Why capital maintenance should be a key development tool ?

R. Boucekkine, Bl. Martinez and C. Saglam

Discussion Paper 2007-44

Département des Sciences Économiques
de l'Université catholique de Louvain

UCL

Why capital maintenance should be a key development tool*

Raouf Boucekkine[†] Blanca Martinez [‡] Cagri Saglam [§]

December 5, 2007

Abstract

We study optimal growth models *à la* Nelson and Phelps (1966) where labor resources can be allocated either to production, technology adoption or capital maintenance. We first characterize the balanced growth paths of a benchmark model without maintenance. Then we introduce the maintenance activity *via* the depreciation rate of capital. We characterize the optimal allocation of labor across the three activities. Though maintenance deepens the technological gap by diverting labor resources from adoption, we find that it generally increases the long run output level. Moreover we find that long term output response to policy shocks is slightly higher in the presence of maintenance.

Keywords: Adoption, Maintenance, Technological gap, Output gap

Journal of Economic Literature: E22, E32, O40.

---

*We thank seminar participants at Universidade Santiago de Compostela, European University Institute at Florence and Universit'e catholique de Louvain for many worthwhile suggestions. We also acknowledge the support of the Belgian research programmes "Poles d'Attraction inter-universitaires" PAI P5/21, and "Action de Recherches Concertée" 03/08-302.

[†]Corresponding author. Department of economics and CORE, Université catholique de Louvain, and University of Glasgow. Raouf.Boucekkine@uclouvain.be

[‡]Universidad Complutense de Madrid. blmartin@ccee.ucm.es

[§]Bilkent University, Turkey. csaglam@bilkent.edu.tr

1 Introduction

There is a common view of economic development according to which technology transfers from the industrialized countries is a perequisite for the developing countries to take off. This view is completely in line with the neoclassical growth model (Solow, 1956). In the latter framework, the unique way to ensure long term growth in GDP per capita is a permanent rise in the stock of technological knowledge of the economy. Capital accumulation, measured for example by the investment rate, only matters in the short term dynamics.

How have technology transfers performed over the past decades? There exists a huge literature (notably empirical) on this subject. One of the main issues investigated concerns the existence of spillover efficiency benefits to host country economies from technology transfer projects (see the excellent survey of Blomstrom and Kokko, 1998). Therefore, the focus of the analysis is not only the performance of these projects in the particular firms and geographic areas where they are implemented, but also and especially their sectoral and macroeconomic implications.

An unavoidable aspect of technology transfers performance concerns the existence of numerous barriers to technology adoption in the host countries. In a recent empirical inspection into the nature of these adoption costs, based on the reported performances of some 50 major international projects conducted by the 36 largest Canadian consulting engineering firms in developing countries, Niosi, Hanel and Fiset (1995) conclude that "technology transfer costs are positive and mostly concentrated in the area of training".

Naturally, for a technology transfer project to be successful and to yield substantial sectoral spillovers, a necessary condition is to reduce drastically the size of the adoption costs. These costs are twofold. Some are related to the unavoidable learning and (slow) diffusion of technologies (see David, 1990, for a masterful historical perspective), and some come from the institutional arrangements at work in the host countries. The second class of barriers to adoption derive from the host country's education and trade policies. In particular, the trade policies restricting the access to the domestic markets and/or impeding majority ownership by foreign firms are likely to discourage technology transfers. Since the eighties, many developing countries have undertaken the necessary reforms to get rid of these barriers. It is the case in Turkey (from the early 80s), Mexico (from 1984) and India (from 1991) for example. Using a large panel data of Mexican manufacturing firms during a period of trade liberalization (1984-1990), Grether (1999) finds that technology transfer projects (via foreign direct investment) do not lead to significant spillovers at the sector level. This is mainly due to the very limited capacity of technological absorption of the developing countries, which makes problematic even a rough imitation of the imported technologies. Moreover, labor resources are scarce, and labor mobility is generally strictly limited by the wage differential existing between the subsidiaries of the multinational corporations and the domestic firms.

The absence of clear spillovers challenges the optimistic view of technology transfer, and indeed, it casts a doubt on the usefulness of technology adoption in an environment where the labor resources are scarce and the technological absorption is tenuous. This is especially true if we take into account the increasing sophistication of the new technologies. What could be an optimal technology adoption pace for a developing country? Are there any alternative policy to adoption? We shall address these issues in this paper. In particular, we shall advocate that **the maintenance of the technologies in use and the associated stock of capital is a very good alternative to adoption in terms of long term income per capita**.
Surprisingly, the recent macroeconomic literature has almost disregarded maintenance.[1] Among the very few exceptions dealing with maintenance in the macroeconomy, one can enumerate McGrattan and Schmitz (1999), Licandro and Puch (2000), Collard and Kollintzas (2001), and Boucekkine, Martinez and Saglam (2006).[2] All these papers are mostly concerned with the cyclical properties of maintenance and its implications for the business cycle. In particular, the connection between the adoption and maintenance decisions from the economic development point of view is not thoroughly studied. For example, Boucekkine, Martinez and Saglam (2006) studied an optimal growth structure with maintenance within a vintage capital structure and embodied technical change, and mainly focus on the propagation mechanisms allowed by the latter characteristics.

The purpose of this paper is to investigate within a much simpler setting the

[1]Not so in the seventies with the notable contributions of Feldstein and Rothschild (1974), and Nickell (1975).

[2]Another contribution dealing with investment and capital maintenance is due to Boucekkine and Ruiz-Tamarit (2003), but it takes a deliberate microeconomic approach.

relative virtues of capital maintenance versus technology adoption from the point of view of a developing country which main target is to raise long-run income level. There are several reasons to believe that adoption and maintenance decisions are indeed connected, and should be treated as such. An obvious reason is that many firms have in mind the maintenance implications of their adoption decisions. A firm can disregard the adoption of a new technology if it anticipates a costly pace of maintenance costs both in physical and human capital. This is even more crucial when technological advances are embodied in capital. There is another reason to treat maintenance and adoption within the same framework. Actually, just like adoption, maintenance diverts resources from the other sectors and activities, it consequently "competes" with adoption in this respect. Maintenance activities do require human and physical capital just like adoption, though one can reasonably think that adoption is more intensive in human capital. The labor opportunity cost of maintenance is stressed in Tiffen and Mortimore (1994) who studied the role of capital maintenance and technology adoption in the growth recovery of Kenya. Maintenance expenditures are indeed included in social cost-benefit analysis in this country case but "...it is not always realized that labor on maintenance may have a rising opportunity cost...this requires a wise management of recurrent maintenance costs if the benefits of investment are to be lasting".

