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Bridging the technology gap with limited human capital resources☆

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ABSTRACT

We study whether restrictions concerning the mode of implantation of multinational firms (MNCs) are desirable for a developing country in terms of its technology acquisition strategy. More precisely, we aim at determining under which conditions domestic equity ownership constraints imposed on MNCs turn out to be beneficial for a country aiming at narrowing its technology gap with the world frontier while facing a limited supply of skilled labor resources. We base ourselves on an extension of the "variety model" of technology-driven growth, and are able to demonstrate that the desirable regulation depends non-monotonically on the overall available amount of skilled human capital. We further find that a positive shock on the pace of technological progress at the world frontier increases the scope of conditions under which ownership constraints become desirable.

1. Introduction

In industrialized countries, technological change results from innovative research activities conducted at the technology frontier. In developing countries however, firms are often faced with a limited amount of skilled labor resources, constraining them to imitation rather than innovation. For those countries, one of the main identified opportunities for acquisition and diffusion of advanced technologies is the exposure to the state-of-the-art techniques introduced by multinational corporations (MNCs), who are expected to bring along and rely on their proprietary technology in order to compete efficiently with local firms (Glass and Saggi, 1999). In order to optimize the impact of foreign direct investment (FDI), developing countries have often required investors to meet certain specified goals with respect to their operations in the host country (UNCTAD, 2002): if some of those instruments have been progressively prohibited during the last decade in compliance with international commitments,[1] one of the measures still in use in various developing countries consists of imposing "domestic equity ownership constraints", i.e. requiring the establishment of a joint venture (JV) with domestic participation.

The rationale behind such a requirement is the belief that local participation will facilitate the diffusion of the MNC proprietary technology to the domestic partner.[2] However, in the presence of such a technology dissipation threat, investors are likely to transfer an older vintage of their technology to the local production facility (Moran, 2002; Saggi and Javorcik, 2004; Takii, 2004). Developing countries are thus facing a trade-off between a higher level of technology being transferred in the case of wholly foreign-owned plants, and facilitated local learning and diffusion of whatever knowledge is transferred in the case of jointly-owned investment projects.

Contrasted empirical results hint at the existence of conflicting effects. While some studies found no difference in the extent of technology transfers stemming from majority- and minority-owned foreign presence (Blomstrom and Sjöholm, 1999), others found higher productivity spillovers to local producers in the case of JVs (Javorcik and Sparateanu, 2008; Takii, 2005). However, the latter studies finding JVs to trigger higher spillovers fail to disentangle two possible effects. The first one is the already previously evoked "knowledge dissipation" effect, i.e. a better access to whatever knowledge is transferred through the actions of the local shareholder. The second effect is linked to the "contiguous knowledge" phenomenon, i.e. the idea that knowledge can only be disseminated at a certain distance (Papageorgiu, 2002). In the case of a developing country, the less sophisticated technologies being transferred to JVs might thus be easier to absorb for the domestic

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[1] Some performance requirements, such as local content requirements, have been explicitly prohibited by the WTO Agreement on Trade-Related Investment Measures (TRIMs), being inconsistent with Articles III and XI of GATT (1994) (UNCTAD, 2001).

[2] The latter may use the knowledge acquired through the partnership with the foreign investor for its own local activities, or hire local personnel the MNC would otherwise not have trusted with key positions, leading to knowledge dissipation through employee turnover (Djankov and Hoekman, 1997).

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partner (Javorcik and Sparateanu, 2008). While we deem the "contiguous knowledge" effect to be relevant for developing countries far from the frontier, it might not be the case for developing countries already further up on the development path, that might consider the lower technology level being transferred as a drawback. Hence, the debate on the desirability of ownership constraints would benefit from a clear identification of the different effects at work: does the desirability of JVs stem from the "knowledge dissipation" effect, or from the "contiguous knowledge" one?

The aim of this paper is thus to investigate different technology adoption strategies for a developing country faced with a limited amount of skilled labor resources, and more in particular to determine whether imposing restrictions on the mode of implantation of MNCs can be beneficial even when considering the lower vintage transferred to JVs as being a *drawback*. In other words, can we find ownership constraints to be desirable, when their only advantage is the "knowledge dissipation" effect?

We develop a variant of the Romer (1990) "variety model", where growth is sustained through an expansion of the number of available products. In our developing country framework, the technology sector does not conduct any innovative R&D activity, but rather strictly resorts to the imitation of innovations coming from abroad through FDI. We furthermore impose a limited technological absorption, i.e. we assume it is never possible to fully bridge the technology gap with respect to the frontier (Nelson and Phelps, 1966). Along Benhabib and Spiegel (1994), we then allow for the fixed level of human capital in the economy[3] as well as for the technology level at the frontier to have an impact on the speed and efficiency of the catching-up process.

In this simple framework, developing countries then face two alternatives regarding their technology upgrading strategy: the "full liberalization" option leaves MNCs free of choosing their mode of implantation in the country, while the "ownership constraint" strategy imposes implantation restrictions to entering firms, most often in the form of a joint venture with a local partner. In the "ownership constraint" case, our conjecture is that local participation will then ensure an easier dissipation of the MNC's proprietary knowledge: we hence assume lower adoption costs in terms of human capital, an important feature in the case of a developing country faced with scarce skilled resources. However, the "frontier" technology level to which local firms have access is then assumed to be strictly lower than the world frontier, exemplifying the fact that when facing JV requirements, MNCs may transfer older vintages to avoid losing their intangible assets. On the other hand, in the "full liberalization" case, local firms will have access to more advanced technologies, but the imitation process will be more intensive in human capital.

We then determine to which extent the two available strategies contribute to narrowing the technology gap, and specify under which circumstances one dominates the other in terms of technology upgrading for the host country. We find that the relevance of imposing ownership constraints depends on the relative strength of the two opposite forces at work in this case, which are a higher human capital efficiency in the technology adoption process, opposed to a lower level of technology being transferred. We show that in most cases,[4] full liberalization proves itself optimal when the overall available human capital in the economy is either very low or relatively high, while ownership constraints are desirable for intermediate overall human capital levels.

Hence, we demonstrate that the desirable technology upgrading strategy of a developing country facing human capital resource constraints depends non-monotonically on the overall available amount of the limiting factor, and show that even if the lower technology level in the case of domestic equity participation is considered a drawback, ownership constraints can be relevant provided we keep the assumption of a better knowledge diffusion. We then finally demonstrate that in the case of a technological acceleration abroad, an increase in the pace of technological progress broadens the scope of conditions under which domestic equity ownership constraints are found to be desirable.

The question of the optimal mode of entry of MNCs has already been extensively treated, whether it be in terms of the strategy of the entering firm (Eicher and Kang, 2005; Huizinga, 1995; Saggi and Javorcik, 2004; Van Assche and Schwartz, 2013), in terms of policy recommendations for developing countries (Hoekman et al., 2005; Muller and Schnitzer, 2006), or both (Javorcik and Wei, 2009; Sawada, 2010). However, these papers mostly tackle the question in a static, microeconomic framework comparing the costs and benefits associated to each mode of entry. Our model, though similarly aiming at providing strategy recommendations, bears a closer relationship to the dynamic growth theory literature studying the existing link between FDI and economic growth (Berthelemy and Demurger, 2000; Borensztein et al., 1998).[5] To the best of our knowledge, our model is the first one to allow for different technology levels being transferred *depending* on the constraints imposed to MNCs, i.e. that takes into account some possible strategic behavior of the MNC in a macroeconomic dynamic framework. We further believe that our assumption of a limited technology absorption is not only relevant in a developing country case, but also enables us to analyze the reduction of the technology gap in a straightforward way, while this problem is usually only indirectly tackled through variations in production capacity (Glass and Saggi, 1999).

