Technological convergence and the connections between adoption, maintenance and investment activities *

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Abstract

This paper explores the interactions between maintenance, adoption and investment activities when labor is heterogeneous. We consider that adoption activities are intensive in human capital whereas capital maintenance requires unskilled labor. Among the main results, we find that the optimal skilled and unskilled labor allocation are independently determined. Hence, maintenance (adoption) activities are not affected by changes in the efficiency of adoption (maintenance)parameters. We next simulate the model in order to study the convergence speed to the long run technological gap and the role of human capital in the process of catching-up.

Keywords: Technology adoption, Maintenance activities,Technological convergence

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1 Introduction

In growth theory, depreciation has traditionally been taken as a constant proportion of the existing capital stock. This hypothesis is an oversimplification that leaves aside some important economical issues affecting the depreciation rate. Depreciation happens due to aging, accelerates with utilization and decelerates with maintenance. Although the costs of maintaining and repairing equipment and structures have been deeply treated in the engineering and management literature[1], there only exist a few contributions exploring the role of maintenance in the macroeconomy. Some recent ones (Licandro and Puch (2000), Collard and Kollintzas (2001), among others) are mostly concerned with the cyclical properties of maintenance and its implications for the business cycle. McGrattan and Schmitz (1999), and Boucekkine and Ruiz-Tamarit, (2000)) analyze, in a partial equilibrium framework, the substitutability properties between maintenance and investment. Finally, Boucekkine, Martinez and Saglam (2001) incorporate maintenance and adoption activities in an optimal growth model with disembodied technical progress and homogeneous labor, where adoption and maintenance "compete" for labor resources. Among other findings, they obtain that maintenance is a kind of substitute to adoption.

In fact, there exist many economic channels linking maintenance to adoption activities. Besides the resources competition, the embodied nature of technical progress (repeatedly invoked in a number of theoretical and empirical contributions[2]) reinforces the connections between maintenance and adoption activities. Embodied technical progress increases the "quality" of new capital goods and maintaining them becomes more important. On the other hand, the expected maintenance costs may discourage the implementation of new technologies.

When maintenance and adoption are jointly incorporated in the same framework, their resources requirements are a key issue. A number of empirical contributions have emphasized the role of skill in implementing a new technology. In Geenwood and Yorokoglu (1997) and Benhabid and Spiegel (1994), the process of adopting technologies is intensive in human capital: skilled labor is crucial at adopting a technology and learning it. Maintenance

[1]See, for example, Pham and Wang (1996).

[2]In particular, Greenwood, Hercowitz and Krusell (1997) estimate that around 60% of US productivity growth can be attributed to embodied technological change.

practices seem to be more automated and carry out by unskilled workers. But, as new technologies are more complex, they may increase the technical expertise of the maintenance workforce.

In this paper we focus on the connections between maintenance, adoption and investment activities, when labor is heterogeneous. We introduce two types of workers, *i.e.* skilled and unskilled. We assume the extreme case in which that adoption is human capital intensive whereas maintenance activities only require unskilled labor. This is a reasonable assumption since it seems quite natural the maintenance is *a priori* much less intensive in human capital. The connections between investment and capital maintenance have been recently analyzed, in a partial equilibrium framework, without a categorical result. McGrattan and Schmitz (1999) suggest that maintenance and investment are to some extend substitutes for each other. In contrast, Boucekkine and Ruiz-Tamarit (2001) point out the sensitivity of the substitution versus complementary features to the postulate depreciation function. We extend the analysis to a general equilibrium framework taking into account the embodied-disembodied nature of technical progress. We think in a closed economy which does not innovate and simply adopt technologies previously invented elsewhere. Since technological adoption is costly, technological follower countries have incentives to invest in dominated technologies giving rise to a positive technological gap. Some recent empirical literature (Jaumotte (1999), Desdroigts (2000)) focus in the process of catching-up experienced by developing countries. As our adoption framework a la Nelson and Phelps (1966) is suitable to be contrasted with the technological convergence literature, we carry on some simulations in order to study the convergence speed to the long run technological gap and to analyze the role of human capital in the process of catching-up. The rest of the paper is organized as follows. In Section 2 we introduce the model, characterize the balanced growth paths and give some comparative statics results. Section 3 is devoted to analyze the technological convergence properties of the model. Section 4 concludes.

2 The model

We consider an economy with three types of activities: production of final output, capital maintenance and technological adoption. Three inputs are available: physical capital, skilled and unskilled labor. We first describe the economy activities and after equilibrium conditions are introduced. We shall confine our analysis to the planner's problem.

2.1 Description of the economy

Production of final good

The economy produces an homogeneous final good with a Cobb-Douglas technology using capital and two types of labor:

$$Y_t = A_{t-1} K_{t-1}^{\alpha} h_t^{\phi} l_t^{1-\alpha-\phi} \quad (1)$$

where K_{t-1}, h_t and l_t denote respectively capital, skilled and unskilled labor employed in the production of final good. A_{t-1} denotes the total factor productivity existing at t; we assume that it takes one period to incorporate the technological improvements in the productive sector. This delay can be interpreted as a implementation delay.