In this paper, we study the outcomes of optimal growth models *à la* Nelson and Phelps (1966) where the labor resources can be allocated freely either to production, adoption or maintenance. Technological progress is disembodied, the central planner has to decide how much labor has to be devoted to increasing the stock of knowledge of the economy (adoption or imitation) and how much labor should be assigned to the maintenance of capital. Labor on maintenance decreases the depreciation rate of capital. A fraction of labor is devoted to adopt the innovations coming from abroad. There is no R&D activity and labor resources are fixed. This is likely to generate an everlasting technological gap as in the original Nelson and Phelps' contribution. In this set-up, could it be a case where capital maintenance is preferred to adoption? What is the optimal allocation of human capital resources across activities? If presumably the maintenance activity diverts labor from adoption and is therefore likely to deepen the technological gap, does it in counterpart rise the (detrended) level of income as it reduces the negative impact of capital depreciation? How do maintenance and adoption decisions shift under exogenous changes in the pace of technological progress, and how does this affect the economy? Does maintenance improve the responsiveness of the economy to policy shocks? These questions will be tackled along this paper. Since the short run dynamics of the considered models do not add much to the results obtained for the balanced growth paths, we restrict our analysis to the latter.

The paper is organized as follows. The next section is devoted to briefly present and characterize the steady state equilibrium of a benchmark model of adoption *à la* Nelson and Phelps without maintenance. Section 3 incorporates maintenance in the benchmark model and examines how this affects the properties of the model in the steady state. Section 4 concludes.

2 The benchmark model

We consider an economy which comprises a continuum of infinite lived agents, indexed from 0 to 1. All individuals share the same preferences that are characterized by the lifetime utility function:

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

where $0 < \beta < 1$ is a constant discount factor and C_t is consumption in period t. There is no desutility of labor and labor supply is exogenous and equal to one. This is the simplest way to model (skilled) labor scarcity in an economy, one of the main characteristics of developing economies.
The economy includes two sectors: the final good sector and the imitation (or technology adoption) sector. The functioning of the imitation sector is as follows. We denote by A^0_{t-1} the state of knowledge at the beginning of period t, that is the best technological level achievable, which could be interpreted as the technological level of the industrialized countries. A^0_t is assumed to grow exogenously at a factor γ, $A^0_t = \gamma^t$, $\forall t \geq 0$, with $\gamma > 1$. The production function of the imitation sector resembles Nelson and Phelps' specification (1966). Denote by A_{t-1} the technological level in use in the economy at the beginning of period t. The imitation sector increases this level over time

according to the following production function:

$$\begin{aligned} A_t &= A_{t-1} + \phi_t u_t^{\theta} \left[A_{t-1}^0 - A_{t-1} \right] \\ 0 &< \theta < 1. \end{aligned}$$

u_t represents the amount of labor resources devoted to imitation in period t, and ϕ_t is an exogenous variable capturing the potential shocks to this sector. An increase in ϕ_t may for example reflect an exogenous improvement in the skills on the labor force. It may also reflect a trade policy reform easing technology transfers. Note that imitation (or adoption) has decreasing returns to labor, ie. is concave with respect to u. Doubling the labor fraction devoted to adoption will increase the technology in practice level by a factor strictly lower than two. This assumption mimics the hypothesis usually done in the R&D literature according to which there exist decreasing returns to the research effort (for example, see Caballero and Jaffe, 1993). We assume that just like research, technology adoption is subject to a crowding effect which mainly reflects redundancy in the adoption effort.

We assume that $A_{-1}^0 > A_{-1}$, that is initially, at $t = 0$, the technology in use in the economy is below the technology frontier, which is a necessary assumption as far as we are concerned with developing countries. We also assume that $\phi_t < 1$, $\forall t$. Indeed, it can be readily checked that the imitation technology implies that

$$A_t = \left(1 - \phi_t u_t^{\theta}\right) \; A_{t-1} + \phi_t u_t^{\theta} \; A_{t-1}^0.$$

Given that the total labor resources are normalized to one, the assumption $\phi_t < 1$ is sufficient to ensure that A_t is a (strict) convex combination of A_{t-1} and A_{t-1}^0. Hence we have always $A_{t-1} < A_t < A_{t-1}^0$ as long as u_t is nonzero. At any date t, there is no way to close the gap between the technology in use and the technology frontier. This is the simplest way to model **a limited capacity of technological absorption**. This crucial aspect can be also captured via the explicit concept of technological gap developed by Nelson and Phelps. In effect, following these authors, the technological gap, TG_t, at t is by definition $\frac{A_{t-1}^0 - A_{t-1}}{A_{t-1}}$, which by equation (3) implies:

$$TG_t = \frac{1}{\phi_t u_t^{\theta}} \; \left(\frac{A_t}{A_{t-1}} - 1 \right).$$

The technological gap depends on the adoption effort u_t and on the exogenous productivity variable ϕ_t. Under our assumptions, it is always strictly positive. In particular, it does not vanish in the the steady state, a remarkable property of Nelson and Phelps' adoption models which makes them most appropriate to study economic development problems.

The final good sector has the traditional structure, with notably a Cobb-Douglas technology using capital and labor, with α the capital share.

$$Y_t = A_{t-1} K_{t-1}^{\alpha} l_t^{1-\alpha},$$

K_{t-1} is the stock of capital available at the end of period $t-1$, l_t is amount of labor assigned to the final good sector. Technological progress, represented by the stock of knowledge available at the beginning of period t, A_{t-1}, is disembodied. We now study the central planner problem corresponding to this economy.

2.1 The central planner problem

The fundamental decision to be taken by a central planner in such an economy is very simple: For a given stock of capital K_{-1}, and stock of knowledge A_{-1}, how much labor has to be devoted to increase the stock of knowledge and how much has to go to production, for the welfare of the economy to be maximized?

$$Max_{\{K_t, A_t, u_t, l_t, Y_t, C_t, I_t\}} \sum_{t=0}^{\infty} \beta^t U(C_t)$$

subject to

$$Y_t = A_{t-1} K_{t-1}^{\alpha} l_t^{1-\alpha}, \tag{1}$$

$$K_t = [1-\delta] K_{t-1} + I_t, \tag{2}$$

$$A_t = A_{t-1} + \phi_t u_t^{\theta} \left[A_{t-1}^0 - A_{t-1}\right], \tag{3}$$

$$1 = l_t + u_t, \tag{4}$$

$$Y_t = C_t + I_t, \tag{5}$$

given A_{-1} and K_{-1} and the corresponding positivity conditions (notably $0 \leq u_t \leq 1$). δ is the capital depreciation rate and I_t is gross investment.

