasized the role of imports in technology transfer and provided new results to clarify the positive link between imports ant technology spillovers. They carried out an empirical analysis for the case of 17 industrialized countries observed during the period from 1973 to 2000. They studied income differences between countries according to certain variables such as domestic R&D, international spillovers and the accumulation of factors of production. An interesting result of this empirical work is that technology transfer plays a fundamental role in explaining income differences between countries and that imports are an important channel of this transfer. Moreover, they highlight the importance of the capacity of absorption and adoption of foreign technology according to countries and sectors. In another paper, Keller and Acharya (2008) argued empirically, for the case of the same sample than their previous paper and during the same period, that imports have not only a competition effect but also a learning effect. Import liberalization of goods that incorporates advanced technology generates technology spillover effects and learning externalities, intensifies competition with domestic firms and improves productivity. In a framework of heterogeneous firm model, Perla, Tonetti and Waugh (2015) showed that trade positively impacts the productivity at the firm level and accelerates technology adoption and growth. Many empirical studies using micro data have argued that openness to imports contributes to significant productivity gains at the firm level through increasing competition with domestic firms for countries such as Chile (see Pavcnik, 2002), India (see Topalova and Khandelwa 2011) and the USA (see Keller and Yeaple 2003). However, other studies focusing only on the competition effect from trade liberalization have showed that positive effects on productivity are only observed in the short run; in the long run, the impact is negative (see Melitz and Ottaviano 2008; Melitz 2003; Chen, Imbs, and Scott 2009). Some empirical papers testing for the spillover effects from trade using micro data did not confirm the presence of externalities because their theoretical model did not take them into account (see Keller 2004).

Hence, theoretical models, based on either endogenous innovation or firm heterogeneity, do not take into account the specificities of developing countries. Economic history shows that countries such as South Korea and Taiwan, among others, have successfully taken off on the basis of an industrialization process where imports of goods intensive in advanced technology and export promotion have played an essential role. Those countries have become producers and exporters of high-tech goods as part of a successful strategy of import substitution.

The present paper takes into account such specificities. It concerns the role of the capital goods imports, incorporating a more advanced technology than domestic goods, in the human capital accumulation and growth process in a developing country. As argued above by some eminent economists, the research-development sector is not very developed in a developing country and we cannot really consider an innovation activity similar to that of the developed world. Therefore, developing countries can benefit from international technology produced by developed countries by importing capital goods incorporating technology, which generates learning by using effects (see Mincer 1993, 1994, 1996; Rosenberg 1976, 1982) and improves human capital accumulation and the rate of growth.

I construct an endogenous growth model to investigate the role of capital goods imports in the growth and development process assuming a small open developing economy. Imports are financed by exporting a part of final goods. I show that foreign capital goods, more productive and technically more advanced than domestic goods, contribute to human capital accumulation and growth by intensifying learning effects and playing a role in knowledge diffusion.

The use of imports is increasing, as the productivity gap between imported and domestic capital goods is high and their domestic price is low. When studying the comparative statics, I show that the improvement of the learning effects by using foreign capital goods, in addition to the effects generated by the use of domestic capital goods contributes to human capital accumulation and long run growth rate. Moreover, export promotion improves growth by allowing more imports. During the transitional dynamics, I find that the use of imported equipment decreases in the long run when the productivity gap falls, once the economy has accumulated enough human capital. The model is described and solved in the next section. I conclude in the third section.

2. THE MODEL

I consider a small open developing economy importing capital goods and exporting consumer goods. I assume that domestic goods are produced using three factors: domestic physical capital, imported capital goods, and human capital. The production function is given by:

$$Y = A(K^{1-\gamma}K^{*})^{\alpha}H^{1-\alpha}, \tag{1}$$

where Y is GDP, A is a productivity parameter, K is domestic capital goods, K^* is imported capital goods, and H is human capital. K and K^* are supposed to be imperfect substitutes.

The production function satisfies the Inada conditions:

$$\frac{\partial Y}{\partial K}\xrightarrow[K\to 0]{}+\infty;\frac{\partial Y}{\partial K}\xrightarrow[K\to +\infty]{}0;\frac{\partial Y}{\partial K^*}\xrightarrow[K^*\to 0]{}+\infty;\frac{\partial Y}{\partial K^*}\xrightarrow[K^*\to +\infty]{}0$$
$$\frac{\partial Y}{\partial H}\xrightarrow[H\to 0]{}+\infty;\frac{\partial Y}{\partial H}\xrightarrow[H\to +\infty]{}0.$$

Domestic physical capital accumulation is represented by the following equation:

$$\dot{K} = (1-e)A(K^{1-\gamma}K^{*\gamma})^{\alpha}H^{1-\alpha} - C - \delta K \tag{2}$$

where C is consumption, e is the share of exports in GDP, and δ is the capital depreciation rate. $0 \le \delta \le 1$, $0 < e < 1$.

Imported capital goods are financed by exporting final goods. Assuming that K and K^* depreciate at the same rate, imported capital goods accumulation is such that,

$$\dot{K}^* = eY - \delta K^* \tag{3}$$

Human capital accumulation is generated by a process of learning by using capital goods:

$$\dot{H} = \phi K^{1-\beta}K^{*\beta} \tag{4}$$

ϕ is a learning parameter.

$$\phi \succ 0,\ 0 \prec \beta \prec 1.$$

The representative consumer maximizes the following intertemporal utility function:

$$U = \int_0^{\infty} \exp(-\rho\, t)\ u(C)\ dt, \tag{5}$$

where ρ is the subjective discount rate.

$$u(C) = \frac{C^{1-\sigma}}{1-\sigma}, \sigma \neq 1$$
$$u(C) = Log(C), \sigma = 1$$
$$u'(C) > 0, u''(C) < 0.$$

σ is the risk aversion parameter, $\sigma = 1/\theta$. θ is the intertemporal elasticity of substitution.