The rest of the paper is organized as follows. Section 2 presents the model, Section 3 is devoted to deriving the equilibrium conditions and the corresponding balanced growth path, and Section 4 displays our main results through some relevant comparative statics and dynamics. Section 5 concludes.

2. The model

Our model builds upon the horizontal differentiation growth framework introduced by Romer (1990), where technological progress stems from an expansion of the number of product varieties, and the conception of the related designs involves a share of the total human capital. We consider an economy consisting of three sectors: a final good sector, an intermediary good sector and an imitation sector. The final good sector produces a good that serves as numeraire and is either consumed or used in the production of intermediate goods. The sector is perfectly competitive, and the production technology uses a part of the total amount of available human capital, along with a variety of intermediate goods. The intermediate goods sector consists of monopolistic producers of differentiated products, using the final good as an input. Last, the imitation sector supplies the intermediate goods producers with designs, with the imitation of a Northern blueprint requiring a specific amount of human capital.

2.1. Final and intermediate good sectors

The production technology of the final good sector is of the form:

$$Y_t = (H_{Yt})^{1-\alpha} \sum_{j=1}^{A_t} X_{jt}^{\alpha} \tag{1}$$

[3] Indeed, the aim of our model is not to provide any endogenous growth mechanism, but rather to model the efficiency of a developing country in catching up and bridging the technology gap; hence, we do not allow for the accumulation of human capital à la (Lucas, 1988), but rather focus on the growth impact of the *level* of available human capital (Benhabib and Spiegel, 1994; Boucekkine et al., 2006).

[4] More specifically, the technology level transferred by MNCs when facing ownership constraints has to be over a certain level that we fully characterize.

[5] Berthelemy and Demurger (2000) in particular use the Romer (1990) framework to develop an endogenous growth model, where FDI interacts with the long-run growth rate through a dual technology sector.

where Y_t is the output, H_{Yt} is the amount of human capital employed in final good production, X_{jt} is the amount of the intermediate good j used in the production of the final good, and A_t is the technology, defined as the number of varieties of intermediate good being available. Perfect competition guarantees that production factors are paid at their marginal productivity:

$$X_{jt} = H_{Yt}\left(\frac{\alpha}{P_{jt}}\right)^{\frac{1}{1-\alpha}} \tag{2}$$

$$w_{Yt} = (1-\alpha)(H_{Yt})^{-\alpha}\sum_{j=1}^{A_t} X_{tj}^{\alpha} \tag{3}$$

where w_{Yt} is the final sector wage rate, and P_{jt} is the price of intermediate good j. Eq. (2) represents the demand curve for intermediate goods.

The intermediate goods sector is composed of monopolistic firms using the designs produced by the imitation sector. One unit of an intermediate variety costs one unit of final good to produce. Using Eq. (2), P_{jt} can be computed as a markup over marginal costs:

$$P_{j,t} = P_t = \frac{1}{\alpha}. \tag{4}$$

Substituting for this result into Eq. (2), the demand function for any intermediate variety can be reformulated as $X_t = \alpha^{\frac{2}{1-\alpha}} H_{Yt}$. Plugging this result into Eq. (1), we get the following expression for the final good output:

$$Y_t = A_t H_{Y,t} \alpha^{\frac{2\alpha}{1-\alpha}}. \tag{5}$$

Finally, sales of a given intermediate variety yield positive net returns, denoted by V_t:

$$V_t = \sum_{s=t}^{\infty} R_t^s (P_s - 1) X_s = \sum_{s=t}^{\infty} R_t^s (1-\alpha)\alpha^{\frac{1+\alpha}{1-\alpha}} H_{Y,s} \tag{6}$$

with r_t being the interest rate at time t, $R_t^t = 1$ and $R_t^s = \prod_{\tau=t+1}^{s}\left(\frac{1}{1+r_\tau}\right)$.

2.2. Technology

There is free entry in the imitation sector, which serves the role of providing the intermediate goods sector with designs for the different varieties of intermediate goods. Firms in this sector do not conduct any innovative R&D activity: they rather imitate the innovations coming from abroad. This assumption of Southern firms devoting resources to imitative R&D is consistent with the product cycle literature (Glass and Saggi, 1999; Grossman and Helpman, 1991; Vernon, 1966). It merely states that a developing country economy trying to bridge (or at least narrow) the technology gap finds it easier to imitate already existing state-of-the-art technology rather than innovate from scratch. We further assume that the developing country will specifically target MNCs, which have often already proceeded to most of the adaptations of the technology to the host country standards, thus reducing significantly the resources and time a local firm has to invest in order to use the technology (Glass and Saggi, 1999).

The production process of new designs can then be described by the following generic law of motion of technology:

$$A_t = A_{t-1} + H_{A,t}^{\epsilon_i}\left(\Omega_t^L - A_t\right)$$

with H_{At} being the fraction of the total amount of human capital (skilled labor) devoted to the research and development sector, Ω_t the "frontier" technology level the developing country can copy from when carrying out imitative R&D activities (with $\Omega_t > A_t$), and $\epsilon_i < 1$ a parameter capturing the labor efficiency in the R&D sector.[6] This is a Nelson and Phelps (1966) type law of motion of technology, with A_t being a convex combination of Ω_t, the "frontier" technology level, and of A_{t-1}, the technology level of the country at time t-1.

This implies that our model will only display exogenous growth, a feature that we consider consistent with the case of a developing country conducting imitation and no innovation. This also implies that the higher Ω_t, the higher A_t: our law of motion does *not* include a "contiguous knowledge" feature,[7] which is consistent with our aim of studying the optimal regulation strategy of developing countries finding themselves already higher up the development path.

In order to capture the discrepancies between the two possible technology upgrading strategies, we then impose different values for ϵ_i and Ω_t, *depending* on the chosen regulation ("full liberalization" or "ownership constraints"). In the "full liberalization" case, the labor productivity parameter is ϵ_a, and the developing country has access to the world technology frontier, A_t^L. In the "ownership constraint" case, the labor productivity parameter is ϵ_b, and the technology level the imitative sector has access to is M_t^L, which we define as the *specific* technology level transferred by MNCs when facing ownership constraints and a higher threat of knowledge dissipation. We thus get two alternative laws of motion of technology, depending on the strategy being followed by the developing country: Eq. (a) describes the "full liberalization" case, while Eq. (b) describes the "ownership constraint" one.

$$A_t = A_{t-1} + H_{A,t}^{\epsilon_a}\left(A_t^L - A_t\right) \tag{a}$$

$$A_t = A_{t-1} + H_{A,t}^{\epsilon_b}\left(M_t^L - A_t\right) \tag{b}$$

We impose the two following assumptions, aiming at capturing the trade-off between the two available strategies: $\epsilon_a < \epsilon_b < 1$ and $M_t^L < A_t^L$.

The first assumption, $\epsilon_a < \epsilon_b$, imposes a higher efficiency of human capital in the "ownership constraint" case than in the "full liberalization" one. Such an assumption captures the "knowledge diffusion" effect, i.e. the fact that local firms find it easier to access and imitate the MNC's proprietary technology in the case of a JV agreement. The logic is that the MNC is bound to reveal part of its specific knowledge to its domestic partner in order to carry out business; this knowledge can then be used by the latter for its own local activities. The local firm can also hire local personnel the MNC would otherwise not have trusted with key positions, leading to knowledge dissipation through employee turnover (Djankov and Hoekman, 1997).