$\alpha \in (0,1)$ measures the elasticity of output with respect to capital, whereas $\phi \in (0,1)$ measures that of skilled labor. We assume constant returns to scale. The final good can be used for consumption (C) or investment in physical capital (I). The economy's resource constraint is:

$$Y_t = C_t + I_t \quad (2)$$

Maintenance activities

Capital evolves over time according to the following law of motion:

$$K_t = [1 - \delta(m_t)]\, K_{t-1} + I_t \quad (3)$$

$\delta(.)$ is the depreciation function which depends on the maintenance effort. We assume that maintenance activities require unskilled labor. By choosing m_t, the planner determines the physical depreciation rate at period t. There are some properties that the depreciation rate should check:

(i) $\delta(m) > 0,\ \ \delta'(m) < 0,\ \ \delta''(m) > 0$

(ii) $\delta(0) = \overline{\delta}, \qquad \lim_{m->L} \delta(m) = \underline{\delta} > 0, \quad \overline{\delta} > \underline{\delta} > 0$

(i) imposes the depreciation rate to be a decreasing an convex function of the maintenance effort. These properties are commonly assumed in the endogenous depreciation literature[3].

(ii) gives an upper and a lower bound of the depreciation rate characterizing two extreme cases. When the planner does not devote any resources to capital maintenance activities, the depreciation rate is constant and equal to $\overline{\delta}$. If the planner devotes all unskilled labor resources (L) to capital maintenance, the economy can not go below a minimal value corresponding to the natural depreciation rate, $\underline{\delta}$.

Adoption activities

Technological progress results from the effort of a few developed countries that push the knowledge frontier in search of new productivity gains. But, for most of the countries the relevant question is not which technologies to develop, but which technologies to adopt. Our economy is one of the latest. It simply adopts technologies that have already been discovered elsewhere. Human capital or skilled labor is commonly cited as a prerequisite of development and of successful implementation of new technologies. When human capital is relatively scarce, the advanced techniques are too expensive to implement, and developing countries do not adopt the leader one arising a technological gap. As in Nelson and Phelps (1966) we assume that technologies are continuously invented as an exogenous rate γ, and the technological level of the economy in practice is a function both of the level of human capital and the technological frontier:

$$A_t = A_{t-1} + d_t u_t^{\theta} \left[A_{t-1}^{0} - A_{t-1} \right] \tag{4}$$

$$0 < d_t u_t^{\theta} < 1 \tag{5}$$

$$0 < \theta < 1 \tag{6}$$

where u_t is the amount of skilled labor used in the adoption side of the economy, d_t represent the productivity of adoption activities, and A_{t-1}^{0} represents the best technological level achievable, which can be interpreted as the

[3] See Boucekkine and Ruiz-Tamarit (2001), and McGrattan and Schmitz (1999).

technological frontier, *i.e.*, the level of technological progress in the leader countries. Inequality (5) is the non-explosivity condition, which assures that detrended technological level in practice is bounded in the long run; condition (6) implies that adoption has decreasing returns to labor, *ie.* is concave with respect to u.

Note that the opportunity of adopting new technologies is subject to three main restrictions. The first is the existence of a constraint in human capital, meaning that a minimum amount of skilled labor is needed for adoption to be undertaken; that is, if the economy does not devote any skilled labor to adoption, the total productivity level should be constant. The second is the existence of diminishing returns to adoption, which captures the notion of "crowding" associated with the duplication of adoption effort in the presence of a limited stock of invented technologies[4]. Finally, as the technical level in practice gets closer to the technological frontier, it becomes increasingly difficult for skilled labor to effect an improvement, and given that skilled labor supply is fixed, it gives rise a positive technological gap in the long run. Note that the technological gap of the economy is given by $TG_t = \frac{A^0_{t-1} - A_{t-1}}{A_{t-1}} = \frac{1}{d_t u_t^\theta}\left[\frac{A_t}{A_{t-1}} - 1\right]$. Hence, although the growth of total factor productivity is influenced by the adoption effort in the short run, in the long run it must settle down to a rate of γ. These properties are inherent to Nelson and Phelps' adoption models.

Household behavior

There are two types of households, skilled and unskilled. They both consume and supply labor inelastically. We model these households as one representative household supplying H units of skilled labor and L units of unskilled labor. He maximizes the discounted value of instantaneous utility

$$\sum_{t=0}^{\infty} \beta^t U(C_t)$$

where $0 < \beta < 1$ is the discount factor, and C_t is consumption in period t. Hereafter, we will assume a logaritmic utility function.

Labor market equilibrium conditions

[4]We assume that just like research (see Jones (1995)), adoption is subject to a crowding effect.

Equilibrium in the skilled labor market implies that all the skilled workers are employed either in the final good sector (as skilled labor) or in the adoption sector.

$$H = h_t + u_t \tag{7}$$

Equilibrium in the unskilled labor market implies that the unskilled labor force is employed either in the final good sector (as unskilled labor) or in maintenance activities.

$$L = l_t + m_t \tag{8}$$

We next describe the planner problem and the equilibrium conditions.