The utility function satisfies the Inada conditions:

$$u'(c) \xrightarrow[c\to 0]{} +\infty, u'(c) \xrightarrow[c\to +\infty]{} 0.$$

The constraint of wealth is given by:

$$\dot{a} = ra + w_H + (p_M - 1)\, eY - c, \qquad (6)$$

where a is wealth, r is the interest rate, w_H is human capital remuneration, and p_M is domestic price of imported capital goods which is endogenous.

$(p_M - 1)eY$ is the amount of lump-sum transfers distributed to consumers, and is equal to the rent received from importing foreign capital goods. I assume that foreign capital goods are imported by the government at a given international price, supposed equal to 1, and sold to local firms at a price p_M.

Non-negativity of the present value of wealth is such that:

$$\lim_{t\to+\infty}\left\{a(t)\exp\left[-\int_0^t r(v)dv\right]\right\} \geq 0$$

Household behavior

Maximizing equation (5) with respect to equation (6) gives the following first order conditions:

$$c^{-\sigma} = \lambda \qquad (7)$$

$$\lambda r = \rho\lambda - \dot{\lambda} \qquad (8)$$

The transversality condition is:

$$\lim_{t\to+\infty}[\lambda(t)\; a(t)] = 0, \qquad (9)$$

Differentiating equation (7) with respect to time and using equation (8) we get:

$$\frac{\dot{C}}{C} = \frac{1}{\sigma}(r - \rho), \qquad (10)$$

Behavior of the representative firm

The representative firm maximizes its profit flow with respect to K and K^*, taking the human capital as given:

$$\Pi = (1 - ep_M)A[K^{1-\gamma}K^{*\gamma}]^{\alpha}H^{1-\alpha} - (r+\delta)K - (r+\delta)K - (r+\delta)p_M K^* - w_H H \qquad (11)$$

The first order conditions are:

$$(1 - ep_M)\alpha(1-\gamma)AK^{\alpha(1-\gamma)-1}K^{*\alpha\gamma}H^{1-\alpha} = r + \delta \qquad (12)$$

$$(1 - ep_M)\alpha\gamma AK^{\alpha(1-\gamma)}K^{*\alpha\gamma-1}H^{1-\alpha} = (r+\delta)p_M \qquad (13)$$

Using equations 12 and 13, we obtain:

$$M = \frac{\gamma}{(1-\gamma)}p_M^{-1} \qquad (14)$$

where $M = \frac{K^*}{K}$ and $\frac{\gamma}{1-\gamma} > 0.$

The ratio of imported to domestic capital goods is a decreasing function of the domestic price of foreign capital goods.

Rewriting equation (14), we get an expression of M as a function of productivity gap between foreign and domestic capital goods:

$$M = \frac{(1-\gamma)}{\gamma}\frac{Pm_{K^*}}{Pm_K} \qquad (15)$$

Thus, the higher the productivity gap is, the more important the use of foreign capital goods in the domestic production process is.

Equilibrium

Using equations 10, 12 and 13, we can rewrite the dynamics of consumption:

$$\frac{\dot{C}}{C} = \frac{1}{\sigma}\left[(1 - ep_M)\alpha(1-\gamma)K^{\alpha(1-\gamma)-1}K^{*\alpha\gamma}H^{!-\alpha} - \delta - \rho\right] \qquad (16)$$

And the transversality condition is:

$$\lim_{t\to+\infty}\left\{K\exp\left[-\int_0^{+\infty}\frac{\partial Y}{\partial K} - \delta - g_K\right]dv\right\} = 0. \qquad (17)$$

where g_K is the growth rate of domestic capital goods.

Dynamics

The dynamics of the economy are described by the following first-order differential equations:

$$\dot{X} = \left[\Omega X^{-1} M^{\beta} - \Delta X^{\varepsilon} M^{\varsigma} + Z + \delta\right] X \qquad (18)$$

$$\dot{M} = \left[\xi X^{\varepsilon} M^{\eta} - \Delta X^{\varepsilon} M^{\beta} + Z\right] M \qquad (19)$$

$$\dot{Z} = \left[\left(\frac{\alpha(1-\gamma)}{\sigma} - 1\right) A X^{\varepsilon} M^{\varsigma} - \frac{\rho}{\sigma} + \left(1 - \frac{1}{\sigma}\right)\delta + Z\right] Z \qquad (20)$$

where $X = \frac{H}{K}, Z = \frac{C}{K}, M = \frac{K^*}{K}$,

$\Omega \equiv \phi A; \Delta \equiv (1-e)A; \varepsilon \equiv 1 - \alpha; \varsigma \equiv \alpha\gamma; \xi \equiv eA; \eta = \alpha(1-\gamma)$

X and M are predetermined variables.