The second assumption, $M_t^L < A_t^L$, illustrates the fact that when ownership constraints are imposed, investors are likely to transfer an older vintage of their technology to the local production facility, reacting to the greater threat of knowledge dissipation (Huizinga, 1995). Such a tendency is confirmed by several empirical investigations: Dimelis and Louri (2002), analyzing the differences in productivity between foreign-owned and local firms in Greece and controlling for the foreign ownership level, found that the advantage of foreign ownership stems from the full and majority-owned firms only, as opposed to the minority foreign- and domestically owned ones. Takii (2004), considering a panel data set of Indonesian firms over the period 1990–1995, similarly

[6] More precisely, ϵ_i is the elasticity of the technology progression ΔA_t between time t-1 and t with respect to skilled labor: a higher ϵ_i means that the technology adoption process is less intensive in terms of human capital, which is a desirable trait in our framework of a developing country with a limited amount of skilled resources at its disposal.

[7] Introducing a "contiguous knowledge" constraint in the law of motion of technology is usually done by making imitation very difficult or even impossible if the "relative backwardness" ratio $\frac{A_t}{\Omega_t}$ is under a certain level (Papageorgiu, 2002).

found that wholly foreign-owned plants tend to have higher productivity than other foreign-owned plants, concluding that if countries force MNCs to operate with relatively low foreign investment shares, the nature of technology transferred to their affiliates, and thus productivity levels of the affiliates are limited.

We thus have two possible laws of motion of technology, depending on the regulation chosen at the equilibrium, i.e. full liberalization (*a*) or ownership constraints (*b*). In order to keep the presentation of the dynamic equilibrium and balanced growth path as compact as possible, we however consider a unique law of motion of technology, being a *convex combination* of the two possible strategies:

$$\Delta A_t = \beta\left(H_{A,t}^{\epsilon_a}\left(A_t^L - A_t\right)\right) + (1-\beta)\left(H_{A,t}^{\epsilon_b}\left(M_t^L - A_t\right)\right), \quad \beta = \{0,1\}. \tag{7}$$

Note that β is *not* a control variable, since it does not result from an explicit optimization programme carried out by a central planner. In our model, β is a fixed exogenous parameter, merely describing the technology upgrading strategy of the developing country. For the modeling of a country having chosen the "full liberalization" option, we set $\beta = 1$, while $\beta = 0$ means that we consider a country which has gone for the "ownership constraint" option.

Since human capital is the only input in the R&D process, the *total* production cost of designs over one period is $w_{At}H_{At}$, and the production cost of a *single* blueprint is $\frac{w_{A,t}H_{A,t}}{\Delta A_t}$. Free entry in the imitation sector ensures that the costs incurred for the design of a new intermediate product are equal to the present value of the expected future profits associated to the sales of that product (denoted by V_t in our framework). Using Eq. (6), such a cost-benefits equalization yields the following free-entry condition that has to be respected at equilibrium:

$$\frac{w_{A,t}H_{A,t}}{\Delta A_t} = \sum_{s=t}^{\infty} R_t^s (1-\alpha)\alpha^{\frac{1+\alpha}{1-\alpha}} H_{Y,s}. \tag{8}$$

2.3. Consumers

The economy admits a representative, infinitely-lived household composed of N identical members who consume, save for future consumption and supply labor for R&D and production activities. We assume zero population growth; also, for the sake of simplicity, we assume that every consumer inelastically supplies exactly one unit of human capital, so that the number of consumers N and the total amount of available human capital in the economy H coincide.

The representative household seeks to maximize the discounted sum of instantaneous utility:

$$\sum_{t=0}^{\infty} \rho^t \ln(C_t) \tag{9}$$

with the household budget constraint given by

$$A_{t+1} = (1 + r_{t+1})A_t + w_{Y,t}H_{Y,t} + w_{A,t}H_{A,t} - C_t \tag{10}$$

where A_t are the total asset holdings of the household and r_t the interest rate. The first-order necessary condition for this problem yields the standard Euler equation:

$$\frac{C_{t+1}}{C_t} = (1 + r_{t+1})\rho \tag{11}$$

with ρ being the discount factor.

3. Balanced growth paths

3.1. Equilibrium conditions

Equilibrium on the labor market implies two conditions, pertaining respectively to market clearing and wage equalization:

$$H = H_{Y,t} + H_{A,t} \tag{12}$$

$$w_{A,t} = w_{Y,t} = w_t = (1-\alpha)\left(H_{Y,t}\right)^{-\alpha} A_t X_t^{\alpha} \tag{13}$$

with H being the total human capital resources available in the economy. The absence of time subscript for this variable in Eq. (12) states that those resources are constant over time: we allow for the possibility of the amount H to increase permanently following an exogenous shock, but we do not incorporate in the model any mechanism ensuring a cumulative and balanced law of motion for this variable.[8]

Finally, the resource constraint is given by the equation:

$$Y_t = C_t + A_t \alpha^{\frac{2}{1-\alpha}} H_{Y,t} \tag{14}$$

exemplifying the 2 possible uses of the final good output: consumption and production of intermediate goods (the imitation sector only uses human capital, and no final good input).

Proposition 1. An intertemporal equilibrium is a sequence $[Y_t, w_t, r_t, H_{A,t}, H_{Y,t}, A_t, C_t]_{t=0}^{\infty}$ such that, given the initial condition A_{t-1}, total output of the final good Y_t is given by Eq. (5), the technology level A_t is given by Eq. (7), labor in the imitation sector H_{At} is given by Eq. (8), the interest rate r_t is given by Eq. (11), labor in the final good sector H_{Yt} is given by Eq. (12), wages w_t are given by Eq. (13) and the aggregate consumption level C_t is given by Eq. (14).

3.2. Balanced growth paths

The Nelson and Phelps (1966) law of motion we introduced leaves us with an exogenous growth model, a feature we deem consistent with our goal of modeling a developing country economy resorting to imitation of the frontier technology. Along the balanced growth path (BGP), H_{Yt}, r_t, and H_{At} remain constant, while the remaining variables grow at constant rates. As shown by Eqs. (5), (13) and (14), A_t is the hinge determining the rate of growth of all the variables displaying a trend. We then consider the law of motion of technology (Eq. (7)). Since we study the case of a developing country, we impose $A_{t-1} < A_t^L$. The choice of a Nelson and Phelps (1966) specification then results in the property that the technological absorption of the modeled country is limited, i.e. $A_t < A_t^L \ \forall\ t$.

Proposition 2. Provided $A_{t-1} < A_t^L$, we have $A_t < A_t^L$.

Proof. See Appendix.

Hence, by transitivity we find the technological absorption capacity of a country to be limited: the technological gap cannot be closed at any fixed time t. Furthermore, considering the technology gap TG_t as defined by Nelson and Phelps (1966), i.e. $TG_t = \frac{A_t^L - A_t}{A_t}$, we find that the latter can only vanish asymptotically if the labor assignment H_{At} tends to infinity, which is not allowed in our model.

Since the technology gap can't be bridged, the rate of growth g_A of the variable A_t along the BGP cannot exceed the one of the technology frontier A_t^L: $g_A \leq \gamma$, γ being the exogenously given rate of growth of both variables A_t^L and M_t^L. We indeed assume that M_t^L grows at the same rate than the world frontier A_t^L: we conjecture that even though

[8] We deem this assumption consistent with our goal of modeling strategic technology upgrading decisions of a developing country having access to a limited amount of skilled labor resources.

MNCs are expected to transfer an older vintage of their technology to JV-type affiliates, regular upgrades of this older vintage will anyway occur; we further assume that those upgrades will be performed along the same pace than the progression of the world technology frontier γ.[9] The computation of the balanced growth path imposes furthermore that $g_A \geq \gamma$ in order to obtain a stationary equilibrium. Considering the condition stated before, we're left with the only possible case $\gamma = g_A$.