2.2 The planner's problem

The central planner solves the following problem in order to maximize the discounted sum of instantaneous utility:

$$\max_{\{K_t, A_t, h_t, u_t, m_t, l_t\}} \quad \sum_{t=0}^{\infty} \beta^t U(C_t)$$

subject to equations (1)-(8), and given A_{-1} and K_{-1}.

The interior solution of this optimization problem is characterized by the following first order conditions:

$$(1-\alpha-\phi)A_{t-1}K_{t-1}^{\alpha}h_t^{\phi}l_t^{-\alpha-\phi}U'(C_t) = w_t \tag{9}$$

$$\left[-\delta'(m_t)\right] K_{t-1}U'(C_t) = w_t \tag{10}$$

$$\lambda_t d_t \theta u_t^{\theta-1}(A_{t-1}^0 - A_{t-1}) = \mu_t \tag{11}$$

$$\phi A_{t-1}K_{t-1}^{\alpha}h_t^{\phi-1}l_t^{1-\alpha-\phi}U'(C_t) = \mu_t \tag{12}$$

$$U'(C_t) = \left[\left[1-\delta(m_{t+1})\right] + \alpha A_t K_t^{\alpha-1}h_{t+1}^{\phi}l_{t+1}^{1-\alpha-\phi}\right]\beta U'(C_{t+1}) \tag{13}$$

$$K_t^{\alpha}L_{t+1}^{1-\alpha}U'(C_{t+1}) = r\lambda_t - (\lambda_{t+1} - \lambda_t) + \lambda_{t+1}d_{t+1}u_{t+1}^{\theta} \tag{14}$$

Where w and μ are the multipliers associate to unskilled and skilled labor restrictions respectively, and λ is the multiplier associated to the adoption function.

Equations (9) and (10) are the optimality conditions with respect to the unskilled labor: marginal productivity of unskilled labor devoted either to production of final good or to maintenance activities should be equal to its shadow price, w. Equations (11)-(12) are the optimality conditions with respect to skilled labor; they set the marginal productivity of adoption (production) skilled labor equal to the skilled labor shadow price, μ. Equation (13) is the standard Euler equation yielded in growth models. Equation (14) requires that the marginal productivity of knowledge should be equal to its marginal cost, that can be interpreted as an user cost. Taking into account that the parameter $r = \frac{1}{\beta} - 1$ represents the rate of time preference, this user cost includes the interest opportunity cost, minus the potential gain in the value of knowledge from t to $t+1$, plus the gap opportunity cost at $t+1$. Indeed, the term $\lambda_{t+1} d_{t+1} u_{t+1}^{\theta}$ is the reduction in the potential gains of additional adoptions.

We are now able to define an equilibrium for our economy.

Definition 1 *Given the initial conditions A_{-1} and K_{-1}, the optimal solution for this economy is a path for $\{A_t, K_t, m_t, l_t, h_t, u_t, Y_t, C_t, I_t\}_{t \geq 0}$ that satisfies the restrictions (1)-(8), the first order conditions (9) to (14), the usual positive constraints, and the following inequality:*

$$\phi l_t \geq (1 - \alpha - \phi) h_t \tag{15}$$

Note that we have imposed, by the labor market equilibrium conditions, that all skilled (unskilled) workers were employed in skilled (unskilled) jobs. However, as skilled workers are able to work in unskilled jobs, the previous equilibrium to be optimum requires that the skilled shadow wage were equal or bigger than the unskilled labor shadow wage. This is exactly that condition (15) imposes.

We next investigate the long run properties of this equilibrium. We characterize the optimal growth paths and analyze the interrelation between maintenance, adoption and investment activities. Whereas adoption increases the productivity of the capital stock (quality), maintenance and investment raise the capital stock (quantity). The question that we want to address is if the planner uses both channels to rise output, or one activity goes in detriment of the others. Notice that as maintenance and adoption require different inputs they do not compete for labor resources. But, both activities are connected *via* the production function: they divert labor resources from production and also, maintenance affects the capital input to be used in production and adoption increases the output through the total factor productivity.

2.3 Long run equilibrium

We next define the balanced growth paths of the economy and give some sensitivity results.

Definition 2 *Along the balanced growth paths: (i) adoption, maintenance and production labor are constants, (ii) technological progress in practice grows at a rate γ, (iii) consumption, production, capital and investment grow at a rate $\gamma^{\frac{1}{1-\alpha}}$.*

The growth rates of the variables of the model along the balanced growth paths are easily obtained by writing the restrictions among the different growth rates that the system (1)-(14) impose. The long run levels are given by the following restrictions:

$$\begin{aligned}
[-\delta'(m)]K &= (1-\alpha-\phi)AK^{\alpha}h^{\phi}l^{-\alpha-\phi} \qquad (16)\\
h\beta d\theta(1-A)u^{\theta-1} &= \phi A(\gamma-\beta(1-du^{\theta}))\\
A(\gamma-1) &= du^{\theta}(1-A)\\
H &= h+u\\
\frac{\gamma^{\frac{1}{1-\alpha}}}{\beta} &= 1-\delta(m)+\alpha AK^{\alpha-1}h^{\phi}l^{1-\alpha-\phi}\\
LT &= l+m\\
Y\gamma^{\frac{1}{1-\alpha}} &= AK^{\alpha}h^{\phi}l^{1-\alpha-\phi}\\
K &= K[1-\delta(m)]\gamma^{\frac{-1}{1-\alpha}}+I\\
Y &= C+I\\
TG &= \frac{\gamma-1}{du^{\theta}}
\end{aligned}$$

Before checking the existence of the stationary equilibrium, we first characterize the optimal allocation of skilled and unskilled labor.