Steady state

All variables grow at the same rate:

$$\dot{C}/C = \dot{H}/H = \dot{K}/K = \dot{K}^*/K^*$$

On the balanced growth path, equations 18, 19 and 20 become:

$$\Omega X^{-1} M^{\beta} - \Delta X^{\varepsilon} M^{\zeta} + Z + \delta = 0 \qquad (21)$$

$$\xi X^{\varepsilon} M^{\eta} - \Delta X^{\varepsilon} M^{\beta} + Z = 0 \qquad (22)$$

$$\left[\frac{\alpha(1-\gamma)}{\sigma} - 1\right] A X^{\varepsilon} M^{\varsigma} - \frac{\rho}{\sigma} + \left(1 - \frac{1}{\sigma}\right)\delta + Z = 0 \qquad (23)$$

Unicity

Let's show that the values of X, Z and M on the balanced growth path are unique. From equations 21, 22 and 23, we can deduce the following implicit function of M:

$$\begin{aligned}\Psi(M) \;=\; & \Omega\left[\left(\frac{\alpha(1-\gamma)}{\sigma} - 1\right) M^{\varsigma} - \frac{\rho}{\sigma} + \left(1 - \frac{1}{\sigma}\right)\delta\right]^{-\frac{1}{\varepsilon}} \left[\xi M^{\eta} - \Delta M^{\beta}\right]^{\frac{1}{\varepsilon}+1} M^{\beta} \\ & + \left[\left(\frac{\alpha(1-\gamma)}{\sigma} - 1\right) M^{\varsigma} - \frac{\rho}{\sigma} + \left(1 - \frac{1}{\sigma}\right)\delta\right] \left[M^{\varsigma} - \xi M^{\eta} + \Delta M^{\beta}\right] + \delta = 0\end{aligned} \qquad (I)$$

I show in Appendix 1 that:

$$\Psi'(M) \prec 0; \lim_{M \to +\infty} \Psi = -\infty; \lim_{M \to -\infty} \Psi = +\infty$$

Given the following restrictions on parameters: $\alpha(1-\gamma) \prec \sigma$; $\beta \succ \eta$; $\Delta \succ \xi$.

Thus, as the implicit function is continuous and decreasing with M, it passes through a unique and positive zero. It can also be shown that X and Z are unique and positive. Hence, we have the following proposition.

Proposition 1: The balanced growth path is positive and unique.

Stability

The stability of the dynamical system of equations 18-19-20 is defined by the eigenvalues of the following Jacobian matrix:

$$\bar{J} = \begin{bmatrix} \left.\frac{\partial \dot{X}}{\partial X}\right|_{BGP} & \left.\frac{\partial \dot{X}}{\partial M}\right|_{BGP} & \left.\frac{\partial \dot{X}}{\partial Z}\right|_{BGP} \\ \left.\frac{\partial \dot{M}}{\partial X}\right|_{BGP} & \left.\frac{\partial \dot{M}}{\partial M}\right|_{BGP} & \left.\frac{\partial \dot{M}}{\partial Z}\right|_{BGP} \\ \left.\frac{\partial \dot{Z}}{\partial X}\right|_{BGP} & \left.\frac{\partial \dot{Z}}{\partial M}\right|_{BGP} & \left.\frac{\partial \dot{Z}}{\partial Z}\right|_{BGP} \end{bmatrix}$$

where:

$$\left.\frac{\partial \dot{X}}{\partial X}\right|_{BGP} = \left[-\Omega \bar{X}^{-2} \; \bar{M}^{\beta} - \Delta\varepsilon \bar{X}^{\varepsilon-1} \bar{M}^{\varsigma}\right] \bar{X}$$

$$\left.\frac{\partial \dot{X}}{\partial M}\right|_{BGP} = \left[\beta\Omega \bar{X}^{-1} \bar{M}^{\beta-1} - \Delta\varsigma \bar{X}^{\varepsilon} \bar{M}^{\varsigma-1}\right] \bar{X}$$

$$\left.\frac{\partial \dot{X}}{\partial Z}\right|_{BGP} = \bar{X}$$

$$\left.\frac{\partial \dot{M}}{\partial X}\right|_{BGP} = \left[\xi\varepsilon \bar{X}^{\varepsilon-1} \bar{M}^{\eta} - \Delta\varepsilon \bar{X}^{\varepsilon-1} \bar{M}^{\beta}\right] \bar{M}$$

$$\left.\frac{\partial \dot{M}}{\partial M}\right|_{BGP} = \left[\xi\eta \bar{X}^{\varepsilon} \bar{M}^{\eta-1} - \Delta\beta \bar{X}^{\varepsilon} \bar{M}^{\beta-1}\right] \bar{M}$$

$$\left.\frac{\partial \dot{M}}{\partial Z}\right|_{BGP} = \bar{M}$$

$$\left.\frac{\partial \dot{Z}}{\partial X}\right|_{BGP} = \left[\left(\frac{\alpha(1-\gamma)}{\sigma} - 1\right) A\varepsilon \bar{X}^{\varepsilon-1} \bar{M}^{\varsigma}\right] \bar{Z}$$

$$\left.\frac{\partial \dot{Z}}{\partial M}\right|_{BGP} = \left[\left(\frac{\alpha(1-\gamma)}{\sigma} - 1\right) A\varsigma \bar{X}^{\varepsilon} \bar{M}^{\varsigma-1}\right] \bar{Z}$$

$$\left.\frac{\partial \dot{Z}}{\partial Z}\right|_{BGP} = \bar{Z}$$

Proposition 2: The balanced growth path is locally stable. It is a saddle-point.