Proposition 3. If A_t^L and M_t^L grow at the rate γ, then all the other variables grow at the same strictly positive rate: $\gamma = g_A = g_C = g_w = g_Y$.

To fully characterize the steady state values along the balanced growth path, we detrend the system of equations and introduce the following stationarized variables:

$$a_t = \frac{A_t}{A_t^L}, \tilde{Y}_t = \frac{Y_t}{A_t^L}, \tilde{w}_t = \frac{w_t}{A_t^L}, \tilde{C}_t = \frac{C_t}{A_t^L}, m_t = \frac{M_t^L}{A_t^L}.$$

Dropping the time subscript for the steady state values of the variables, the long-run restrictions then become:

$$r = \frac{1+\gamma}{\rho} - 1 \tag{15}$$

$$H_A = \frac{H\alpha\gamma}{1+\gamma-\rho+\alpha\gamma} \tag{16}$$

$$H_Y = \frac{H(1+\gamma-\rho)}{1+\gamma-\rho+\alpha\gamma} \tag{17}$$

$$a = \frac{\beta\left(\frac{H\alpha\gamma}{1+\gamma-\rho+\alpha\gamma}\right)^{\epsilon_a} + (1-\beta)\left(\frac{H\alpha\gamma}{1+\gamma-\rho+\alpha\gamma}\right)^{\epsilon_b} m}{\beta\left(\frac{H\alpha\gamma}{1+\gamma-\rho+\alpha\gamma}\right)^{\epsilon_a} + (1-\beta)\left(\frac{H\alpha\gamma}{1+\gamma-\rho+\alpha\gamma}\right)^{\epsilon_b} + \frac{\gamma}{1+\gamma}} \tag{18}$$

$$\tilde{w} = a(1-\alpha)B^{\frac{1}{1-\alpha}}\alpha^{\frac{2\alpha}{1-\alpha}} \tag{19}$$

$$\tilde{Y} = aB^{\frac{1}{1-\alpha}}\left(\frac{H(1+\gamma-\rho)}{1+\gamma-\rho+\alpha\gamma}\right)\alpha^{\frac{2\alpha}{1-\alpha}} \tag{20}$$

$$\tilde{C} = aB^{\frac{1}{1-\alpha}}\left(\frac{H(1+\gamma-\rho)}{1+\gamma-\rho+\alpha\gamma}\right)\alpha^{\frac{2\alpha}{1-\alpha}}\left(1-\alpha^2\right). \tag{21}$$

Since the increase in the number of intermediate good varieties is the sole engine of growth of our model, we focus on a, i.e. the ratio (constant along the BGP) between the local technology level A_t and the world technology level A_t^L. We can directly infer from Proposition 2 that $a < 1$, ensuring that the technology gap, defined as $TG = \frac{A^L - A}{A} = \frac{1}{a} - 1$, will not be bridged at the steady state. However, we have that $TG \to 0$ as soon as $a \to 1$: a developing country willing to narrow as much as possible its technology gap will then try to bring the steady state value of a as close as possible to 1.

Eqs. (19), (20) and (21) furthermore indicate that higher values of the ratio a coincide with higher values of $\tilde{Y}$, $\tilde{C}$ and $\tilde{w}$, i.e. higher steady state levels of detrended output, consumption and wages. In particular, since $\tilde{C}$ is strictly increasing along a, a higher value of a yields a higher level of detrended consumption, i.e. a higher level of welfare at the steady-state.

Finally, one can notice from Eq. (19) that the technology ratio a positively depends on the overall human capital stock H. Even though the growth rate of the variables displaying a trend is exogenously fixed at γ in our model, this result is reminiscent of the scale effects traditionally present in first-generation R&D-driven growth models. Albeit severely criticized in the literature (Jones, 1995a, 1995b), we deem this property as acceptable in our framework, since the main objective of this paper is to determine the most desirable technology upgrading strategy at a *given* level of human capital H. Furthermore, in our model the ratio a is increasing not in the size of the economy[10] but in the overall level of human capital, a feature which is consistent with both theoretical and empirical investigations of the engines of growth (cf, among others, Benhabib and Spiegel, 1994).

Given the fact that the value of a depends on the chosen FDI regulation policy (i.e. “full liberalization” or “ownership constraints”), we now determine which regulation brings a the closest to 1.

4. Choice of the technology upgrading strategy

4.1. The influence of the human capital constraint

We first determine the relative values of the ratio a under the two possible regulation policies, keeping in mind that the nearer a comes to 1, the smaller the steady state technology gap TG is[11]:

1. “Full liberalization” case. Setting $\beta = 1$, which corresponds to the “full liberalization” case, the value of the ratio $\frac{A}{A^L} = a_a$ and of the associated technology gap $\overline{TG}_a$ is:

$$a_a = \frac{H_A^{\epsilon_a}}{H_A^{\epsilon_a} + \frac{\gamma}{\gamma+1}}, \quad \overline{TG}_a = \frac{\gamma}{(\gamma+1)H_A^{\epsilon_a}}.$$

2. “Ownership constraints” case. Setting $\beta = 0$, which corresponds to the “ownership constraints” case, the value of the ratio $\frac{A}{A^L} = a_b$ and of the associated technology gap $\overline{TG}_b$ is:

$$a_b = \frac{H_A^{\epsilon_b} m}{H_A^{\epsilon_b} + \frac{\gamma}{\gamma+1}}, \quad \overline{TG}_b = \frac{H_A^{\epsilon_b}(1-m)(\gamma+1)+\gamma}{\overline{H}_A^{\epsilon_b} m(\gamma+1)}.$$

A developing country wishing to maximize the ratio $\frac{A}{A^L}$ at the steady state then needs to determine which long-run value of this technology ratio, a_a or a_b, is the greatest. As we will now see, for a given ratio $m = \frac{M^L}{A^L}$ (i.e. for a given level of technology M^L transferred by the MNCs in the case they face ownership constraints), this will non-monotonically depend on the country's limited amount of available skilled resources H.

Proposition 4. So as to determine the strategy (i.e. full liberalization or ownership constraints) narrowing as much as possible a developing country's steady state technology gap, one has to consider the following condition:

$$a_a > a_b \iff (1-m)\frac{(\gamma+1)}{\gamma} > m\left(\frac{H\alpha\gamma}{1+\gamma-\rho+\alpha\gamma}\right)^{-\epsilon_a} - \left(\frac{H\alpha\gamma}{1+\gamma-\rho+\alpha\gamma}\right)^{-\epsilon_b}.$$

Depending on the parameter values γ, α, ρ, ϵ_a, ϵ_b and on the value taken by the ratio $m = \frac{M^L}{A^L} < 1$, we then have 2 possible cases:

(1) full liberalization is the strategy which minimizes the steady state technology gap for any level of the human capital stock H,
(2) full liberalization is the strategy which minimizes the steady state technology gap for small and high values of H ($H < H_l$ and $H > H_h$), while ownership constraints minimize the steady state technology gap for intermediate values of H $H(H \in (H_l, H_h))$.

[9] Indeed, even if MNCs transfer a technology being less advanced in *absolute level* to the affiliates where the risk of knowledge leakage is higher, they will however not let this technology get totally outdated.

[10] Indeed, even though we assumed unit inelastic labor supply and hence fixed the number of individuals in the representative household at H for the sake of simplicity, one could assume any population size without impacting any of the long-run restrictions, provided the overall human capital stock H remains unchanged.