Proposition 1 *The long run equilibrium can be solved in independent subblocks for the optimal unskilled and skilled labor allocations. Hence, the optimal skilled (unskilled) allocation is not affected by the maintenance (adoption) parameters.*

We can reduce the long run equilibrium equations to two equations which solves separately the optimal allocation of skilled and unskilled labor across activities:

$$f(u) = \phi u[\gamma - \beta(1 - du^{\theta})] - \beta\theta(\gamma - 1)(H - u) = 0$$
$$g(m) = 1 - \delta(m) + \frac{\alpha[-\delta'(m)](L - m)}{(1 - \alpha - \phi)} - \frac{\gamma^{\frac{1}{1-\alpha}}}{\beta} = 0 \qquad (17)$$

Then, proposition 1 is checked.

The main implication of proposition 1 is the zero interaction between maintenance and adoption activities in determining the equilibrium. This result is a consequence of the different skilled and unskilled labor shadow prices. As we argued before, due to the different input requirements for both activities, the direct labor competition between them, founded in Boucekkine, Martìnez and Saglam (20001), is broken down. But, since both activities affect output diverting resources from production, some dependence could rise *via* the production sector. The independence between both labor allocations is mainly driven by the different shadow prices. As skilled and unskilled labor devoted to production have different shadow prices, their optimal allocations are totally determined equalizing the marginal productivity of skilled (unskilled) labor across activities. In order to characterize the steady state growth paths and deal with the existence and uniqueness issues, we need to specify the depreciation function and hence, some restrictions on the parameters are required.

Assumption 1 *(i)* $\delta(m) = a - cm^b$, $0 < b < 1$; $a - cL^b > 0$

(ii) $cL^b < (1 - b)\left(\frac{\gamma^{\frac{1}{1-\alpha}}}{\beta} - 1 + a\right)$

(iii) $\frac{L}{H} > \frac{(1-\alpha-\phi)+\alpha(1-b)}{\phi}$

The previous assumption states an explicit depreciation function which satisfies the requirements *(i)*-*(ii)*. The restriction on the values of the parameters are required to m be positive and less than total unskilled resources. Besides, the requirement *(iii)* implies that the proportion of unskilled labor over skilled labor is enough big in order to check that the unskilled shadow price is smaller than the skilled one along the balanced growth path.

Proposition 2 *Assume that the depreciation function and the parameters of the model check assumption 1, then:*

(i) *a stationary equilibrium exists and it is unique.*

(ii) *Skilled workers have no incentives to work in unskilled jobs.*

(iii) $\frac{\partial u}{\partial d} < 0$; $\frac{\partial m}{\partial d} = 0$; $\frac{\partial TG}{\partial d} < 0$; $\frac{\partial I}{\partial d} > 0$

(iv) $\frac{\partial u}{\partial c} = 0$; $\frac{\partial m}{\partial c} > 0$; $\frac{\partial TG}{\partial c} = 0$; $\frac{\partial I}{\partial c} > 0$ *for* $b > \overline{b}$.

(v) $\frac{\partial u}{\partial \gamma} > 0$; $\frac{\partial m}{\partial \gamma} < 0$; $\frac{\partial TG}{\partial \gamma} > 0$; *However, the sign of* $\frac{\partial I}{\partial \gamma}$ *is ambiguous.*

where $\overline{b} = \frac{(\gamma^{\frac{1}{1-\alpha}} - 1)(1-\alpha-\phi)}{(\gamma^{\frac{1}{1-\alpha}} - 1 - a)(1-\alpha-\phi) + a\phi}$.

The formal proof is given in the appendix. The comparative statics results help us to understand the mechanism at work with our heterogeneous labor assumption. First, when an exogenous improvement in the adoption technology takes place, there exists a transfer of skilled labor from the adoption sector to the production side of the economy. This result can be against our first intuition but is consistent with the restrictions imposed in the adoption function. In fact, an improvement in the productivity of adoption activities reduces the potential gains of adoption, due to the economy is closer to its equilibrium technological gap. However, adoption labor, measured in efficiency units increases in the long run, and so the technological gap is reduced. The optimal allocation of unskilled labor remains constant under an increment in d. This results is quite easy to understand having in mind proposition 1, and taking into account that the distribution of unskilled labor across activities is not altered by the level of disembodied technical progress (which increases with du^{θ}). In fact, A is not a determinant of the allocation of labor resources across activities. A rise in the level of disembodied technical progress has, *a priori*, a direct effect on the marginal productivity of unskilled production labor, but it should be the same for maintenance labor since unskilled labor has the same shadow price. Therefore, the distribution of labor resources across activities need not be modified. The positive effect of d on the investment level is guided by the increment in the capital stock (due to the positive effect of A and h on K). The parameter c can be interpreted as a productivity parameter of the maintenance technology. When c increases more resources are devoted to capital maintenance since maintenance activities are more productive. However, it has no influence in the adoption sector and the distribution of skilled labor across activities remains constant; since the technological gap is only affected by the adoption effort, c does not alter the long run technological gap. Note that a rise in the maintenance effort decreases (increases) the marginal productivity of maintenance (unskilled production) labor; in the long run they both should be equal to the unskilled reservation wage. It is clear from equation (16), that the previous adjusted process is carried through the capital stock, which raises in order to equalize the marginal productivity of unskilled labor across activities.