Proof: see Appendix 2.

The dynamical system includes two predetermined variables representing state variables X and M, and a control variable.

I show in Appendix 2 that the determinant of the Jacobian matrix is positive and its trace is negative. The system admits two negative eigenvalues, each associated with a state variable.

In the steady state we have: $\bar{g}_Y = \bar{g}_K = \bar{g}_{K*} = \bar{g}_H = \bar{g}_c = \bar{g}$.

From equation (4), we can express the steady state growth rate as an increasing function of M:

$$\bar{g}_Y = \bar{g}_H = \frac{\dot{H}}{H} = \phi \bar{X}^{-1} \bar{M}^{\beta} \quad (24)$$

Using equation (14) we show that the growth rate is a decreasing function of p_M:

$$\bar{g}_Y = \phi \frac{\gamma^{\beta}}{(1-\gamma)^{\beta}} \bar{X}^{-1} p_M^{-\beta} \quad (25)$$

Comparative statics

In Appendix 3, I provide the proof of the following implicit function:

$$F(\phi, \rho, e, \bar{g}) = \phi^{\Xi}(eA)^{-\Xi}\begin{bmatrix} \frac{\eta}{\sigma} A^{\chi(\kappa+\varsigma)} \phi^{\omega(\kappa+\varsigma)} (eA)^{-\frac{\chi}{\varepsilon+1}(\kappa+\varsigma)} \bar{g}^{\chi(\kappa+\varsigma)} - eA\bar{g}^{\chi(\kappa+\eta)} \phi^{\omega(\kappa+\eta)} (eA)^{-\frac{\chi}{\varepsilon+1}(\kappa+\eta)} + \\ (1-e)\bar{g}^{\chi(\kappa+\beta)} \phi^{\omega(\kappa+\beta)} (eA)^{-\frac{\chi}{\varepsilon+1}(\kappa+\beta)} \end{bmatrix}$$

$$-\frac{\rho}{\sigma} + \left(1 - \frac{1}{\sigma}\right)\delta = 0.$$

where:

$$\Xi = \frac{\varepsilon}{\varepsilon+1}; \chi = \frac{\varepsilon+1}{\beta\varepsilon+\varsigma}; \kappa = \frac{\varepsilon(\beta-\varsigma)}{\varepsilon+1}; \omega = \frac{\varepsilon}{\beta\varepsilon+1}$$

Implicit function theorem gives:

$$\frac{\partial \bar{g}}{\partial \rho} = -\frac{\partial F(\phi, e, \rho, \bar{g}) / \partial \rho}{\partial F(\phi, e, \rho, \bar{g}) / \partial \bar{g}}$$

$$\frac{\partial \bar{g}}{\partial \phi} = -\frac{\partial F(\phi, e, \rho, \bar{g}) / \partial \phi}{\partial F(\phi, e, \rho, \bar{g}) / \partial \bar{g}}$$

$$\frac{\partial \bar{g}}{\partial e} = -\frac{\partial F(\phi, e, \rho, \bar{g}) / \partial e}{\partial F(\phi, e, \rho, \bar{g}) / \partial \bar{g}}$$

I show in Appendix 3 that:

$$\frac{\partial \bar{g}}{\partial \rho} < 0; \frac{\partial \bar{g}}{\partial \phi} > 0; \frac{\partial \bar{g}}{\partial e} = -\frac{\partial F(\phi, e, \rho, \bar{g}) / \partial e}{\partial F(\phi, e, \rho, \bar{g}) / \partial \bar{g}} > 0$$

Hence, growth rate is a decreasing function of ?. The more important the learning parameter is, the higher the growth rate is. The more important the share of exports in production is the higher the rate of growth is. Export promotion makes it possible to finance imports of capital goods and increases their use in the production process creating important learning effects that accelerate human capital accumulation and growth.

Transitional dynamics

First, I calibrate the model by choosing values for the parameters from the literature on endogenous growth and the assumptions of the present model. Then, I proceed to simulations. The value of parameters and the results of simulations are reported in the following tables:

Table 1
Parameters values

α	β	γ	ρ	σ	Φ	A	e
0.7	0.6	0.6	0.02	0.5	0.01	0.15	0.1

Table 2
Simulation results

Z	X	M	g	r
0.99	0.54	0.74	0.0156	0.048

The simulation of the model, given the values of parameters, provides a growth rate close to 1.6% and an interest rate close to 5%. Moreover, the variable Z is close to 1, while variables X and M are less than 1.

As the initial value of the variable Z is non-predetermined, a unique initial value of this variable can be chosen on the balanced growth path for a given initial value for each of the predetermined variables X and M.

During the transition to the balanced growth path, starting from a low initial value of the stock of domestic physical capital, human capital, physical capital and production increase until they reach their steady state values.

Initially, Z decreases (C decreases and K increases), and the variables X and M increase (H and K* increase faster than K). Thus, by opening to trade and using in the production process imported capital goods more than domestic capital goods, a small developing economy is growing at a faster rate.

However, as the stock of domestic capital increases, the variables M and X decrease until converging towards their steady state. Thus, as shown by simulation results, in the long run, the domestic capital stock is larger than the imported capital stock. Moreover, simulations show that X is larger than M which is almost equal to one. Therefore, the use of imports decreases with the improvement of domestic physical capital and human capital through the learning effects. The economy does not remain permanently dependent on foreign capital goods for its growth process once it has developed its own stocks of human and physical capital.