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

$$U'(C_t) = \beta U'(C_{t+1}) \left[\alpha A_t K_t^{\alpha-1} l_{t+1}^{1-\alpha} + 1 - \delta\right], \tag{6}$$

$$\beta K_t^{\alpha} l_{t+1}^{1-\alpha} U'(C_{t+1}) = \lambda_t - \beta \lambda_{t+1} \left[1 - \phi_{t+1} u_{t+1}^{\theta}\right], \tag{7}$$

$$(1-\alpha) A_{t-1} K_{t-1}^{\alpha} l_t^{-\alpha} U'(C_t) = \omega_t, \tag{8}$$

$$\lambda_t \phi_t \theta u_t^{\theta-1} \left[A_{t-1}^0 - A_{t-1}\right] = \omega_t, \tag{9}$$

plus the standard transversality conditions. ω and λ are the multipliers associated with the labor market clearing condition and with the law of accumulation of knowledge respectively. ω_t can be interpreted as the shadow wage at t, and λ_t as the shadow price of knowledge at this date. Equation (6) is the standard Euler equation obtained from Ramsey growth models. Equation (7) provides the optimal rule for knowledge accumulation. The marginal productivity of knowledge (evaluated in terms of the marginal utility at $t+1$ because of our choice of timing) should be equal to its shadow price at t, minus the potential gain in the value of knowledge from t to $t+1$. Equations (8)-(9) are the optimality conditions with respect to the labor variables. Since labor is homogenous, the marginal productivity of labor devoted either to production or to adoption should be equal to the shadow wage.
We now investigate the steady state properties of the dynamic system (1)-(9).

2.2 The balanced growth paths

We assume a logarithmic utility function. Along the balanced growth path u_t and l_t are constant, and the remaining variables grow at constant rates. Denoting by g_X the long-run growth factor of a variable X_t and x its long run level, we have the following properties:

Proposition 1 *(i) If $\gamma > 1$ is the long-run growth factor of A, the all other variables growth at strictly positive rates with*

$$g_A = \gamma$$

$$g_C = g_K = g_I = g_Y = g_A^{\frac{1}{1-\alpha}} = \gamma^{\frac{1}{1-\alpha}}$$

(ii) a unique stationary equilibrium exists for our economy.

(iii)the long run technological gap being $TG = \frac{\gamma-1}{\phi u^\theta}$, we have the following comparative statics properties:

$$\frac{\partial u}{\partial \phi} < 0, \quad \frac{\partial TG}{\partial \phi} < 0$$
$$\frac{\partial u}{\partial \gamma} > 0, \quad \frac{\partial TG}{\partial \gamma} > 0$$

The first part of Proposition 1 is trivially checked by writing the restrictions among the different growth rates that the system (1)-(9) impose. To compute the long run levels, the same approach has to be followed. In order, to simplify a little bit, we use equation (9) to eliminate the multiplier λ. The resulting eight restrictions are:

$$\begin{aligned}
\frac{\gamma^{\frac{1}{1-\alpha}}}{\beta} &= \alpha a k^{\alpha-1} l^{1-\alpha} + 1 - \delta \\
\frac{\beta k^\alpha l^{1-\alpha} \gamma^{\frac{-1}{1-\alpha}}}{c} &= \frac{\omega\left[\gamma - \beta(1-\phi u^\theta)\right]}{\phi\theta u^{\theta-1}(1-a)} \\
(1-\alpha) a k^\alpha l^{-\alpha} &= c\omega\gamma^{\frac{1}{1-\alpha}} \\
a(\gamma-1) &= \phi u^\theta (1-a) \\
k\gamma^{\frac{1}{1-\alpha}} &= (1-\delta)k + i\gamma^{\frac{1}{1-\alpha}} \\
y &= c + i \\
l + u &= 1 \\
y\gamma^{\frac{1}{1-\alpha}} &= a k^\alpha l^{1-\alpha}.
\end{aligned}$$

It is then quite easy to prove that the previous stationary system always exists and is unique. The proof is in the appendix. The comparative statics results are important to understand the basic mechanisms at work in our model. The same mechanisms will work in the extension considered afterwards. First note that if the productivity of the adoption activity increases, *ie.* ϕ rises, the fraction of labor devoted to adoption goes down but the technological gap goes down too. Given the expression of the long run technological gap, this means that the product $\phi\ u^\theta$ rises when ϕ goes up despite the reduction in the adoption effort. It is not hard to understand this outcome. Productivity improvements in adoption allow to increase the stock of knowledge even with a lower labor contribution to this activity. In such a case, more labor is assigned to production. If the increase in ϕ compensates the decrease in u, *ie.* if $\phi\ u^\theta$ increases, so that the stock of knowledge keeps on rising, the economy gains a double advantage: More production (and so more consumption and more welfare) and lower technological gap.

When γ increases, the technological gap is likely to rise sharply if the economy does not increase substantially its imitation effort. However if the adoption effort increment is too big, a very low fraction of labor will be left for production, and the consumption level and welfare of the economy will fall dramatically. There is a clear trade-off here. In our model, this trade-off is settled as follows: While the labor allocation to adoption will rise, it will not rise enough to offset the negative effect of the exogenous technological acceleration on the technological gap.

Let us introduce maintenance now.

3 Incorporating capital maintenance in the adoption model

We introduce maintenance of capital as a labor service. Labor can be devoted to a third activity, maintenance, and we denote by m. The clearing condition of the labor market becomes:

$$1 = l_t + u_t + m_t. \tag{10}$$

We only consider preventive maintenance in this paper. Maintenance services allow to reduce the physical depreciation of capital, as in Licandro and Puch (2000), and Boucekkine and Ruiz-Tamarit (2003).[3] In such a framework, capital evolves over time according to the following law of motion:

$$K_t = [1 - \delta(m_t)]\, K_{t-1} + I_t. \tag{11}$$

By choosing m, the firms or the central planner determine the depreciation rate $\delta(m)$. The depreciation rate should fulfill the following requirements (see for example, Boucekkine and Ruiz-Tamarit, 2003):

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

[3] In contrast, corrective maintenance, namely the repair of equipment failures, would require a much more complicated analytical treatment.

(ii) $\lim_{m \to 1} \delta(m) = \overline{\delta}$

Conditions (i) are the expected positivity, monotonicity and convexity requirements. Condition (ii) ensures that the economy can not go below a minimal value corresponding to the "natural" depreciation of capital, $\overline{\delta}$. This is the unique deviation considered in this section with respect to the benchmark model. In particular, the adoption side of the model is unchanged, *ie.* equation 3) is not altered. This means that the adoption decision is only connected to the maintenance decision through the labor resources constraint (10). In certain cases, the pace of adoption can slowdown because of the expected induced maintenance costs, as we mentioned in the introduction. This is especially the case when technological advances are embodied in capital goods. If technological progress is disembodied, the link between capital accumulation and the implementation of innovations is broken down, and one can perfectly disconnect the two decisions. In such a case, adoption and maintenance interact *via* labor resources competition. This is the approach followed in this paper. Technological progress is disembodied, the maintenance services affect the pace of capital accumulation and the adoption efforts shape the pace of technological progress within the country.