The effect on the investment level is more complex due to the existence of three competing effects:

$$\frac{\partial I}{\partial c} = \frac{I}{K}\frac{\partial K}{\partial c} - Kbcm^{b-1}\gamma^{\frac{-1}{1-\alpha}}\frac{\partial m}{\partial c} - Km^{b}\gamma^{\frac{-1}{1-\alpha}}$$

The first one is the positive capital effect just argued above. The second one is the indirect maintenance effect: an increase in the maintenance effort reduces the depreciation rate discouraging investment. The third one is the direct negative effect: given K and m, a rise in c improves the maintenance efficiency and leads to a decrement in the investment level. Which of the conflicting effects will dominate depends mainly on the parameter b, which is not an elasticity number in the mathematical sense, but measures the sensitivity of capital depreciation to changes in the maintenance labor. When b is small, the sensitivity of capital depreciation is higher for small values of m: The more maintenance benefits are obtained for small values of m and the less impact on the capital level at determining investment; as a consequence the dominant effect is the negative one. As b increases, more unskilled resources divert to capital maintenance, rising the reallocation labor process, which enlarges the capital effect. When b is large enough the long run investment is mainly driven by the long run capital stock.

We next focus on the comparative statics results of a technological acceleration. When γ rises, the technological frontier is shifted upwards, and then it directly increases the technological gap. As a consequence, adoption diverts resources from production in order to benefit from the technological improvement and to reduce the deeper technological gap. However, the adoption effort is not enough to compensate the negative effect of γ on the technological gap, and it deepens in the long run. Note that if the planner diverts too many skilled labor from production to adoption it would be harmful for consumption. The optimal allocation of skilled labor is also affected by a technological acceleration. Notice that equation (17) is obtained from the Euler condition taking into account the equality between the marginal productivity of unskilled labor across activities. A rise in γ increases the marginal cost of delaying consumption and then, it should have a counterpart in the marginal benefits of investment. Maintenance and production competes in reaching this objective: m decreases the depreciation rate but diverts resources from production; l directly increases production at the expense of the depreciation rate. The optimal response leads to a decrease in the maintenance activities in benefit of the production side. Recall that when labor is homogeneous the same negative effect on maintenance is obtained; in that case it mainly reflects the arbitrage between "productive" (l) and "non-productive" activities ($u+m$). In the heterogeneous labor model both activities also acts in opposite directions when γ rises, but this is due to the resources unskilled competition in the maintenance and in the production sector. Although we can find a negative effect on the capital level (directly obtained by equation (16)), γ implies more economic interactions than d and c (γ affects both skilled and unskilled allocations), and the investment effect is analytically ambiguous.

3 Technological gap and technological convergence

In the neoclassical theory, technology is assumed to be a public good and poorer countries may converge to rich ones because there are diminishing returns to capital. In contrast, in the technology-gap approach, technology is not a public good and developing countries costly adopt technologies invented elsewhere. In this context, there is another source of convergence, that is, technological convergence: developing countries may exhibit a chance to catch up because of the opportunity for faster growth through technology adoption and implementation. The idea is that developing countries experience technological spillovers from the technological leader countries. The size of this spillovers increases with the initial technological gap, giving rise to a technological catch-up. Both approaches introduce human capital in a different way; the standard approach treats human capital as an ordinary input in the production function, whereas in the technological-gap approach human capital plays a role in determining productivity.

Mankiw, Romer and Weil (1992) has empirically investigated the first alternative. They found that the diminishing returns to physical and human capital accumulation explain most of the observed convergence in standard of living. Some recent empirical papers[5] investigate the technological convergence approach. They analyze if differences in growth rates are primarily due to differences in human capital stocks that acts as a factor constituting a country's ability to engage in technological progress. These empirical studies delivers some main results. First, developing countries experience a technological catch-up, conditional to their initial long run equilibrium. Second, human capital is found to play a decisive role in the absorption of technologies. Finally, the technology sector is human capital intensive.

The aim of this section is to analyze the convergence properties of our model and to study the role of human capital in the convergence speed to the long run equilibrium. Note that our model is an exogenous growth model, and does not let us investigate the differences in growth rates due to differences in the human capital level and the process to reach the leader country as in Benhabid and Spiegel (1994). Nevertheless, as productivity growth is endogenous in the short run, we are able to analyze the convergence speed to the balanced growth path. The simulations are performed using the methodology proposed by Boucekkine (1995) for saddle-point trajectories. We set the following parameters values:

parameters fixed a priori								other parameters		
L	H	a	b	α	ϕ	β	γ	d	θ	c
9	1	0.12	0.15	0.3	0.2	0.97	1.03	0.7	0.5	0.075

A first set of parameters is fixed a priori to what we consider as reasonable values given the empirical evidence available. The remaining parameters b, c, d and θ has been chosen in order to match four statistics: a natural depreciation rate of 0.1%, a maintenance cost around 6%, an adoption cost around 10% and a ratio of the skilled shadow wage over the unskilled one is around four.