3. CONCLUSION

The purpose of this paper was to study the impact of capital goods imports, that are technologically more advanced than domestic capital goods, on economic growth in a small open economy. The use of such imports in the production process generates learning effects and accelerates human capital accumulation. The domestic producer is more encouraged using foreign capital goods when the productivity gap between foreign and domestic capital goods is high and the domestic price of imports is low.

Increasing technical skills through learning effects contributes to the creation of a local technological capacity. This process of dissemination of foreign technology incorporated into imported capital goods is a positive external effect. The economy will not remain permanently dependent on foreign capital goods once it has developed its own stocks of human and physical capital.

Thus, trade between a small economy and the rest of the developed world is dynamically beneficial in reducing the technological gap and accelerating the accumulation of the reproducible factor. The assumption of learning through use of foreign capital goods positively impacts the rate of growth because it is synonymous of knowledge spillover at the international level. Technology spillovers are an essential element in explaining the dynamic link between international trade and economic growth.

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APPENDIX

Appendix 1: Unicity

Implicit function of *M* from equations 21, 22 and 23:

Using equations 21-22 we express X as a function of M:

$$X = A^{\frac{1}{1-\alpha}}\left(\delta - \frac{\rho+\delta}{\sigma}\right)^{\frac{1}{1-\alpha}}\left[e\left(1+\frac{\alpha\gamma}{\sigma}\right)M^{\alpha\gamma-1} - \frac{\alpha(1-\gamma)}{\sigma}M^{\alpha\gamma}\right]^{\frac{-1}{1-\alpha}} \tag{I}$$

Replacing in equation (21), we can express *Z* as a function of *M*:

$$Z = \left(\frac{\rho+\delta}{\sigma} - \delta\right)\left[e\frac{1+\alpha\gamma}{\sigma}M^{\alpha\gamma-1} - \frac{\alpha(1-\gamma)}{\sigma}M^{\alpha\gamma}\right]^{-1}\left[eM^{\alpha\gamma-1} + (e-1)M^{\alpha\gamma}\right] \tag{II}$$

Replacing (I) et (II) in equation (22), we find the following implicit function of *M*:

$$\Psi(M) = \left(\delta - \frac{\rho+\delta}{\sigma}\right)\frac{1}{\sigma}\left[e(1+\alpha\gamma)M^{\alpha\gamma-1} - \alpha(1-\gamma)M^{\alpha\gamma}\right]^{-1}(1-e)M^{\alpha\gamma} +$$
$$\frac{\Phi}{\sigma}A^{-\frac{1}{1-\alpha}}\left(\delta - \frac{\rho+\delta}{\sigma}\right)^{\frac{-1}{1-\alpha}}\left[e(1+\alpha\gamma)M^{\alpha\gamma-1} - \alpha(1-\gamma)M^{\alpha\gamma}\right]^{\frac{1}{1-\alpha}}M^{\beta} + \delta = 0$$

For *M* to be unique, let's show that Ψ is monotone and continuous in the neighborhood of *M*. We compute the first derivative with respect to *M*, and the limits:

$$\Psi'(M) = \left(\delta - \frac{\rho+\delta}{\sigma}\right)\frac{1}{\sigma}\left\{\begin{array}{l}(1-e)M^{\alpha\gamma}\left[-\frac{e\alpha\gamma(\alpha\gamma-1)M^{\alpha\gamma-21} - \alpha(1-\gamma)M^{\alpha\gamma-1}}{[e(1+\alpha\gamma)M^{\alpha\gamma-1} - \alpha(1-\gamma)M^{\alpha\gamma}]^2}\right] + \\ (1-e)\alpha\gamma M^{\alpha\gamma-1}[e(1+\alpha\gamma)M^{\alpha\gamma-1} - \alpha(1-\gamma)M^{\alpha\gamma}]^{-1}\end{array}\right\} +$$
$$\frac{\Phi}{\sigma}A^{\frac{1}{1-\alpha}}\left(\delta - \frac{\rho+\delta}{\sigma}\right)^{\frac{-1}{1-\alpha}}\left\{\begin{array}{l}\frac{1}{(1-\alpha)\sigma}[e(1+\alpha\gamma)M^{\alpha\gamma-1} - \alpha(1-\gamma)M^{\alpha\gamma}]^{\frac{1}{1-\alpha}-1}\left[\begin{array}{l}e(1+\alpha\gamma)(\alpha\gamma-1)M^{\alpha\gamma-2} \\ -\alpha(1-\gamma)\alpha\gamma M^{\alpha\gamma-1}\end{array}\right]M^{\beta} \\ +\beta M^{\beta-1}[e(1+\alpha\gamma)M^{\alpha\gamma-1} - \alpha(1-\gamma)M^{\alpha\gamma}]^{\frac{1}{1-\alpha}}\end{array}\right\}$$

$$\Psi'(M) \succ 0 \quad \text{if} \quad \sigma \succ \frac{\rho}{\delta} + 1 \quad \text{and} \quad M \prec \frac{\alpha(1-\gamma)}{e(1+\alpha\gamma)};$$

$$0 \prec \alpha \prec 1;\ 0 \prec \gamma \prec 1;\ 0 \prec e \prec 1.$$

The calculation of the limits gives:

$$\lim_{M\to+\infty}\Psi = -\infty$$

$$\lim_{M\to-\infty}\Psi = +\infty,$$

given the restriction: $\sigma > \frac{\rho}{\delta} + 1$

Thus, as Ψ is continuous and monotone as a function of *M*, it admits a unique zero, *M*.