Both activities affect the production function, *via* the capital input for maintenance, and directly through total factor productivity A_t for adoption. Actually there is a third (indirect) effect on production coming from these two decisions: As u and/or m rise, there is less labor left for production. Hence, despite its simple structure, our model presents enough interaction channels to allow for a non-trivial discussion. Beside the derivation of the optimal allocation of resources across activities, a very interesting issue arises in our set-up, as mentioned in the introduction: If maintenance diverts labor from adoption and is therefore likely to deepen the technological gap, does it in counterpart rise the level of income since it tends to increase the stock of capital? The above stated three effects of maintenance and adoption on output suggest that this question may not be settled in a simple analytical fashion. We tackle it below after characterizing the central planner problem.

3.1 The central planner problem

The central planner problem is the same as the one considered in the benchmark model with two differences, the accumulation law of capital (equation

(11) instead of (2)) and the clearing condition of the labor market (equation (10) instead of (4)). The interior solution of this optimization problem is characterized by the following first order optimality conditions:

$$U'(C_t) = \beta U'(C_{t+1}) \left[\alpha A_t K_t^{\alpha-1} l_{t+1}^{1-\alpha} + 1 - \delta\left(m_{t+1}\right)\right], \qquad (12)$$

$$\beta K_t^{\alpha} l_{t+1}^{1-\alpha} U'(C_{t+1}) = \lambda_t - \beta\lambda_{t+1}\left[1 - \phi_{t+1} u_{t+1}^{\theta}\right],$$

$$(1-\alpha) A_{t-1} K_{t-1}^{\alpha} l_t^{-\alpha} U'(C_t) = \omega_t,$$

$$\lambda_t \phi_t \theta u_t^{\theta-1}\left[A_{t-1}^0 - A_{t-1}\right] = \omega_t,$$

$$K_{t-1}\left[-\delta'(m_t)\right] U'(C_t) = \omega_t, \qquad (13)$$

where ω and λ are defined as in subsection 2.1. The necessary conditions with respect to knowledge, A_t, labor, l_t, and adoption, u_t, are not altered. As one can check, the second, third and fourth equation of the system just above, corresponding to the latter conditions, are the optimality conditions (7), (8) and (9) of the central planner problem in the benchmark model. The Euler equation (12) now incorporates the impact of maintenance on capital accumulation. A change in the maintenance path over time affects the accumulation of capital and the paths of production and consumption. A new optimality condition has to be taken into account. Equation (13) characterizes indeed the optimal maintenance decision. The marginal benefit from maintaining the stock of capital (evaluated in terms of the marginal utility of consumption) should be equal to the shadow wage, which is the marginal cost of maintaining capital. We now provide a characterization of the balanced growth paths.

3.2 Balanced growth paths

The balanced growth paths are defined as in subsection 2.2. In particular, we are seeking paths where l_t, m_t and u_t are constant and comprised between 0 and 1, and where the other variables grow at a constant rate. It is not difficult to check that Proposition 1 still applies in our extension, that is $g_A = \gamma$, and $g_C = g_K = g_I = g_Y = \gamma^{\frac{1}{1-\alpha}}$. In order to come with an analytical characterization as simple as possible of the existence and uniqueness issues, we parameterize the depreciation function as follows:

$$\delta(m) = \delta - \mu m^{\eta}$$

$$
\begin{aligned}
0 &< \eta < 1 \\
\delta &> \mu > 0.
\end{aligned}
$$

The restrictions on the values of the parameters are set to fulfill the requirements (i)-(ii) to be satisfied by an admissible depreciation function. $0 < \eta < 1$ is required for depreciation function be convex, and $\delta > \mu$ means that the "natural" depreciation rate, $\overline{\delta} = \delta - \mu$ is positive. Parameter δ is the capital depreciation if the planner does not devote any labor to maintain capital and $\delta - \mu$ is the natural depreciation rate. With this specification, the model implies the following restrictions of the levels of variables along a balanced growth path:

$$
\begin{aligned}
\frac{\gamma^{\frac{1}{1-\alpha}}}{\beta} &= \alpha a k^{\alpha-1} l^{1-\alpha} + 1 - \delta + \mu m^{\eta} \\
\frac{\beta k^{\alpha} l^{1-\alpha}}{\gamma^{\frac{1}{1-\alpha}}\ c} &= \frac{\omega\left[\gamma - \beta(1-\phi u^{\theta})\right]}{\phi\theta\ u^{\theta-1}(1-a)} \\
\eta\ \mu\ m^{\eta-1} k &= c\omega\ \gamma^{\frac{1}{1-\alpha}} \\
(1-\alpha) a\ k^{\alpha} l^{-\alpha} &= c\omega\gamma^{\frac{1}{1-\alpha}} \\
a(\gamma - 1) &= \phi\ u^{\theta}(1-a) \\
\gamma^{\frac{1}{1-\alpha}}\ c &= a k^{\alpha} l^{1-\alpha} + \left[1 - \delta + \mu m^{\eta}\right] k - \gamma^{\frac{1}{1-\alpha}}\ k \\
l + m + u &= 1 \\
\gamma^{\frac{1}{1-\alpha}}\ y &= a k^{\alpha} l^{1-\alpha}
\end{aligned}
$$

The long-run system involves eight variables: l, u, m, c, y, k, a and ω. It is possible to find a set of sufficient conditions for an admissible solution to exist and to be unique, and to derive some comparative statics.

Proposition 2 *Assume that the parameters of the model check the following condition*

$$
\mu \quad < \quad (1-\eta)\left[\frac{\gamma^{\frac{1}{1-\alpha}}}{\beta} - 1 + \delta\right]
$$

Then:
(i) a unique steady solution exists with $0 < u < 1$*,* $0 < m < 1$ *and* $0 < l < 1$*,*

(ii) the following comparative statics apply:

(v) with respect to ϕ, $\frac{\partial u}{\partial \phi} < 0$, $\frac{\partial m}{\partial \phi} > 0$, $\frac{\partial l}{\partial \phi} > 0$, *and* $\frac{\partial TG}{\partial \phi} < 0$.

(vv) with respect to γ, $\frac{\partial u}{\partial \gamma} > 0$ *and* $\frac{\partial m}{\partial \gamma} < 0$. *The sign of* $\frac{\partial l}{\partial \gamma}$ *and* $\frac{\partial TG}{\partial \gamma}$ *is ambiguous.*

The proof of the proposition is extremely heavy, it is reported in the appendix. First let us comment on the assumption made in the proposition. Quite straightforwardly, this assumption imposes a lower bound for the technological progress factor, γ. This lower bound depends mainly on the maintenance parameters δ, η and μ. Since $\beta < 1$ and $\gamma > 1$, and since the parameters δ and μ are directly related to the capital depreciation rates, and thus are small real numbers, our assumption should be very easily checked except when η tends to 1. This never happens in our numerical experiments as we will see later in this subsection.