To deal with the analysis and study the convergence properties, we compare two identical economies but suffering from a different technological gap

[5] See Jaumotte (1999), Desdroigts (2000) and Benhabib and Spiegel (1994)

than the long run equilibrium one (5% and 10% respectively). The parameter values are settled as previously. Since TG is only affected by the adoption effort, we assume that initially the economy optimally diverts unskilled resources to production and capital maintenance, but the allocation of skilled labor is biased to production.

Figure 1 displays the adoption effort for both economies. When the economy is far from its long run equilibrium there exists more potential gains from adoption and the economy reacts investing more in adopting new technologies. u_t increases the convergence speed[6] as which the technological gap is reduced (Figure 2), and it takes around 10 periods for both economies to reach the stationary technological gap. It suggests that as far an economy is from the long run equilibrium technological gap the larger advantage of the adoption gains and the faster convergence speed to the equilibrium technological gap. As the technological gap shrinks and reach the closer economy, adoption gains decreases and both economies converge. Figure 3 shows a longer convergence process for the level of output, in comparison with the technological gap. This can be explained by two forces. When the economy starts the convergence process takes into account the necessity of reaching the long run value of detrended technological level to get the long run equilibrium level of detrended output. Then it initially reacts increasing both maintenance and adoption labor in detriment of production (both skilled and unskilled production labor decrease), and after the adoption gains are run down, the economy deals with the reallocation labor adjustment process. Hence, the technological convergence process is totally driven by the adoption effort, whereas the output convergence is guided by the technical level in practice and by the optimal resources allocations between activities. Figures 1 and 4 clearly show that the labor reallocation process is longer the deeper initial technological gap is.

To analyze the role of human capital in the convergence process to the long run equilibrium, we compare two economies with different labor force composition: 10% and 20% of skilled labor population respectively. The long run equilibrium values for both economies are given in the table below[7].

[6]The convergence speed is defined as $\frac{\partial\left(\frac{A_t}{A_{t-1}}\right)}{\partial\left(\frac{e^{\gamma(t-1)}-A_{t-1}}{A_{t-1}}\right)} = du_t^{\theta}$

[7]We consider same calibration given previously.

	m	u	TG	Y
$(L = 9, H = 1)$	0.3867	0.1746	0.10254	5.2353
$(L = 8, H = 2)$	0.333	0.2914	0.0794	6.105

Comparing the long run equilibrium detrended values of both economies, the economic human capital benefits are clear. Although it decreases the unskilled labor resources devoted to maintenance and production, it increases the long run output and shrinks the technological gap. We also assume that both economies are 5% far from the stationary technological gap. Figures 5 to 8 display the deviations of the two economies from the balanced growth path for the relevant variables of the economy. The solution paths obtained suggest that the larger the human capital endowment is, the faster the convergence speed to the equilibrium technological gap and the smaller the reallocation labor process will be. Indeed, the economy endowed with more skilled labor resources responds devoting more resources to adoption, which speeds up the convergence process to its equilibrium technological gap.

As in the convergence process depending on the initial technological gap, the initial adoption effort leads also to an initial output loss. In that case, the initial decrease in the level of output increases with the initial technological gap (more labor devoted to adoption and maintenance divert labor from production). But in the convergence process depending on the initial human capital stock, adoption effort and output loss are not positively correlated. Comparing the two economies, the economy more intensive in human capital incurs in a larger adoption effort, but the resulting decrease in the level of output is smaller.

Overall, we can extract some important results from the previous analysis. First, our model predicts technological convergence conditional to its long run equilibrium, and the negative consequences on the output level are directly related to the deepness of the initial technological gap. Second, human capital speeds up the technological convergence process. Finally, the labor force composition seems to play a fundamental role in the output decrease induced by the transfer of labor production resources to the adoption side: Countries endowed with more proportion of skilled workers can reach faster the equilibrium technological gap and this faster process does not necessarily implies an initial larger decrease in the output level.

4 Conclusion

In this paper, we have tried to clarify the interactions between maintenance, adoption and investment activities when they are treated in the same framework. To this end, we have considered that adoption activities are intensive in human capital whereas capital maintenance requires unskilled labor. This is an acceptable assumption since empirical literature has stressed the fundamental role of skills in the process of implementation a new technology, and hence, it seems quite natural that maintenance is a priori less intensive in human capital. Although some interaction should be expected, we find that the optimal skilled and unskilled labor allocation are independently determined, and maintenance (adoption) activities are not altered by changes in the efficiency of adoption (maintenance) parameters. Hence, exogenous improvements in the adoption and maintenance technologies tends to increase the long run level of investment. When a technological acceleration takes place, adoption and maintenance acts in opposite directions, due to the resources unskilled competition in the maintenance and in the production sector. As a rise in the rate of technical progress affects both skilled and unskilled allocations and implies more economic interactions, its effect on investment is analytically ambiguous.