Appendix 2: Stability

To study the stability of the dynamic system given by equations 21, 22 and 23, let's calculate the determinant of the Jacobian matrix and the associated eigenvalues. I opt for the numerical method.

By taking the values of the parameters reported in Table 1, the determinant, the eigenvalues and the eigenvectors are:

Determinant = 0.00005 > 0

Eigenvalues: {0.065, -0.038, -0.02}

Eigenvectors: {{-0.58, -0.15, -0.79}, {-0.58, -0.37, -0.81}, {-0.28, 0.01, 0.95}}

Thus, there are two negative eigenvalues associated with the two predetermined variables, the ratio of human capital to domestic physical capital (*X*) and the ratio of foreign capital to domestic physical capital (*M*), and a positive eigenvalue associated with the predetermined variable, the ratio of consumption to physical capital (*Z*). The determinant of the Jacobian matrix is positive, and its trace is negative. Therefore, the dynamic system is stable.

Appendix 3: Comparative statics

Implicit function of $\bar{g}$, ρ, ϕ, *e*:

In the steady state, we have:

$\bar{g} = g_c = g_K = g_H = g_{K*}$

Let's express *M* as a function of g:

Using g_c and g_{K*} we find:

$$A\bar{X}^{1-\alpha} = \left(\frac{\rho+\delta}{\sigma} - \delta\right)\left[\frac{\alpha(1-\gamma)}{\sigma}\bar{M}^{\alpha\gamma} - \left(\frac{\alpha\gamma}{\sigma} + e\right)\bar{M}^{\alpha\gamma-1}\right]^{-1}$$

$$\bar{g} = e\left(\frac{\rho+\delta}{\sigma} - \delta\right)\left[\left(\frac{\alpha(1-\gamma)}{\sigma}\right)\bar{M}^{-1} - \left(\frac{\alpha\gamma}{\sigma} + e\right)\right]^{-1}$$

Therefore,

$$\bar{M} = \alpha(1-\gamma)\sigma^{-1}\left[e\left(\frac{\rho+\delta}{\sigma} - \delta\right)(\bar{g} + \delta)^{-1} + \frac{\alpha\gamma}{\sigma} + e\right]^{-1}$$

Replacing in the implicit function of *M* computed in appendix 1, we find the implicit function of $\bar{g}$ and the parameters:

$$F(\bar{g}, \Phi, \rho, e, \delta, \sigma, \alpha, \gamma) = \left(\delta - \frac{\rho+\delta}{\sigma}\right)\sigma^{-1}(1-e)\left\{\begin{matrix} e(1+\alpha\gamma)\alpha^{-1}(1-\gamma)^{-1}\sigma\left[\begin{matrix} e\left(\frac{\rho+\delta}{\sigma} - \delta\right)(g+\delta)^{-1} \\ +\frac{\alpha\gamma}{\sigma} + e \end{matrix}\right] \\ -\alpha(1-\gamma) \end{matrix}\right\}^{-1}$$

$$+ \Phi A^{-\frac{1}{1-\alpha}}\left(\delta - \frac{\rho+\delta}{\sigma}\right)^{\frac{-1}{1-\alpha}}\sigma^{-\left(1+\beta+\frac{\alpha\gamma}{1-\alpha}\right)}\alpha^{\beta+\frac{\alpha\gamma}{1-\alpha}}\left[e\left(\frac{\rho+\delta}{\sigma} - \delta\right)(g+\delta)^{-1} + \frac{\alpha\gamma}{\sigma} + e\right]^{-\left(\beta+\frac{\alpha\gamma}{1-\alpha}\right)}$$
$$\left\{e(1+\alpha\gamma)\sigma\alpha^{-1}(1-\gamma)^{-1}\left[e\left(\frac{\rho+\delta}{\sigma} - \delta\right)(g+\delta)^{-1} + \frac{\alpha\gamma}{\sigma} + e\right] - \alpha(1-\gamma)\right\}^{\frac{1}{1-\alpha}} + \delta = 0$$

A.3.1 Impact of Φ on $\bar{g}$

The theorem of implicit function gives:

$$\frac{\partial \bar{g}}{\partial \Phi} = -\frac{\frac{\partial F}{\partial \Phi}}{\frac{\partial F}{\partial \bar{g}}}$$

$$\frac{\partial F}{\partial \Phi} = A^{-\frac{1}{1-\alpha}}\left(\delta - \frac{\rho+\delta}{\sigma}\right)^{\frac{-1}{1-\alpha}} \sigma^{-\left(1+\beta+\frac{\alpha\gamma}{1-\alpha}\right)}\alpha^{\beta+\frac{\alpha\gamma}{1-\alpha}}\left[e\left(\frac{\rho+\delta}{\sigma}-\delta\right)(g+\delta)^{-1}+\frac{\alpha\gamma}{\sigma}+e\right]^{-\left(\beta+\frac{\alpha\gamma}{1-\alpha}\right)}$$

$$\frac{\partial F}{\partial \Phi} \prec 0 \text{ if } \sigma \succ \frac{\rho}{\delta}+1$$