Much more importantly, the comparative statics results already give some insight into the complex interactions at work in our model. In the case of an exogenous improvement in the adoption technology, *ie.* when ϕ rises, the registered comparative statics are quite similar to those of the benchmark model. Despite the adoption effort is reduced, the technological gap goes down as the product $\phi\ u^{\theta}$ decreases. The reduction in the labor allocation for adoption permits the assignment of more labor resources to maintenance. Maintenance and adoption work in opposite directions, and this property seems to be one of the most salient outcomes of the model in several situations. Indeed, the same property arises in the case where a technological acceleration occurs, *ie.* γ rises. The labor allocation to adoption increases while labor on maintenance goes down. The fact that adoption and maintenance move in opposite directions in both cases reflects mainly the arbitrage between "productive" and "non-productive" labor, namely between l and the sum $u + m$. Suppose that both adoption and maintenance increase in response to a technological acceleration. Then labor allocation to production and so to consumption is likely to decrease sharply. When only adoption or maintenance labor shifts upward, this guarantees that in the worse case labor allocation to production will only decrease slightly. Actually, the reaction of variable l when γ changes is analytically ambiguous while it increases clearly when ϕ goes up. There is an easy explanation to this contrast. When ϕ varies, it has a unique **direct** effect, namely on the imitation technology. It results in a change in labor on adoption, and it only affects the maintenance labor *via* the labor resources constraint. In contrast, when γ moves, it does not only affect **directly** the adoption technology, it also enters explicitly the optimal capital accumulation decision,[4] which depends on m. Hence, when γ moves, there are definitely more economic interactions and mechanisms at work in comparison with the shock on ϕ. As a consequence, while the latter case permits a complete analytical characterization, the former does not.

The ambiguity in labor on production when γ shifts upward is responsible for another ambiguity to arise: The technological gap can *a priori* increase or decrease under a technological acceleration, while it clearly goes up in the benchmark model. Recall that $TG = \frac{\gamma-1}{\phi u^{\theta}}$ as in the benchmark model. In the latter model, a technological acceleration stimulates a bigger labor allocation to adoption. However, this rise in labor on adoption is not sufficient to keep as close to the technological frontier as before the acceleration. When maintenance is included, labor on adoption is additionally favored by the decrease in maintenance, unless the labor resources freed by this reduction in maintenance are ultimately assigned to production. Since the effect of a technological acceleration on l is ambiguous, so is its effect on the magnitude of adoption rise. This explains in turn the ambiguity of the technological gap response.

3.3 Numerical experiments

Since some comparative statics are analytically ambiguous, we resort to numerical experiments. In order to compare the outcomes of the benchmark model with those of the model with maintenance, we proceed as follows:

(i) First, parameter values in the benchmark model will be selected so that the equilibrium values approximately mimics observed features of the US economy.[5]

(ii) Second, we introduce maintenance and carry out a sensitivity analysis for the maintenance parameters μ and η.

[4] Which is given by the first equation of the steady state system of equations listed at the beginning of this subsection.

[5] This should be considered as a benchmark calibration. Calibration on developing countries data was found simply unreliable especially because of the depreciation-maintenance part of the model. In any case, the main results of the paper are corroborated with the necessary sensitivity exercises.

The results of the calibration procedure are given in Table 1. We assign values of 0.96 to the discount factor (β), 1/3 to the capital share (α) and 0.08 to the depreciation rate (δ). These values are typical in neoclassical growth theory model research. We set the adoption parameters ϕ and θ in order to obtain a capital-GDP ratio close to 2.5, and a share of investment on GDP around 0.2. Finally we set γ such that the growth rate of output be about 0.02.
The calibration of the maintenance technology parameters are more problematic. Given that the literature does not provide much guidance, we fix η in order to obtain a maintenance costs not far from the unique data we know, the 6% figure of the Canadian survey, for a wide range of values of μ. We carry out a sensitivity analysis and present results for $\eta = 0.25$ and $\overline{\delta} = \delta - \mu$ equal to 0.02 and 0.002. [6]

The implications of these parameterizations on the steady equilibria are summarized in Table 2. Three main observations can be made:

(i) When maintenance is incorporated, the labor allocations to adoption and production mechanically decrease. In all our numerical experiments, production labor seems to decrease more than adoption labor (-2.16% and -1.5% respectively when the benchmark model is compared to the extended model 1). In contrast, (detrended) capital rises sharply (around 27% when the benchmark model is compared to the extended model 1).

(ii) One trade-off is already clear: As adoption labor goes down, the incorporation of maintenance labor increases the technological gap (1.1% and 1.74% when the benchmark model is compared to the extended models 1 and 2 respectively). That is to say the magnitude of the technological gap increment is definitely lower than the magnitude of the drop in adoption labor. This property derives immediately from the assumption that the imitation technology has decreasing returns with respect to labor.

(iii) Another trade-off has to be studied: the effect of maintenance on output level. Note that final output in each model will not correspond to GDP in the national accounts. This is because from the standpoint of theory resources devoted to technology adoption and to maintenance are investments. GDP will correspond to y in the model. Total output will be $y + wu$ in the

[6] with this parametrization maintenance costs are between 2% and 3% of GDP. Adoption costs represent around 9% of GDP in the benchmark case and are close to 8% when maintenance is introduced.

benchmark model and $y + wu + wm$ in the extended models.
If maintenance is incorporated, production labor decreases but capital goes up. Moreover, adoption labor decreases, which lowers the level of technological progress in the production sector. Overall, the impact on (detrended) income is ambiguous. However the increment in the capital stock is so big that it more than compensates the negative effects of decreasing production and adoption labor allocations. Indeed, detrended income rises by 7.58% (Resp. 11.61%) when the benchmark model is compared to the extended model 1 (Resp. model 2).

The finding (iii) is highly interesting if one has in mind non leading economies and developing economies. In such a context increasing income and fighting poverty is certainly an important objective, much more important that reducing the technological gap for example. Said in other words, reducing the income gap is nowadays much more crucial than technological catching up for such countries. Our simple model suggests that an optimally designed maintenance policy will raise income without worsening so much the technological gap. Does the presence of maintenance also improve the responsiveness of the economy to policy shocks? Will a trade or education reform work better when maintenance is taken into account? We will study this issue in the next sub-section.

Before, let us numerically study the comparative statics with respect to γ, which are, as we mentioned above, analytically intractable. We increase γ by 1% and compute the induced increments in m, u, l and TG relative to the increment in γ. Table 3 summarizes the results. As expected, this technological acceleration is associated with an increase in the adoption or imitation effort and with a decreasing labor allocation to production and maintenance labor. It should be noted that the change in production labor is very small (around -0.054% and -0.048% in the extended model 1 and 2 respectively) while the increment in adoption labor is more substantial (around 0.58% in both extended models). The magnitude of the resulting drop in maintenance labor is consequently close to the adoption labor increment. that is a technological acceleration induces a kind of *swap* of maintenance activity for more adoption. Nonetheless, and exactly as in the benchmark model, this higher adoption effort is not sufficient to reduce the long run term technological gap. In our models, reducing the long run term technological gap through a strong enough adoption effort is always incompatible with welfare maximization.

