Imitation in a non-scale R&D growth model

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Abstract. Motivated by recent empirical evidence this paper extends a non-scale R&D growth model to allow for technological imitation in addition to innovation. It is shown that a simple modification of the standard R&D equation results in a more general model that can explain not only the growth process of developed countries that mostly innovate, but also the growth process of developing countries that mostly imitate.

Keywords: Imitation; Innovation; R&D-based growth model

JEL classification: O32; O40

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1. Introduction

Recent work by Helpman and Hoffmaister (1997) reveals that even though technological innovation is crucial to economic growth, only a small group of industrial countries account for most of the world's innovation. Helpman and Hoffmaister find that, within the OECD, the seven largest economies accounted for over 90% of R&D in 1991. They also report that in 1990, industrial countries accounted for 96% of the world's R&D expenditure. This evidence suggests that the pioneer R&D growth models (i.e. Romer (1990), Grossman and Helpman (1991), Aghion and Howitt (1992), and Jones (1995a) (R-GH-AH-J)) are applicable only to the developed countries that innovate. This paper extends a non-scale R&D growth model to make it applicable not only to the few countries that innovate but also to most countries that imitate. The three main features of the model presented here are the following: First, it preserves the appealing monopolistically competitive structure of the R&D growth models. Second, it is consistent with the Jones (1995a, 1995b) prediction that in the long-run there are no "scale effects." Third, it allows for technological imitation thus becoming applicable to most countries that grow mainly through adoption of existing technologies. Even though the paper is similar in structure to R-GH-AH-J, it is closer in spirit to Nelson and Phelps (1966), Benhabib and Spiegel (1994, 2000, 2002), Parente and Prescott (1994), Barro and Sala-i-Martin (1997), and Perez-Sebastian (2000).[1]

2. The Model

The leader-follower model presented below is a variant of the Jones (1995a) non-scale R&D growth model where technical progress and long-run growth is the outcome of expansion of the set of intermediate goods. The only difference between the leader and the follower country is that the leader only innovates where the follower re-invents as well as imitates existing technology.[2] The model economy consists of three sectors: The final-good sector which is perfectly competitive and produces a single homogenous consumption good. The monopolistically competitive intermediate-goods sector that supplies a variety of inputs to the final-good's producers. Finally, the R&D sector that supplies the intermediate-goods producer with different designs/blueprints.

[1] For a list of other papers on technological imitation and growth see Benhabib and Spiegel (2002).

[2] Re-invention is the process of building one's own version of existing technology without adopting it from abroad.

Since our model follows closely the basic structure of the standard R&D growth model, detailed presentation of the decentralized problem is omitted.[3] Instead, we present the equations that characterize our model with primary attention to the modified R&D equation which is the primary innovation of the paper.

The follower and the leader countries are structurally the same and are characterized by two equations. First, the production function of final and intermediate goods is given by

$$Y = (L_Y)^{1-\alpha} \int_0^A (X_i)^\alpha \, di, \tag{1}$$

where Y is output, L_Y is the portion of labor employed in the output sector, X_i is the amount of intermediate good i, A is a domestic technology index denoting the number of intermediate goods used in output production, and $\alpha \in (0,1)$ is the share of intermediate good X_i in output. Second, the law of motion of technology is given by[4]

$$\dot{A} = [\delta L_A^\lambda A]^\gamma [\mu L_A^\lambda (\frac{A^*}{A})]^{1-\gamma}, \tag{2}$$

where L_A is the portion of labor employed in the R&D sector, A^* is the stock of foreign technology (leader's technology), $\delta, \mu \in (0,1)$ are innovation and imitation parameters respectively, $\lambda \in (0,1)$ is a parameter that allows for the possibility of duplication, and $\gamma \in (0,1)$ is the technology share.

There are a number of points worth making here. First, notice equation (2) is an extended version of the Jones (1995a) R&D equation that includes an imitation term.[5] The extended R&D equation can best be described by referring to the two RHS terms of equation (2), $[\delta L_A^\lambda A]^\gamma$ and $[\mu L_A^\lambda (\frac{A^*}{A})]^{1-\gamma}$. The former term, $[\delta L_A^\lambda A]^\gamma$, represents the ability of a country to grow by innovating (or re-inventing) new (existing) varieties of intermediate goods. The second term, $[\mu L_A^\lambda (\frac{A^*}{A})]^{1-\gamma}$, is the main contribution of this model and captures the potential for a follower country to imitate. It states that imitation is a function of labor employed in the business of adopting existing technology, L_A, and a "catching-up" term, $\frac{A^*}{A}$. The

[3] The decentralized problem is presented in the working paper version and is available by the author upon request.

[4] Nelson and Phelps (1966) were the first to formally incorporate the notion of technological adoption into a model. More recently, Benhabib and Spiegel (1994, 2000, 2002) have provided empirical evidence supporting technological adoption as a primary engine of growth in developing countries.

[5] It is not necessary that the innovation and imitation processes be characterized by the same specification. Nevertheless, it is reasonable to assume that the two processes are similar and that can conveniently be incorporated into a single specification.

catch-up term captures the idea that the greater the technology gap between a leader and a follower, the higher the potential of the follower to catch up through imitation. The catching-up term is also consistent with the "relative backwardness" hypothesis of Findlay (1978) that the rate of technological progress in a relatively backward country is an increasing function of the gap between its own level of technology and that of the advanced country. Notice however that in our formulation relative backwardness is one of two ingredients necessary for imitation. The other necessary ingredient that enhances the catch-up term is labor in R&D.