$$\frac{\partial F}{\partial \bar{g}} = \left(\delta - \frac{\rho+\delta}{\sigma}\right)\sigma^{-1}(1-e)[e(1+\alpha\gamma)\alpha^{-1}(1-\gamma)^{-1}\sigma]\ e\ \left(\frac{\rho+\delta}{\sigma}-\delta\right)(g+\delta)^{-2}$$
$$\left\{\begin{matrix} e(1+\alpha\gamma)\alpha^{-1}(1-\gamma)^{-1}\sigma\left[e\left(\frac{\rho+\delta}{\sigma}-\delta\right)(g+\delta)^{-1}+\frac{\alpha\gamma}{\sigma}+e\right] \\ -\alpha(1-\gamma)\end{matrix}\right\}^{-2}$$
$$+(\beta+\frac{\alpha\gamma}{1-\alpha})\ \Phi A^{-\frac{1}{1-\alpha}}\left(\delta-\frac{\rho+\delta}{\sigma}\right)^{\frac{-1}{1-\alpha}}\sigma^{-\left(1+\beta+\frac{\alpha\gamma}{1-\alpha}\right)}\alpha^{\beta+\frac{\alpha\gamma}{1-\alpha}}e\left(\frac{\rho+\delta}{\sigma}-\delta\right)(g+\delta)^{-2}$$
$$\left[e\left(\frac{\rho+\delta}{\sigma}-\delta\right)(g+\delta)^{-1}+\frac{\alpha\gamma}{\sigma}+e\right]^{-\left(\beta+\frac{\alpha\gamma}{1-\alpha}\right)-1}$$

$$\left\{e(1+\alpha\gamma)\sigma\alpha^{-1}(1-\gamma)^{-1}\left[e\left(\frac{\rho+\delta}{\sigma}-\delta\right)(g+\delta)^{-1}+\frac{\alpha\gamma}{\sigma}+e\right]-\alpha(1-\gamma)\right\}^{\frac{1}{1-\alpha}}-$$
$$\frac{1}{1-\alpha}e(1+\alpha\gamma)\sigma\alpha^{-1}(1-\gamma)^{-1}e\left(\frac{\rho+\delta}{\sigma}-\delta\right)(g+\delta)^{-2}\left\{\begin{matrix} e(1+\alpha\gamma)\sigma\alpha^{-1}(1-\gamma)^{-1}. \\ \left[e\left(\frac{\rho+\delta}{\sigma}-\delta\right)(g+\delta)^{-1}+\frac{\alpha\gamma}{\sigma}+e\right] \\ -\alpha(1-\gamma)\end{matrix}\right\}^{\frac{1}{1-\alpha}-1}$$
$$\Phi A^{-\frac{1}{1-\alpha}}\left(\delta-\frac{\rho+\delta}{\sigma}\right)^{\frac{-1}{1-\alpha}}\sigma^{-\left(1+\beta+\frac{\alpha\gamma}{1-\alpha}\right)}\alpha^{\beta+\frac{\alpha\gamma}{1-\alpha}}\quad\left[e\left(\frac{\rho+\delta}{\sigma}-\delta\right)(g+\delta)^{-1}+\frac{\alpha\gamma}{\sigma}+e\right]^{-\left(\beta+\frac{\alpha\gamma}{1-\alpha}\right)}$$

$\frac{\partial F}{\partial \bar{g}} > 0$ if $\sigma > 1 + \frac{\rho}{\sigma}$ and given that $0 < \alpha < 1$.

The two derivatives are of opposite sign. This implies that:

$$\frac{\partial \bar{g}}{\partial \Phi} > 0$$

Thus, the learning parameter has a positive effect on the steady-state growth rate.

A.3.2. Impact of e

Theorem of implicit functions gives:

$$\frac{\partial \bar{g}}{\partial e} = -\frac{\frac{\partial F}{\partial e}}{\frac{\partial F}{\partial \bar{g}}}$$

$$\frac{\partial F}{\partial e} = -\left(\delta - \frac{\rho+\delta}{\sigma}\right)\sigma^{-1}\left\{\begin{matrix} e(1+\alpha\gamma)\alpha^{-1}(1-\gamma)^{-1}\sigma\left[e\left(\frac{\rho+\delta}{\sigma}-\delta\right)(g+\delta)^{-1}+\frac{\alpha\gamma}{\sigma}+e\right] \\ -\alpha(1-\gamma) \end{matrix}\right\}^{-1} - \left(\delta - \frac{\rho+\delta}{\sigma}\right)\sigma^{-1}(1-e)$$

$$\left\{(1+\alpha\gamma)\alpha^{-1}(1-\gamma)^{-1}\sigma\left[e\left(\frac{\rho+\delta}{\sigma}-\delta\right)(g+\delta)^{-1}+\frac{\alpha\gamma}{\sigma}+e\right] + e(1+\alpha\gamma)\alpha^{-1}(1-\gamma)^{-1}\sigma\left[\left(\frac{\rho+\delta}{\sigma}-\delta\right)(g+\delta)^{-1}+1\right]\right\}$$

$$\left\{\begin{matrix} e(1+\alpha\gamma)\alpha^{-1}(1-\gamma)^{-1}\sigma\left[e\left(\frac{\rho+\delta}{\sigma}-\delta\right)(g+\delta)^{-1}+\frac{\alpha\gamma}{\sigma}+e\right] \\ -\alpha(1-\gamma) \end{matrix}\right\}^{-2}$$