3.4 Policy shocks, maintenance and long term income

In our models, trade or education policy shocks may be studied *via* the exogenous variable ϕ, which plays the role of a productivity factor in the imitation technology. For example, a trade reform facilitating technology transfers may be captured through a positive shock to variable ϕ. We may model exogenous improvements in human capital exactly in the same way. Table 4 summarizes the response of the economy to a 1% shock on ϕ. By Proposition 2, we know that such a shock induces a drop in the adoption effort and an increase in both production and maintenance labor. Moreover, we know from the same proposition that the technological gap should decrease. However we don't know the magnitude of the response of each labor allocation, which in turn disables us to conclude anything about the output response.

Table 4 is quite informative regarding these issues. While adoption labor decreases by about 0.38%, production and maintenance allocations only increase by 0.04% and 0.056% respectively in the case of the extended model 1 (less in the case of the extended model 2). This is enough to push long term output upwards. Moreover, it should be noted that the output response to the policy shock is higher when maintenance is an alternative choice to adoption and production. Without maintenance, long term output raises by 0.151%. In the extended model 1, output is raises by 0.156%. The difference between the two figures is not big, but it is not negligible.

It is likely that maintenance matters much more in the income response to technology or policy shocks when the latter are more directly related to the capital sector. An elementary way to get rid this point is to study the response of the economy to a change in the production function of capital goods. Assume for example that the parameter δ decreases permanently by 1%. Table 5 gives the results of the experiment. Without maintenance, long term output is raised by 0.28%. In the extended model 1 (Resp. model 2), output is raised by 0.33% (Resp. 0.36%). In such a case, the improvement in the capital sector technology induces a sharp increases in maintenance (0.93% and 1.04%, in the extended model 1 and 2 respectively). In contrast labor allocation to adoption and production, and the resulting technological gap, are only slightly altered.

4 Conclusion

In this paper, we have provided a simple theory of capital maintenance and technology adoption using optimal growth models *à la* Nelson and Phelps where the labor resources of an economy can be allocated freely either to production, adoption or maintenance. There are very few papers dealing with maintenance, and *a fortiori* with the role of capital maintenance in technological choices. In this paper, we analyze a situation where adoption and maintenance "compete" for labor resources. This is only one of the channels through which the two activities interact, as we explain in the introduction. Though this is certainly the easiest way to relate adoption to maintenance, the considered model proves very rich in terms of induced economic mechanisms and interactions, and sheds light on some important properties of maintenance.

Beside mathematically characterizing the optimal allocation of labor across the three activities, we prove for example that equilibrium maintenance and adoption operate in opposite directions when technological or policy shocks occur. Maintenance is a kind of substitute to adoption in such cases. Much more importantly, we find that though capital maintenance deepens the technological gap by diverting labor resources from adoption, it generally increases the long run output level at equilibrium. As we claim in the last section, this is a very interesting result for the proponents of a development theory primarily concerned with raising the income per capital in non leading countries, and not with technological catching up. Moreover reducing the long term technological gap trough a strong enough adoption effort is, in our models, incompatible with welfare maximization. However, we find that the long term output response to policy shocks is only slightly higher in the presence of maintenance.

Obviously, much work remains to do for a much comprehensive appraisal of the role of maintenance as a determinant of technological choices. Beside endogenizing growth, which is not a very hard task, more fundamental refinements have to be undertaken. For example, one may think that maintenance plays a more crucial role if technological advances are embodied in capital goods, and this may reinforce the conclusions of this paper. On the other hand, one may find questionable our assumption according to which adoption and maintenance use the same input (labor), it would be then useful to examine the properties of alternative models where adoption and maintenance do not use exactly the same combination of inputs. All these issues are in our research agenda.

5 References

Blomstrom, M. and A. Kokko (1998), "Multinational Corporations and Spillovers", *Journal of Economic Survey* 12, 247-277.

Boucekkine, R., B. Martinez and C. Saglam(2006), "Capital maintenance Vs technology adoption under embodied technical progress", *Contributions to Macroeconomics*, Volume 6(1), article 7 (The Berkeley Electronic Journals in Macroeconomics).

Boucekkine, R. and R. Ruiz-Tamarit (2003), "Capital Maintenance and Investment: Complements or Substitutes?", *Journal of Economics* 78 , 1-28.

Caballero, R. and A. Jaffee (1993), "How High are the Giant's Shoulders? An Empirical Assessment of Knowledge Spillovers and Creative Destruction in a Model of Economic Growth", *NBER Macroeconomics Annual*, 15-74.

Collard, F. and T. Kollintzas (2000), "Maintenance, Utilization and Depreciation along the Business Cycle", CEPR Discussion Paper 2477.

David, P. (1990), "The Dynamo and the Computer: AN Historical Perspective on the Modern Productivity Paradox", *American Economic Review* 80, 355-361.

Feldstein, M. and M. Rothschild (1974), "Towards an Economic Theory of Replacement Investment", *Econometrica* 50, 393-423.

Grether, JM. (1999), " Determinants of Technological Diffusion in Mexican Manufacturing: A Plant-Level Analysis", *World Development* 27, 1287-1298.

Licandro, O. and L. Puch (2000), "Capital utilization, Maintenance Costs and the Business Cycle", *Annales d'Economie et Statistique* 58,143-164.

McGrattan, E. and J. Schmitz (1999), "Maintenance and Repair: Too Big to Ignore", *Federal Reserve Bank of Minneapolis Quarterly Review* 23, 2-13.

Nelson, R. and E. Phelps (1966), "Investment in Humans, Technology Diffusion and Economic Growth", *American Economic Review* 56, 69-75.

Nickell, S. (1975), "A Closer Look at Replacement Investment", *Journal of Economic Theory* 10, 54-88.

Niosi, J., P. Hanel and P. Fiset (1995), "Technology Transfer to Developing Countries Through Engineering Firms: the Canadian Experience", *World Development* 23, 1815-1824.

Solow, R. (1956), " A Contribution to the Theory of Economic Growth", *Quarterly Journal of Economics* 70, 65-94.

Tiffen, M, and M. Mortimore (1994), "Malthus Controverted: The Role of Capital and Technology in Growth and Environment Recovery in Kenya", *World Development* 22, 997-1010.