From the technological convergence analysis, we find some important results. First, the model predicts technological convergence conditional to its long run equilibrium. Second, human capital speeds up the technological convergence process: countries endowed with more proportion of skilled workers can reach faster the equilibrium technological gap; we find that this faster process does not necessarily implies an initial larger decrease in the output level induced by the transfer of labor production resources to the adoption side.

Obviously, some extensions of the model would be highly interesting for a much comprehensive appraisal of the interactions between maintenance, adoption and investment activities. We have analyzed the extreme case where adoption and maintenance requires different inputs. It would be interesting to redefine the input requirement for both activities, and to introduce human capital accumulation in order to break the constant (intensity) skills over the different kinds of workers assumed in this paper. Although adoption is clearly more human capital intensive, the continuous introduction of new and more complex capital goods in the productive sector increases the technical expertise of the maintenance workers, that is, skill requirements. On the other hand, investment-specific technical progress may leads to different maintenance rules depending on the quality of the capital good to which they are channeled, and the maintenance of the older capital goods may be less human capital intensive that maintaining the newest ones. Indeed, it should be suitable a complete characterization of the depreciation rate which takes into account the different maintenance requirements depending on the quality of the capital goods.

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6 Appendix

1. The equilibrium conditions.

$$
\begin{aligned}
\frac{\beta K_t^{\alpha} h_{t+1}^{\phi} l_{t+1}^{1-\alpha-\phi}}{C_{t+1}} &= \frac{\phi A_{t-1} K_{t-1}^{\alpha} h_t^{\phi-1} l_t^{1-\alpha-\phi}}{C_t d_t \theta u_t^{\theta-1}(A_{t-1}^0 - A_{t-1})} - \\
& \quad \frac{\beta[1-d_{t+1}u_{t+1}^{\theta}]\phi A_t K_t^{\alpha} h_{t+1}^{\phi-1} l_{t+1}^{1-\alpha-\phi}}{C_{t+1} d_{t+1} \theta u_{t+1}^{\theta-1}(A_t^0 - A_t)} \\
-[\delta'(m_t)]K_{t-1} &= (1-\alpha-\phi) A_{t-1} K_{t-1}^{\alpha} h_t^{\phi} l_t^{-\alpha-\phi} \\
\frac{C_{t+1}}{\beta C_t} &= [1-\delta(m_{t+1})] + \alpha A_t K_t^{\alpha-1} h_{t+1}^{\phi} l_{t+1}^{1-\alpha-\phi} \\
Y_t &= A_{t-1} K_{t-1}^{\alpha} h_t^{\phi} l_t^{1-\alpha-\phi} \\
K_t &= [1-\delta(m_t)]K_{t-1} + I_t \\
A_t &= A_{t-1} + d_t u_t^{\theta} \left[A_{t-1}^0 - A_{t-1}\right] \\
L &= l_t + m_t \\
H &= u_t + l_t \\
Y_t &= C_t + I_t \\
\phi l_t &\geq (1-\alpha-\phi) h_t
\end{aligned}
$$

2. Proof of proposition 2.

(i) We can reduce the equilibrium conditions and solve skilled labor and unskilled labor variables separately. Optimal skilled labor allocation checks the following equilibrium equations:

$$
\begin{aligned}
h &= f(u) = \frac{\phi u[\gamma - \beta(1-du^{\theta}]}{(\gamma-1)\beta\theta} \\
h &= g(u) = 1-u
\end{aligned}
$$

$f(u)$ is an increasing function which tends to zero when u tends to zero and is positive for positive values of u. Hence, $g(u)$ is the resources constraint with respect to skilled labor; it is a linear decreasing function which tends to one (zero) when u tends to zero (one). Then, there exist a pair $(u^*, h^*) \ni u^*, h^* \in (0,1)$, which solves the previous equations.

Optimal unskilled labor allocation taking into account the resources constraint $(L = l + m)$ checks:

$$
p(m) = 1 - \delta(m) + \frac{\alpha[-\delta'(m)](L-m)}{1-\alpha-\phi} - \frac{\gamma^{\frac{1}{1-\alpha}}}{\beta} = 0
$$

Under assumption 1 $p(m)$ is a decreasing function of maintenance labor and it has an unique solution.

(ii) A sufficient condition to check (ii) is:

$$m^* \leq L - \frac{(1-\alpha-\phi)H}{\phi}$$

we can rewrite $p(m)$ as

$$L = P(m) = m + \frac{(1-\alpha-\phi)m^{1-b}}{\alpha bc}\left[\frac{\gamma^{\frac{1}{1-\alpha}}}{\beta} - 1 - a - cm^b\right]$$

Under assumption 1 $P(m)$ is an increasing function of m which tends to 0 when $m = 0$,and is bigger that L when $m \to L$. Then, denoting $\widetilde{m} = L - \frac{(1-\alpha-\phi)H}{\phi}$, it is straightforward to prove that $P(\widetilde{m}) > L$ (which implies $\widetilde{m} > m^*$) when $\frac{L}{H} > \frac{(1-\alpha-\phi)+\alpha(1-b)}{\phi}$, and this restriction is satisfied under assumption 1.