$$-\left(\beta+\frac{\alpha\gamma}{1-\alpha}\right)\left[\left(\frac{\rho+\delta}{\sigma}-\delta\right)(g+\delta)^{-1}+1\right]\Phi A^{-\frac{1}{1-\alpha}}\left(\delta-\frac{\rho+\delta}{\sigma}\right)^{\frac{-1}{1-\alpha}}\sigma^{-\left(1+\beta+\frac{\alpha\gamma}{1-\alpha}\right)}\alpha^{\beta+\frac{\alpha\gamma}{1-\alpha}}$$

$$\left[e\left(\frac{\rho+\delta}{\sigma}-\delta\right)(g+\delta)^{-1}+\frac{\alpha\gamma}{\sigma}+e\right]^{-\left(\beta+\frac{\alpha\gamma}{1-\alpha}\right)-1}$$

$$\left\{e(1+\alpha\gamma)\sigma\alpha^{-1}(1-\gamma)^{-1}\left[e\left(\frac{\rho+\delta}{\sigma}-\delta\right)(g+\delta)^{-1}+\frac{\alpha\gamma}{\sigma}+e\right]-\alpha(1-\gamma)\right\}^{\frac{1}{1-\alpha}} +$$

$$\frac{1}{1-\alpha}\left\{\begin{matrix}(1+\alpha\gamma)\sigma\alpha^{-1}(1-\gamma)^{-1}\left[e\left(\frac{\rho+\delta}{\sigma}-\delta\right)(g+\delta)^{-1}+\frac{\alpha\gamma}{\sigma}+e\right]+e(1+\alpha\gamma)\sigma\alpha^{-1}(1-\gamma)^{-1}. \\ \left[\left(\frac{\rho+\delta}{\sigma}-\delta\right)(g+\delta)^{-1}+1\right]\end{matrix}\right\}$$

$$\left\{e(1+\alpha\gamma)\sigma\alpha^{-1}(1-\gamma)^{-1}\left[e\left(\frac{\rho+\delta}{\sigma}-\delta\right)(g+\delta)^{-1}+\frac{\alpha\gamma}{\sigma}+e\right]-\alpha(1-\gamma)\right\}^{\frac{1}{1-\alpha}-1}.$$

$\frac{\partial F}{\partial e} < 0 \ if \ \sigma \succ 1+\frac{\rho}{\sigma}$ and given that $0 < \alpha < 1$.

Therefore, $\frac{\partial \bar{g}}{\partial e} > 0$ given the above restrictions on parameters. Thus, the steady state growth rate is an increasing function of the share of exports in production.

A.3.3. Impact of ρ

$$\frac{\partial F}{\partial \rho} = -\left(\delta - \frac{\rho+\delta}{\sigma}\right)(1-e)e(1+\alpha\gamma)\alpha^{-1}(1-\gamma)^{-1}\left(\frac{\alpha\gamma}{\sigma}+e\right)\left(\frac{\rho+\delta}{\sigma}-\delta\right)^{-2}$$

$$\left\{\begin{matrix} e(1+\alpha\gamma)\alpha^{-1}(1-\gamma)^{-1}\sigma\left[e(g+\delta)^{-1}+\left(\frac{\rho+\delta}{\sigma}-\delta\right)^{-1}\left(\frac{\alpha\gamma}{\sigma}+e\right)\right]^{-2} \\ -\alpha(1-\gamma) \end{matrix}\right\}$$

$$-\Phi A^{-\frac{1}{1-\alpha}}\sigma^{-\left(1+\beta+\frac{\alpha\gamma}{1-\alpha}\right)}\alpha^{\beta+\frac{\alpha\gamma}{1-\alpha}}\left(\beta+\frac{\alpha\gamma}{1-\alpha}\right)e\sigma^{-1}(g+\delta)^{-1}\left[e\left(\frac{\rho+\delta}{\sigma}-\delta\right)(g+\delta)^{-1}+\frac{\alpha\gamma}{\sigma}+e\right]^{-\left(\beta+\frac{\alpha\gamma}{1-\alpha}\right)-1}$$

$$\left\{e(1+\alpha\gamma)\sigma\alpha^{-1}(1-\gamma)^{-1}\left[e(g+\delta)^{-1}+\left(\frac{\rho+\delta}{\sigma}-\delta\right)\left(\frac{\alpha\gamma}{\sigma}+e\right)\right]-\alpha(1-\gamma)\right\}^{\frac{1}{1-\alpha}}+$$

$$\Phi A^{-\frac{1}{1-\alpha}}\sigma^{-\left(1+\beta+\frac{\alpha\gamma}{1-\alpha}\right)}\alpha^{\beta+\frac{\alpha\gamma}{1-\alpha}}\frac{1}{1-\alpha}e(1+\alpha\gamma)\alpha^{-1}(1-\gamma)\left(\frac{\alpha\gamma}{\sigma}+e\right)$$

$$\left\{e(1+\alpha\gamma)\sigma\alpha^{-1}(1-\gamma)^{-1}\left[e(g+\delta)^{-1}+\left(\frac{\rho+\delta}{\sigma}-\delta\right)^{-1}\left(\frac{\alpha\gamma}{\sigma}+e\right)\right]-\alpha(1-\gamma)\right\}^{\frac{1}{1-\alpha}-1}$$

$$\frac{\partial F}{\partial \rho} > 0 \ if \ \sigma \succ 1+\frac{\rho}{\sigma}$$

Thus, growth rate is a decreasing function of ρ.