[11] In the next section, we will sometimes use for the sake of concision the symbol H_A to designate the amount of human capital allocated to the imitative R&D activities at the steady state. It should however be kept in mind that a full analytical expression of H_A is given in Eq. (28).

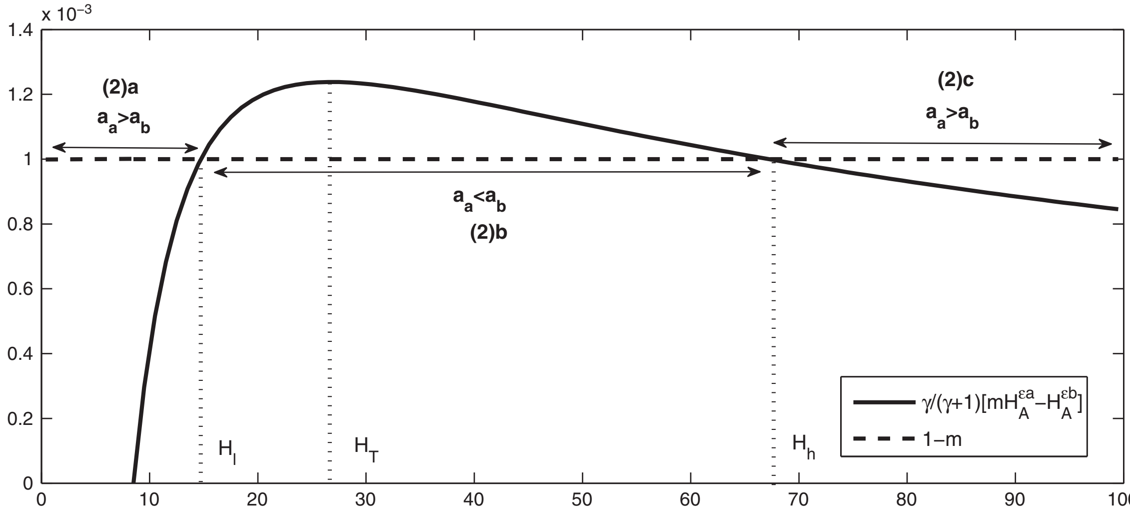

Fig. 1. Optimal regulation along values of H when $\alpha = 1/3$, $\gamma = 0.02$, $\epsilon_a = 0.8$, $\epsilon_b = 0.95$, $\rho = 0.97$, $m = 0.998$.

Proof. Considering the expressions of a_a and a_b, we have:

$$a_a > a_b \quad \Leftrightarrow \quad \frac{H_A^{\epsilon_a}}{H_A^{\epsilon_a}+\frac{\gamma}{\gamma+1}} > \frac{H_A^{\epsilon_b}m}{H_A^{\epsilon_b}+\frac{\gamma}{\gamma+1}}.$$

Rearranging this expression and substituting for the steady state value of H_A as given in Eq. (16), we obtain the condition stated inProposition 4. The left-hand side of the obtained comparison does not depend on H. We then consider the right-hand side $F(H) = m\left(\frac{H\alpha\gamma}{1+\gamma-\rho+\alpha\gamma}\right)^{-\epsilon_a} - \left(\frac{H\alpha\gamma}{1+\gamma-\rho+\alpha\gamma}\right)^{-\epsilon_b}$. We have $\frac{\partial F}{\partial H} = -m\epsilon_a H_A^{-\epsilon_a-1} + \epsilon_b H_A^{-\epsilon_b-1}$. This derivative trivially has a unique root for $H > 0$, that we denote H_T:

$$\frac{\partial F}{\partial H} = 0 \quad \Leftrightarrow \quad H = H_T = \left(\frac{m\epsilon_a}{\epsilon_b}\right)^{\frac{1}{\epsilon_a-\epsilon_b}} \left(\frac{1+\gamma-\rho+\alpha\gamma}{\alpha\gamma}\right).$$

F is strictly increasing for $H \in [0,H_T]$ and strictly decreasing for $H > H_T$, with $F \to 0$ for $H \to \infty$. We then have the two possible cases stated inProposition 4:

(1) if $F(H_T) < (1-m)\frac{(\gamma+1)}{\gamma}$, we always have $a_a > a_b$.
(2) if $F(H_T) > (1-m)\frac{(\gamma+1)}{\gamma}$, we necessarily have two values H_l and H_h such that: $a_a > a_b$ for $H < H_l$ and $H > H_h$, $a_b > a_a$ for $H \in [H_l,H_h]$ (cf Fig. 1).

This ends the proof.

Whether we are in case (1) or (2) depends on the values taken by the ratio m and by the world technology rate of growth γ: the lower m or γ, the higher $(1-m)\frac{(\gamma+1)}{\gamma}$.

Case (1) hence states that if the technology level transferred by MNCs in the case of ownership constraints M^L is too low with respect to the world frontier (i.e. m being significantly lower than 1), a higher productivity of the human capital dedicated to the imitation process will never offset the drawback of having access to completely outdated technologies. In this case it will always be optimal to allow for full liberalization, even if imitation of wholly-owned firms proves itself more human capital intensive (which is an undesirable trait in the case of a developing country having limited skilled labor resources).[12]

[12] This result is due to the fact that our model specification considers having access to a lower technology level in the imitation process as a drawback: had we allowed for a "contiguous knowledge" effect to arise in our law of motion of technology, this result would have been reversed.

Case (2) arises as soon as the technology level transferred by MNCs in the case of ownership constraints becomes high enough for the condition $F(H_T) > (1-m)\frac{(\gamma+1)}{\gamma}$ to be met. Fig. 1 describes the evolution of the optimal regulation as the human capital constraint H is progressively loosened. As stated inProposition 4, full liberalization is then optimal for *very low and high values* of H (cases (2)a and (2)c), while ownership constraints are optimal for *intermediary* values of H (case (2)b).

For values of H for which $H_A < 1$ (i.e. $H < \frac{1+\gamma-\rho+\alpha\gamma}{\alpha\gamma}$), $a_a < a_b$ trivially stems from the fact that the condition $\epsilon_a < \epsilon_b$ ensures the imitation process in the ownership constraint case to be less human capital intensive if and only if $H_A > 1$: when $H_A < 1$, the full liberalization case ensures *both* a higher productivity of human capital and a higher level of technology being transferred. However, for $H \in \left[\frac{1+\gamma-\rho+\alpha\gamma}{\alpha\gamma}, H_l\right]$, case (2)$a$ states that full liberalization is optimal for low values of H, even if the human capital is more productive in the ownership constraint case ($H_A > 1$). The intuition is that even if human capital proves itself more productive, the economy is endowed with so few units of it that their higher productivity cannot compensate the higher level of technology transferred in the case of full liberalization: in this case, the country finds it optimal to open itself fully.

However, as we allow for the human capital constraint to be progressively loosened, H becomes sufficiently high for the condition $H > H_l$ to be met, and we are then in the case of an economy being endowed with enough human capital units for their productivity to matter. Case (2)b then arises for $H_l < H < H_h$. For not too low values of m (case (2)), it will be optimal for an economy facing human capital resource constraints ($H < H_h$) to resort to ownership constraints: the higher productivity of the limited amount of human capital dedicated to the imitation process in that case (knowledge dissipation effect) will more than compensate the lower technology level being transferred by the MNCs. However, as $H \to \infty$ and becomes superior to H_h, the human capital resource constraint is so loosened that faster decreasing returns to scale ($\epsilon_a < \epsilon_b$) do not matter so much anymore: we are in case (2)c, and the optimal regulation for such an economy is again to resort to full liberalization.