6 Appendix

1. **Proof of Proposition 1**: The proof is simple. Indeed, by the means of successive substitutions, one can reduce the system of eight equilibrium restrictions above to a single implicit equation involving only u:

$$H(u) = \beta\theta(\gamma - 1)(1 - u) - (1 - \alpha)u \left[\gamma - \beta(1 - \phi u^{\theta})\right] = 0$$

It could be easily checked that $H(u)$ is a decreasing and concave function which tends to $\beta\theta(\gamma - 1)$ when u tends to zero, and to $-(1 - \alpha)\left[\gamma - \beta(1 - \phi)\right]$ when u tends to one. Since $\gamma > 1$, $\beta < 1$ and $\phi > 0$, we have $[\gamma - \beta(1 - \phi)] > 0$. Thus there exists an unique $u^* \in (0, 1)$ which satisfies $H(u) = 0$. This establishes property (i). The comparative statics are derived explicitly. Denote by $R = \beta(\gamma - 1)\theta + (1 - \alpha)[\gamma - \beta(1 + \phi u^{\theta}(1 - \theta))] > 0$. We have:

$$\frac{\partial u}{\partial \phi} = \frac{-(1 - \alpha)\beta u^{\theta+1}}{R} < 0$$

$$\frac{\partial TG}{\partial \phi} = \frac{-(\gamma - 1)[\beta\theta(\gamma - 1) + (1 - \alpha)(\gamma - \beta(1 - \phi u^{\theta}))]}{\phi^2 u^{\theta} R} > 0$$

$$\frac{\partial u}{\partial \gamma} = \frac{(1 - \alpha)u[1 - \beta(1 - \phi u^{\theta})]}{(\gamma - 1)R} > 0$$

$$\frac{\partial TG}{\partial \gamma} = \frac{1}{\phi u^{\theta}} \left[1 - \frac{(1 - \alpha)\theta[1 - \beta(1 - \phi u^{\theta})]}{R}\right] > 0$$

Since $(1 - \alpha)\theta[1 - \beta(1 - \phi u^{\theta})] < R$, $\frac{\partial TG}{\partial \gamma} < 0$. $\square$

2. **Proof of Proposition 2**: We can reduce the steady state equilibrium conditions to two equations in (m, u).

$$m = g(u) = 1 - u - \frac{(1 - \alpha)u[\gamma - \beta(1 - \phi u^{\theta})]}{\beta\theta(\gamma - 1)} \quad (14)$$

$$F(m, u) = 1 - \delta + \mu m^{\eta} + \frac{\alpha}{1 - \alpha}\mu\eta m^{\eta-1}(1 - m - u) - \frac{\gamma^{\frac{1}{1-\alpha}}}{\beta} = 0 \quad (15)$$

The negative slope of function g in (14) is obvious. Concerning (15), one can apply the implicit function theorem. $F(m, u)$ defines m as a differentiable function of u, $(m = f(u))$ and $f'(u) = -\frac{F_u}{F_m}$. Since F_u and F_m are negative ($F_m < 0$ is assured by the restriction on the parameters imposed in proposition 2), the slope of the implicit function f is also negative. We now check that g is above f when u tends to zero, and g is below f when u tends to one. Let us prove that $g(0) > f(0)$. Note that $g(0) = 1$. On the other hand,

$$F(m, 0) = \left[\mu m^{\eta}\left(1 - \frac{\alpha\eta}{1-\eta}\right) + \frac{\alpha\eta\mu m^{\eta-1}}{1-\alpha}\right] - \frac{\gamma^{\frac{1}{1-\alpha}}}{\beta} - 1 + \delta = 0.$$

The first term of the previous equation defines a decreasing function of m which tends to infinity as m tends to zero and is equal to μ for $m = 1$. Since $\eta < \frac{\gamma^{\frac{1}{1-\alpha}}}{\beta} - 1 + \delta$, it follows that $0 < f(0) < 1$, so $g(0) > f(0)$.
Now observe that $g(1) < 0$ and $f(1) > 0$ since $F(m, 1) = 1 - \delta + \mu m^{\eta}\left(1 - \frac{\alpha\eta}{1-\alpha}\right) - \frac{\gamma^{\frac{1}{1-\alpha}}}{\beta} = 0$ and as by assumption $\mu < (1-\eta)\left[\frac{\gamma^{\frac{1}{1-\alpha}}}{\beta} - 1 + \delta\right]$. So $g(1) < f(1)$. Therefore, the system (14)-(15) defines two (m, u)-curves which intersect only once when both m and u vary in the interval $(0, 1)$. Which establishes property (i).

As for the comparative statics, we consider the following system of equations:

$$\begin{aligned}
(F) \qquad 1 - \delta + \mu m^{\eta} + \frac{\alpha\eta\mu m^{\eta-1}(1-u-m)}{1-\alpha} - \frac{\gamma^{\frac{1}{1-\alpha}}}{\beta} &= 0, \\
(G) \quad \beta(1-u-m)\theta(\gamma-1) - (1-\alpha)u\left[\gamma - \beta(1-\phi u^{\theta})\right] &= 0, \\
(H) \qquad TG - \frac{\gamma-1}{\phi u^{\theta}} &= 0.
\end{aligned}$$

The Jacobian matrix of this system can be expressed by:

$$J = \begin{bmatrix} F_u & F_m & 0 \\ G_u & G_m & 0 \\ H_u & 0 & 1 \end{bmatrix}$$

where the first, second and third columns of J refer to the partial derivatives of the left hand sides of the equations of the system with respect to u, m, and TG. It is easy to check that F_u, F_m, G_u, G_m and H_u are all strictly negative. The Jacobian determinant $(F_uG_m - F_mG_u)$ is thus strictly negative:

$$\det J = F_uG_m - F_mG_u$$

$$= \frac{\beta\theta(\gamma-1)}{m}\left[\mu m^{\eta} - (1-\eta)\left(\frac{\gamma^{\frac{1}{1-\alpha}}}{\beta} - 1 + \delta\right)\right]$$
$$+\left[\gamma - \beta(1-\phi u^{\theta}) + \beta\phi\theta u^{\theta}\right](1-\alpha)F_m < 0. \quad (16)$$

By Cramer's rule we obtain

$$\frac{\partial m}{\partial \phi} = \frac{1}{|\det J|}\left[G_{\phi}F_u\right]$$

as $G_{\phi} = -(1-\alpha)\beta\phi u^{\theta+1} < 0$, $\frac{\partial m}{\partial \phi} > 0$

$$\frac{\partial u}{\partial \phi} = \frac{1}{|\det J|}\left[-G_{\phi}F_m\right] < 0 \quad (17)$$

$$\frac{\partial TG}{\partial \phi} = \frac{H_{\phi}\left(F_u G_m - F_m G_u\right) + H_u F_m G_{\phi}}{|\det J|}$$

where $H_u = \frac{\gamma-1}{\phi^2 u^{\theta}} > 0$ and $H_{\phi} = \frac{(\gamma-1)\theta}{\phi u^{\theta+1}}$. Taking into account (16) and (17), we can express $\frac{\partial TG}{\partial \phi}$ as:

$$\begin{aligned}\frac{\partial TG}{\partial \phi} &= -\frac{(\gamma-1)}{\phi^2 u^{\theta}}\left[1 + \frac{\theta\phi}{u}\frac{\partial u}{\partial \phi}\right]\\ \left|\frac{\theta\phi}{u}\frac{\partial u}{\partial \phi}\right| &= \frac{\theta\phi}{u}\frac{|G_{\phi}F_m|}{|\det J|}\end{aligned}$$