(iii)-(v) The comparative statics results are easily checked, except for $\frac{\partial I}{\partial c}$

$$\frac{\partial I}{\partial c} = \frac{I}{K}\frac{\partial K}{\partial c} - Kbcm^{b-1}\gamma^{\frac{-1}{1-\alpha}}\frac{\partial m}{\partial c} - Km^b\gamma^{\frac{-1}{1-\alpha}}$$

Developing the previous expression, and after tedious computations, we obtain that the sign of $\frac{\partial I}{\partial c}$ depends on the sign of:

$$\left[\gamma^{\frac{1}{1-\alpha}} - \alpha(1-a) - (1-\alpha)\frac{\gamma^{\frac{1}{1-\alpha}}}{\beta}\right] - a\alpha -$$
$$b\left[\gamma^{\frac{1}{1-\alpha}} - \alpha(1-a) - (1-\alpha)\frac{\gamma^{\frac{1}{1-\alpha}}}{\beta} + \frac{a\alpha\phi}{1-\alpha-\phi}\right]$$

which is positive for $b > \frac{(\gamma^{\frac{1}{1-\alpha}}-1)(1-\alpha-\phi)}{(\gamma^{\frac{1}{1-\alpha}}-1-a)(1-\alpha-\phi)+a\phi}$.

Role of the initial technological gap in the convergence process.

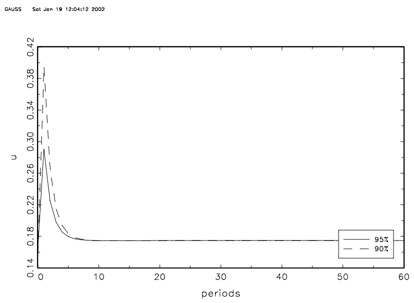

Figure 1 Adoption Labor

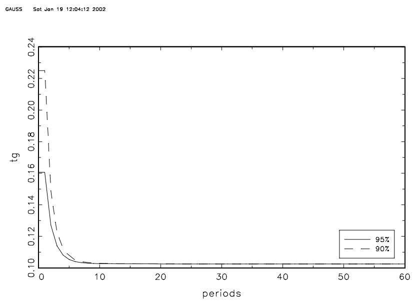

Figure 2 Technological Gap

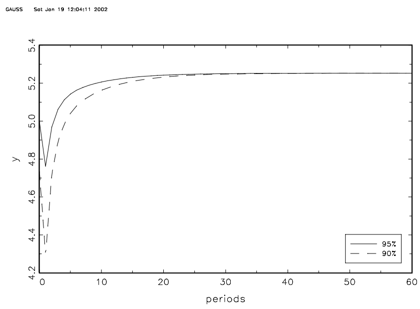

Figure 3 Output

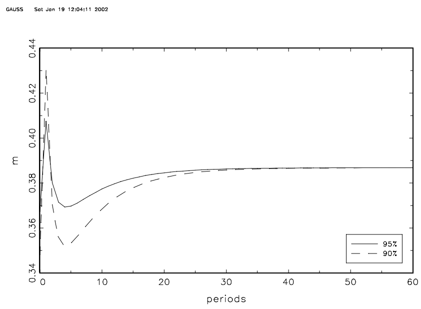

Figure 4 Maintenance Labor

Role of human capital in the convergence process.

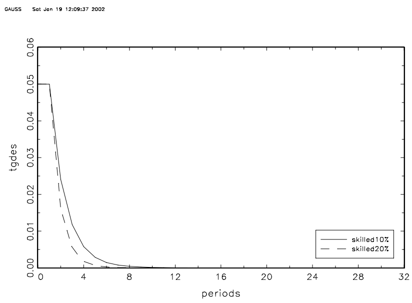

Figure 5 Technological Gap

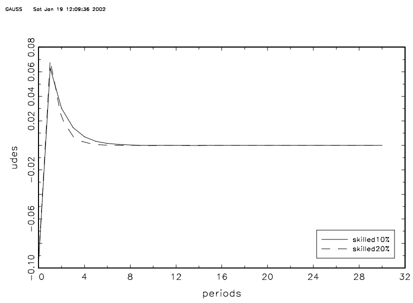

Figure 6 Adoption Labor

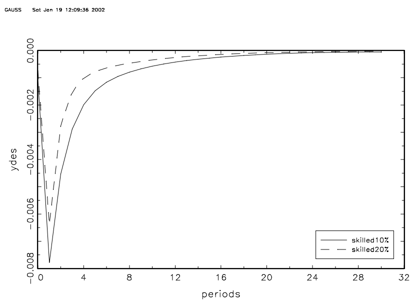

Figure 7 Output

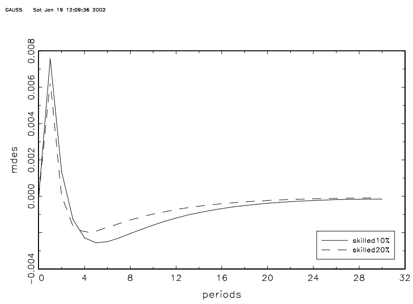

Figure 8 Maintenance Labor