We have hence demonstrated that at the steady state, the desirable technology upgrading strategy of a developing country facing resource constraints depends non-monotonically on the overall available amount of human capital H. We believe this result contributes to the ongoing debate concerning the contrasted empirical outcomes obtained so far in the literature when measuring the extent of technology spillovers once the ownership structure of MNCs is controlled for.

Indeed, as previously evoked, if Blomstrom and Sjöholm (1999) found no difference in the extent of spillovers stemming from minority- and majority owned foreign presence, Dimelis and Louri (2002), Javorcik and Sparateanu (2008) as well as Takii (2005) found opposite results. The most commonly invoked reason is the difference in methodologies being used. However, we emphasize another possible explanation for this discrepancy, also brought forward by Dimelis and Louri (2002), which are the differences in the level of development as well as other structural characteristics of the countries considered for these various empirical studies. Indeed, we have shown that the optimal regulation depends on the overall amount of human capital available within the economy H, as well as on the labor intensity of the imitation process (ϵ_a and ϵ_b), whose values clearly differ from one developing country to another.

This result also clarifies the discussion concerning the assets and drawbacks of ownership constraints. Indeed, if the difference in the technology level transferred by MNCs facing ownership constraints has been widely acknowledged in the existing literature, it is often argued to be a *desirable* feature, interacting positively with the easier imitation triggered by the presence of a local partner (Javorcik and Sparateanu, 2008). Such a result stems from the assumption of the existence of a "contiguous knowledge" effect in the case of developing countries: local competitors then find it easier to absorb the less sophisticated technologies transferred to jointly owned FDI projects. Our model demonstrates that even when the lower technology level in the case of a JV is considered as a drawback, ownership constraints can be relevant provided we keep the assumption of a better access to knowledge in the case of local participation.

4.2. Transition dynamics and comparative statics

4.2.1. Consumption transition dynamics

Proposition4 identified the most efficient strategy when the aim of the country is to narrow as much as possible the *steady state* technology gap TG. As noted above when commenting the long-run restrictions, such a strategy also maximizes the steady-state welfare, since the detrended steady-state consumption level $\tilde{C}$ is strictly increasing along a. However, one can also be interested in comparing the transition dynamics occurring *before* the economy reaches the balanced growth path: does the catching-up strategy which yields the smallest technology gap at the steady state also guarantee welfare-maximizing transition dynamics? In other words, what are the intertemporal consumption (and hence welfare) trajectories associated to each of the available strategies?

In order to compute intertemporal trajectories of the different variables, we proceed to numerical dynamic simulations of our model. We carry out a sensitivity analysis along a wide array of values for m, γ, ρ, ϵ_a and ϵ_b. Our numerical findings are summarized as follows.

Numerical finding 1: Whatever the value of H (i.e. regardless of the optimal strategy at the steady state), *the ownership constraint strategy (b) yields a faster convergence towards the steady state* than the full liberalization strategy (a), due to both a stronger adoption effort during the first period (higher share of human capital devoted to the R&D sector H_A) *and* a higher efficiency of the imitation sector ($\epsilon_b > \epsilon_a$).

Numerical finding 2: Whatever the value of H (i.e. regardless of the optimal strategy at the steady state), the following characteristics of the intertemporal consumption trajectory can be identified:

2.1 The overall consumption level C_t (and hence welfare) is systematically slightly higher in the full liberalization case (a) in the first period of the transition. Indeed, a lower adoption effort under strategy (a) in period 1 ensures a higher share of the human capital being devoted to the production of the final good, hence guaranteeing a slightly higher consumption (and hence welfare) level than under strategy (b).

2.2 Following this first period, the overall consumption level C_t is then systematically higher for at least 2 periods in the ownership constraints case (b), both because of a higher value of the technology stock A_t *and* of a lower adoption effort (indeed, following the first period surge in H_A, the human capital devoted to the R&D sector becomes lower under strategy (b) than under strategy (a) for at least periods 2 and 3).

Numerical finding 3: For values of H for which the full liberalization strategy (a) is optimal at the steady state (i.e. for low and very high values of H), the overall consumption level C_t becomes higher under strategy (a) than under strategy (b) *only in the long-run* (never earlier than period 4 in all of our simulations). On the other hand, for intermediary values of H for which the ownership constraint strategy (b) is optimal at the steady state (i.e. for H such that $H_l < H < H_h$), the overall consumption level C_t becomes higher under strategy (b) than under strategy (a) almost immediately (as soon as the second period in all of our simulations).

Fig. 2 presents the trajectories of the overall consumption C, the human capital devoted to the R&D sector H_A and the technology ratio a for both strategies (i.e. (a) full liberalization and (b) ownership constraints) for an economy displaying the following parameter values: $m = 0.999$, $\gamma = 0.02$, $\alpha = 0.33$, $\rho = 0.97$, $\epsilon_a = 0.8$, and $\epsilon_b = 0.95$. Two cases are considered: the three superior panels represent the transition dynamics associated to the two possible strategies for an overall human capital stock H equal to 10, while the three inferior ones depict the transition dynamics for $H = 25$. For the chosen parameter values, we have that $10 < H_l$, and $H_l < 25 < H_h$: hence, the strategy which minimizes TG at the steady-state is (a) full liberalization for $H = 10$, and (b) ownership constraints for $H = 25$. The transition dynamics displayed by the different variables illustrate the numerical findings listed above.

The intuitions regarding those findings and the graphs presented in Fig. 2 are as follows. The higher efficiency of the R&D process in the case of an ownership constraints strategy (b) makes it optimal to immediately devote a high fraction of the available human capital to the R&D sector, so as to guarantee a fast convergence of the technology level A_t to its steady-state. Hence, the consumption level C_t is systematically lower under strategy (b) than it is under strategy (a) during the first period of the transition towards the steady-state (cf *Numerical finding 1*).

In the strategy (b) case (i.e. ownership constraints), this very strong jump of A_t in the first period of the transition towards the balanced growth path then makes it possible in the subsequent periods to quickly diminish the share of human capital being devoted to the R&D sector, and to benefit from a higher level of A_t in the production process. The production of final goods is positively impacted by those two separate effects, hence also boosting the consumption level. On the other hand, in the case of strategy (a), a slower transition towards the steady-state value of the technology level A_t combined to higher values of H_A (made necessary because of the lower efficiency of the R&D process) dampen the production of final goods and hence the consumption level. As a consequence, C_t is higher under strategy (b) than under strategy (a) during periods 2 and 3 (both for H = 10 and H = 25), and converges faster towards its steady-state value (cf *Numerical finding 2*).

Finally, even for values of H such that strategy (a) is desirable in the long run (cf. case H = 10 in Fig. 2), the welfare level only becomes higher under full liberalization than under ownership constraints after period 4 (cf *Numerical finding 3*).