Developing the previous expression, we can easily check that $\frac{\partial TG}{\partial \phi} < 0$ since $\left|\frac{\theta\phi}{u}\frac{\partial u}{\partial \phi}\right| < 1$. Indeed :

$$\begin{aligned}\left|\frac{\theta\phi}{u}\frac{\partial u}{\partial \phi}\right| &= \frac{\theta\phi}{u}\left|G_{\phi}F_m\right| = |F_m|(1-\alpha)\beta\phi\theta u^{\theta} < |\det J| = \\ &\quad \frac{\beta\theta(\gamma-1)}{m}\left[\mu m^{\eta} - (1-\eta)\left(\gamma^{\frac{1}{1-\alpha}}\beta - 1 + \delta\right)\right] + \\ &\quad \left[\gamma - \beta(1-\phi u^{\theta}) + \beta\phi\theta u^{\theta}\right](1-\alpha)F_m.\end{aligned}$$

As for the comparative statics with respect to γ, we use again Cramer's rule to obtain:

$$\frac{\partial m}{\partial \gamma} = \frac{1}{|\det J|}\left[G_{\gamma}F_u - G_u F_{\gamma}\right] < 0$$

where $G_\gamma = \frac{(1-\alpha)u[1-\beta(1-\phi u^\theta)]}{(\gamma-1)} > 0$, and $F_\gamma = -\frac{\gamma^{\frac{\alpha}{1-\alpha}}}{(1-\alpha)\beta} < 0$

$$\frac{\partial u}{\partial \gamma} = \frac{1}{|\det J|}\left[G_m F_\gamma - G_\gamma F_m\right] > 0$$

$$\frac{\partial TG}{\partial \gamma} = \frac{1}{\phi u^\theta}\left[1 - \frac{(\gamma-1)\theta}{u}\frac{\partial u}{\partial \gamma}\right].$$

The sign of $\left[1 - \frac{(\gamma-1)\theta}{u}\frac{\partial u}{\partial \gamma}\right]$ being ambiguous, so is the sign of $\frac{\partial TG}{\partial \gamma}$.

Let us finally study the comparative statics concerning l, the labor input in production. First, it should be noted that $\frac{\partial l}{\partial \phi}$ depends on the size of $\frac{\partial m}{\partial \phi}$ and $\frac{\partial u}{\partial \phi}$:

$$\frac{\partial l}{\partial \phi} = -\frac{\partial m}{\partial \phi} - \frac{\partial u}{\partial \phi} = \frac{-G_\phi\left(F_u - F_m\right)}{|\det J|}.$$

Developing a bit more the numerator of the previous expression, it is easy to check that the negative effect of ϕ on adoption labor is not compensated by the increment in m. In order to satisfy the labor restriction ($1 = l + m + u$), l should therefore increase.

$$\frac{(1-\alpha)\beta\phi u^{\theta+1}\left[\frac{(1-\eta)}{m}\left(\frac{\gamma^{\frac{1}{1-\alpha}}}{\beta} - 1 + \delta\right) - \mu m^{\eta-1}\right]}{|\det J|} > 0.$$

As for the effect of a change in the parameter γ on l, which is equal to:

$$\frac{\partial l}{\partial \gamma} = -\frac{\partial m}{\partial \gamma} - \frac{\partial u}{\partial \gamma},$$

it is ambiguous. A quick look at the expressions of $\frac{\partial m}{\partial \gamma}$ and $\frac{\partial u}{\partial \gamma}$ is sufficient to understand this result. The sign of the difference of the two latter expression depends on the values of the parameters of the maintenance function with respect to the those of the adoption technology, and there is no *a priori* relationship between the two sets of parameters. The numerical results reported in the main text make clear that the sign of $\frac{\partial l}{\partial \gamma}$ does effectively depend on the parameterization. □

Table 1: Parameterization

β	δ	α	ϕ	θ	γ	η	μ
0.96	0.08	1/3	0.4	0.7	1.01336	0.25	0.06, 0.078

Table 2: Steady state properties

	Benchmark model	**Ext. model 1** $\mu = 0.06$	**Ext. model 2** $\mu = 0.078$
m		0.0211	0.0332
u	0.0954	0.094	0.0931
l	0.904	0.884	0.873
TG	0.172	0.175	0.176
k	2.54	3.22	3.64
Income	1.158	1.245	1.3
$\frac{k}{gdp}$	2.39	2.8	3.1
$\frac{i}{gdp}$	0.23	0.21	0.2

Table 3. The long term effects of a 1% increase in γ

	Ext. model 1 $\mu = 0.06$	**Ext. model 2** $\mu = 0.078$
$\frac{\triangle u}{\triangle \gamma}$	0.579	0.583
$\frac{\triangle m}{\triangle \gamma}$	-0.32	0.35
$\frac{\triangle l}{\triangle \gamma}$	-0.0539	-0.0488
$\frac{\triangle TG}{\triangle \gamma}$	0.565	0.563

Table 4. The long term effects of a 1% increase in ϕ

	Benchmark model	**Ext. model 1** $\mu = 0.06$	**Ext. model 2** $\mu = 0.078$
$\frac{\triangle m}{\triangle \gamma}$		0.056	0.057
$\frac{\triangle l}{\triangle \gamma}$	0.04	0.03916	0.0385
$\frac{\triangle u}{\triangle \gamma}$	-0.3822	-0.03817	-0.3814
$\frac{\triangle TG}{\triangle \gamma}$	-0.7242	-0.7249	-0.7247
$\frac{\triangle Income}{\triangle \gamma}$	0.151	0.154	0.156

Table 5. The long term effects of a 1% increase in δ

	Benchmark model	**Ext. model 1** $\mu = 0.06$	**Ext. model 2** $\mu = 0.078$
$\frac{\triangle m}{\triangle \gamma}$		0.93	1.04
$\frac{\triangle l}{\triangle \gamma}$	0	-0.02	-0.037
$\frac{\triangle u}{\triangle \gamma}$	0	-0.0146	-0.0262
$\frac{\triangle TG}{\triangle \gamma}$	0	0.01	0.018
$\frac{\triangle Income}{\triangle \gamma}$	0.28	0.334	0.366

Département des Sciences Économiques
de l'Université catholique de Louvain
Institut de Recherches Économiques et Sociales

Place Montesquieu, 3
1348 Louvain-la-Neuve, Belgique

ISSN 1379-244X D/2007/3082/044