Hence, a numerical exploration of the intertemporal consumption path under the two possible strategies yields a somewhat less clear-cut recommendation regarding the welfare-maximizing technological upgrading strategy. In particular, even for values of H for which full

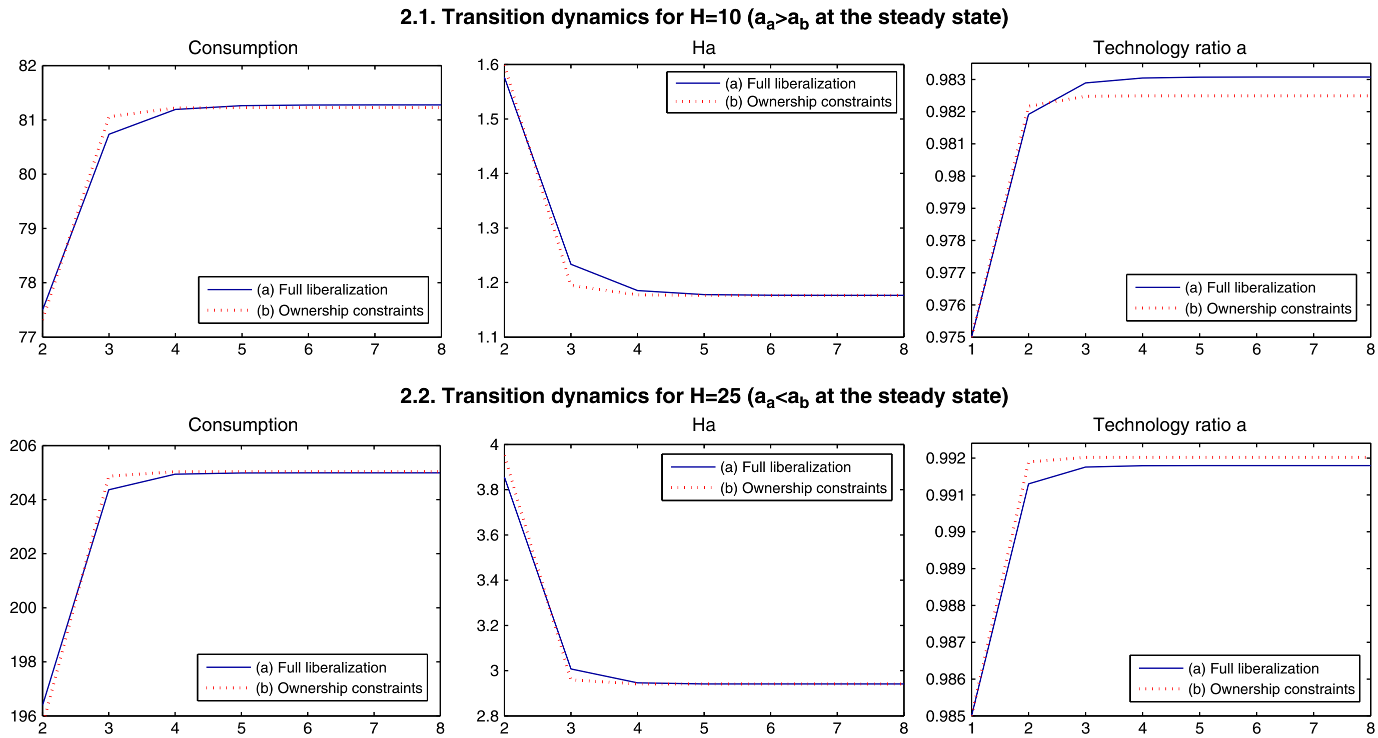

Fig. 2. Transition dynamics for different values of H.

liberalization is desirable at the steady state, ownership constraints might temporarily guarantee a higher level of consumption during the transition towards the balanced growth path.

Further exploring this venue is however beyond the scope of such a simple theoretical framework, and is left for future research. We now finally consider a few relevant comparative statics.

4.2.2. Comparative statics

4.2.2.1. Increase in the human capital stock H. In order to be fully exhaustive, we define the value m_T for the ratio $\frac{M^L}{A^L}$ as the value of m for which ownership constraints become interesting for a given H. We have $m_T = \frac{H_A^{\epsilon a-\epsilon_b}\frac{\gamma}{\gamma+1}+H_A^{\epsilon\alpha}}{H_A^{\epsilon a}+\frac{\gamma}{\gamma+1}}$, with $m_T < 1$ as soon as $H > \frac{1+\gamma-\rho+\alpha\gamma}{\alpha\gamma}$ (i.e. $H_A > 1$). We then have the following comparative statics along H:

Proposition 5. We have the following comparative statics properties along H:

$$\frac{\partial a_a}{\partial H}>0, \quad \frac{\partial a_b}{\partial H}>0, \quad \frac{\partial \tilde{Y}}{\partial H}>0, \quad \frac{\partial \tilde{C}}{\partial H}>0, \quad \frac{\partial \tilde{w}}{\partial H}>0$$
$$\frac{\partial m_T}{\partial H}<0 \quad \forall H \in \left[\frac{1+\alpha\gamma+\gamma-\rho}{\alpha\gamma};\tilde{H}\right], \quad \frac{\partial m_T}{\partial H}>0 \quad \forall H \in \left]\tilde{H};\infty\right[.$$

Proof. See Appendix.

The first four comparative statics merely state that an increase in the overall limited labor supply H will have a positive effect on the main variables of the economy, whether ownership constraints are imposed or not. We can further notice that loosening the labor supply constraint has no effect on the intensity of the steady state adoption effort: as we can seen from the long-run restrictions (28) and (29), H_A and H_Y are constant fractions of H, and the fraction of overall labor being devoted to the R&D sector is not modified by a shock on H. The last result ofProposition 5 can be interpreted along Fig. 1, since we have shown that the function F is increasing in human capital H up to a value H_T. For $H \in [H_l, H_T]$, the distance between F and the constant $(1-m)\frac{(\gamma+1)}{\gamma}$ increases, and hence so does the number of values of m for which ownership constraints are optimal: the threshold value m_T decreases. For $H > H_T$, F starts to decrease along H, and so does the distance between F and the constant $(1-m)\frac{(\gamma+1)}{\gamma}$: m_T then increases along H. We hence have a non-monotonic relationship between the threshold value m_T and the available amount of human capital H.

4.2.2.2. Increase in the world technology growth rate γ. We finally consider the effects of a technological acceleration, i.e. we carry out comparative statics along γ.

Proposition 6. In the case of a technological acceleration abroad, we have the following comparative statics properties:

$$\frac{\partial a_a}{\partial \gamma}<0, \quad \frac{\partial a_b}{\partial \gamma}<0, \quad \frac{\partial H_A}{\partial \gamma}>0, \quad \frac{\partial \tilde{Y}}{\partial \gamma}<0, \quad \frac{\partial \tilde{C}}{\partial \gamma}<0, \quad \frac{\partial \tilde{w}}{\partial \gamma}<0, \quad \frac{\partial \overline{m}_T}{\partial \gamma}<0.$$

Proof. See Appendix.

The first three results show that although a technology shock induces a stronger steady state adoption effort (a bigger fraction of the overall labor supply H is devoted to the R&D sector), this increment is not enough to compensate the increase in the long term technology gap, whichever FDI regulation gets chosen by the developing country. This has a negative effect on the long-run levels of all the variables displaying a trend at the steady state: the increase in H_A induces in turn a decrease in H_Y, and this smaller fraction of labor devoted to the production sector also exerts a negative impact on $\tilde{Y}$, $\tilde{w}$ and $\tilde{C}$. We can further notice that the consumption share in the allocation of the final good remains unaffected by a technological acceleration: indeed, the ratio $\frac{\tilde{C}}{\tilde{Y}}$ is equal to a constant $1-\alpha^2$.

The last result of Proposition 6 finally states that a positive shock on the exogenous rate of growth of technology abroad lowers the threshold value m_T for which ownership constraints become the optimal regulation. This property can be interpreted in the following way: when the world technology is growing at a rather slow pace, the extent of human capital intensity in the imitation process is comparatively less important than the mere *level* of technology being available. However, in case of a technology acceleration, the higher human capital efficiency in the ownership constraints case finds it easier to outweigh the technology discrepancy, as shows the fall in the threshold value of m_T.

5. Conclusion

Using a simple extension of the Romer (1990) technology-driven growth model adapted to the case of a developing country, we determined which type of FDI regulation was desirable with respect to the technology upgrading strategy of a developing host country. We were in particular able to demonstrate that the optimal regulation for a developing country facing resource constraints depends non-monotonically on the overall available amount of human capital H: for small and very high values of H, full liberalization is desirable, while ownership constraints are relevant for intermediary values of H. We were hence also able to show that the “knowledge dissipation” effect is sufficient for ownership constraints to be optimal, since even when considering the lower vintage transferred to joint ventures as being a *drawback*, ownership sharing conditions prove themselves desirable for certain values of available human capital H.

Our paper provides a possible explanation for the contrasted results of studies concerning the effects of JV agreements on productivity of local firms (Blomstrom and Sjöholm, 1999; Javorcik and Sparateanu, 2008; Takii, 2005) and contributes to the ongoing debate about the banning of domestic equity ownership requirements. Joint ventures might prove themselves beneficial, and adding ownership constraints to the list of prohibited performance requirements might prove itself detrimental for developing countries.

Appendix A

A.1. Proof of proposition 2

Proof. A slight reformulation of (7) yields:

$$A_t = \frac{A_{t-1} + \beta H_{A,t}^{\epsilon_a} A_t^L + (1-\beta) H_{A,t}^{\epsilon_b} M_t^L}{1 + \beta H_{A,t}^{\epsilon_a} + (1-\beta) H_{A,t}^{\epsilon_b}}.$$

Multiplying and dividing A_t^L by $1 + \beta H_{A,t}^{\epsilon_a} + (1-\beta) H_{A,t}^{\epsilon_b}$, we get:

$$A_t^L = \frac{A_t^L + \beta H_{A,t}^{\epsilon_a} A_t^L + (1-\beta) H_{A,t}^{\epsilon_b} A_t^L}{1 + \beta H_{A,t}^{\epsilon_a} + (1-\beta) H_{A,t}^{\epsilon_b}}.$$

Using the two key assumptions $M_t^L < A_t^L$ and $A_{t-1} < A_t^L$, we then obtain by comparing the two expressions that $A_t < A_t^L$. This ends the proof.

A.2. Proof of proposition 5

Proof. The sign of the first five derivatives is straightforward. We then have $\frac{\partial m_T}{\partial H} = \frac{\partial m_T}{\partial H_A}\frac{\partial H_A}{\partial H}$. We have the following expression for $\frac{\partial m_T}{\partial H_A}$:

$$\frac{\partial m_T}{\partial H_A} = \frac{H_A^{-1+\epsilon_a-\epsilon_b}\gamma\left(H_A^{\epsilon_b}(1+\gamma)\epsilon_a + \gamma(\epsilon_a-\epsilon_b) - H_A^{\epsilon_a}(1+\gamma)\epsilon_b\right)}{\left(\gamma + H_A^{\epsilon_a}(1+\gamma)\right)^2}.$$

While the denominator is trivially positive, the numerator is found to be strictly increasing along H_A and to have the following sign properties:

$$\left.\frac{\partial m_T}{\partial H_A}\right|_{H_A=1} < 0, \lim_{H_A\to\infty}\left(\frac{\partial m_T}{\partial H_A}\right) = \infty.$$

Hence, since there is a linear, positive relationship between H_A and H, we can infer from these results that there exists a threshold value $\tilde{H}$ for the exogenous overall human capital H such that:

$$\frac{\partial m_T}{\partial H_A} < 0 \quad \forall H \in \left[\frac{1+\alpha\gamma+\gamma-\rho}{\alpha\gamma};\tilde{H}\right], \quad \frac{\partial m_T}{\partial H_A} > 0 \quad \forall H \in \left]\tilde{H};\infty\right[.$$

Combining this result with the fact that $\frac{\partial H_A}{\partial H} = \frac{\alpha\gamma}{1+\gamma-\rho+\alpha\gamma} > 0$, we obtain the result stated inProposition 5. This ends the proof.

A.3. Proof of proposition 6

We have the following detailed expressions for the comparative statics:

$$\frac{\partial H_A}{\partial \gamma} = \frac{H\alpha(1-\rho)}{(1+\gamma+\alpha\gamma-\rho)^2} > 0$$

$$\frac{\partial a_a}{\partial \gamma} = -\frac{(\gamma(1+\alpha+\epsilon_a(\rho-1)) + (\epsilon_a-1)(\rho-1))H_A^{\epsilon_a}}{(\gamma + H_A^{\epsilon_a} + \gamma H_A^{\epsilon_a})^2(1+\gamma+\alpha\gamma-\rho)} < 0$$

$$\frac{\partial a_b}{\partial \gamma} = -\frac{m(\gamma(1+\alpha+\epsilon_b(\rho-1)) + (\epsilon_b-1)(\rho-1))H_A^{\epsilon_b}}{(\gamma + H_A^{\epsilon_b} + \gamma H_A^{\epsilon_b})^2(1+\gamma+\alpha\gamma-\rho)} < 0$$

$$\frac{\partial \tilde{Y}}{\partial \gamma} = \frac{\partial \tilde{Y}}{\partial a}\frac{\partial a}{\partial \gamma} < 0, \quad \frac{\partial \tilde{C}}{\partial \gamma} = \frac{\partial \tilde{C}}{\partial a}\frac{\partial a}{\partial \gamma} < 0, \quad \frac{\partial \tilde{w}}{\partial \gamma} = \frac{\partial \tilde{C}}{\partial a}\frac{\partial a}{\partial \gamma} < 0.$$

And we finally have the following expression for $\frac{\partial m_T(H_A(\gamma),\gamma)}{\partial \gamma}$, whose sign is trivially negative when $H < \tilde{H}$, but is not straightforward as soon as $H > \tilde{H}$:

$$\frac{\partial m_T(H_A(\gamma),\gamma)}{\partial \gamma} = \underbrace{\frac{\partial m_T}{\partial \gamma}}_{<0} + \underbrace{\frac{\partial m_T}{\partial H_A}\frac{\partial H_A}{\partial \gamma}}_{>0 \quad \forall H > \tilde{H}}.$$

Computing the whole expression, we get:

$$\frac{\partial m_T(H_A(\gamma),\gamma)}{\partial \gamma} = \frac{(\gamma\Phi + \Psi)H_A^{\epsilon_a-\epsilon_b}}{(\gamma + H_A^{\epsilon_a} + \gamma H_A^{\epsilon_a})^2(1+\gamma+\alpha\gamma-\rho)}$$

with

$$\begin{aligned}\Phi &= (1-\alpha)\left(H_A^{\epsilon_a} - H_A^{\epsilon_b}\right) - \epsilon_b\left(1 + H_A^{\epsilon_a}\right)(1-\rho) + \epsilon_a\left(1 + H_A^{\epsilon_b}\right)(1-\rho) \\ &= \underbrace{H_A^{\epsilon_a}((1+\alpha)-\epsilon_b(1-\rho)) - H_A^{\epsilon_b}((1+\alpha)-\epsilon_a(1-\rho))}_{<((1+\alpha)-\epsilon_a(1-\rho))\left(H_A^{\epsilon_a}-H_A^{\epsilon_b}\right)<0} \\ &\quad + \underbrace{(1-\rho)(\epsilon_a-\epsilon_b)}_{<0} < 0\end{aligned}$$

$$\Psi = \underbrace{(\rho-1)}_{<0}\underbrace{\left(H_A^{\epsilon_b} - H_A^{\epsilon_a} + \epsilon_b H_A^{\epsilon_a} - \epsilon_a H_A^{\epsilon_b}\right)}_{>\left(H_A^{\epsilon_b}-H_A^{\epsilon_a}\right)(1-\epsilon_a)>0} < 0.$$

And the sign of the denominator being trivially positive, we finally get $\frac{\partial m_T}{\partial \gamma} < 0$. This ends the proof.

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