A novel property of the modified R&D equation is that it encompasses technical progress in countries that lie on the frontier and thus only innovate. Since imitation is not possible in these countries, their R&D equation is reduced to $\dot{A}^{*} = \delta L_A^{\lambda}(A^{*})^{\gamma}$ that is very similar to that of Jones (1995a).[6] Finally, notice that regarding the follower countries, equation (2) implies that scientist and engineers foster both re-invention as well as adoption of new technologies. Notice that latecomers with low A and high L_A have the potential to grow much faster than the leader because of the catching-up effect.

Steady-state growth

As mentioned previously, an important property of the modified R&D equation proposed above is that for the leading country for which technology level is A^{*}, equation (2) is reduced to a version of Jones (1995a) specification as follows:

$$\dot{A}^{*} = \delta L_A^{\lambda}(A^{*})^{\gamma}. \tag{3}$$

Therefore the steady-state growth of the leader is virtually identical to that of Jones (1995a)

$$g_{A^{*}}^{ss} = \frac{\lambda n^{*}}{1-\gamma}, \tag{4}$$

where n^{*} is the exogenous growth rate of labor in the leader country.

The steady state growth of the follower country is easily determined by totally differentiating equation (2) around its steady state as

$$g_A^{ss} = \frac{\frac{\lambda n}{1-\gamma} + g_{A^{*}}^{ss}}{2} \equiv \frac{\lambda\,(n+n^{*})}{2(1-\gamma)} \tag{5}$$

[6] This follows directly by replacing A with A^{*} in equation (2) and assuming that $\delta = \mu$ in the case of the leader country. A minor difference between this specification and that of Jones, is that now γ denotes a technological externality as well as a technological share.

where n is the exogenous growth rate of labor in the follower country (to avoid "leapfrogging" we assume that $n \leq n^*$), and g_{A^*} is the balanced growth rate of the leader economy. Equation (5) states that the balanced growth path of the follower is the arithmetic mean of its own growth and the growth of the leader. The steady-state comparative statics associated with long-run growth are $\frac{\partial g_A^{ss}}{\partial n^*}, \frac{\partial g_A^{ss}}{\partial n}, \frac{\partial g_A^{ss}}{\partial \lambda}, \frac{\partial g_A^{ss}}{\partial \gamma} > 0$.

If we assume that technology share, γ, and duplication parameter, λ, are identical in all countries, then at steady state the follower country may enjoy at most the same growth rate as that of the leader depending on n. In the special case where the exogenous growth rate of labor is the same in the leader and the follower countries (i.e. $n = n^*$) then $g_A = g_{A^*}$.

Transitional growth

The transitional dynamics of the modified R&D equation (2) are investigated by running simulation exercises. Off-steady-state analysis is important in this model because it shows how a follower country's technology converges towards its steady state. Parameters used in our baseline simulation are presented in table 1. In running this simulation, we assume that

Table 1: Parameter values for the baseline simulation

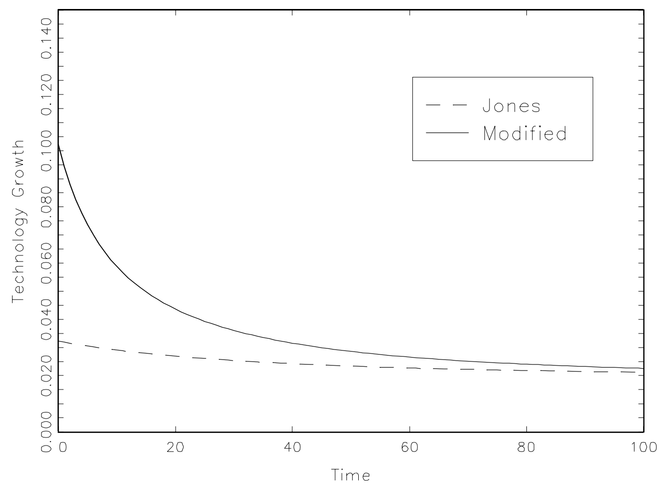
n	0.01	δ	0.1	L_0	1
γ	0.5	μ	0.01	A_0^*	10
λ	0.5	g_A^{ss}	0.5	A_0	1

technology growth of the leader country is given exogenously to the follower countries, and it is set to obtain a steady-state value of $g_{A^*} = 0.02$, to approximately match the average per capita growth rate of the U.S. over the postwar period. We also assume a permanent one percent increase in the level of labor ($n = 0.01$) and initial levels of labor and technology to be $L_0 = 1$, $A_0^* = 10$, and $A_0 = 1$. The rest of the parameters δ, μ, γ, and λ, are chosen to match commonly found values in the empirical literature and to impose the simplifying assumption that $g_A^{ss} = g_{A^*} = 0.02$.[7]

Figure 1 illustrates the transitional path of the modified R&D equation resulting from

[7] Estimates of λ found in the literature vary from 0.2 (Kortum (1993)) to 0.75 (Jones and Williams (2000)). Even though there are no empirical estimates for γ most theoretical models assume $\gamma \geq 1/2$ which implies nonnegative externalities of domestic technology.

Figure 1: Transitional growth path: Jones vs modified R&D equation

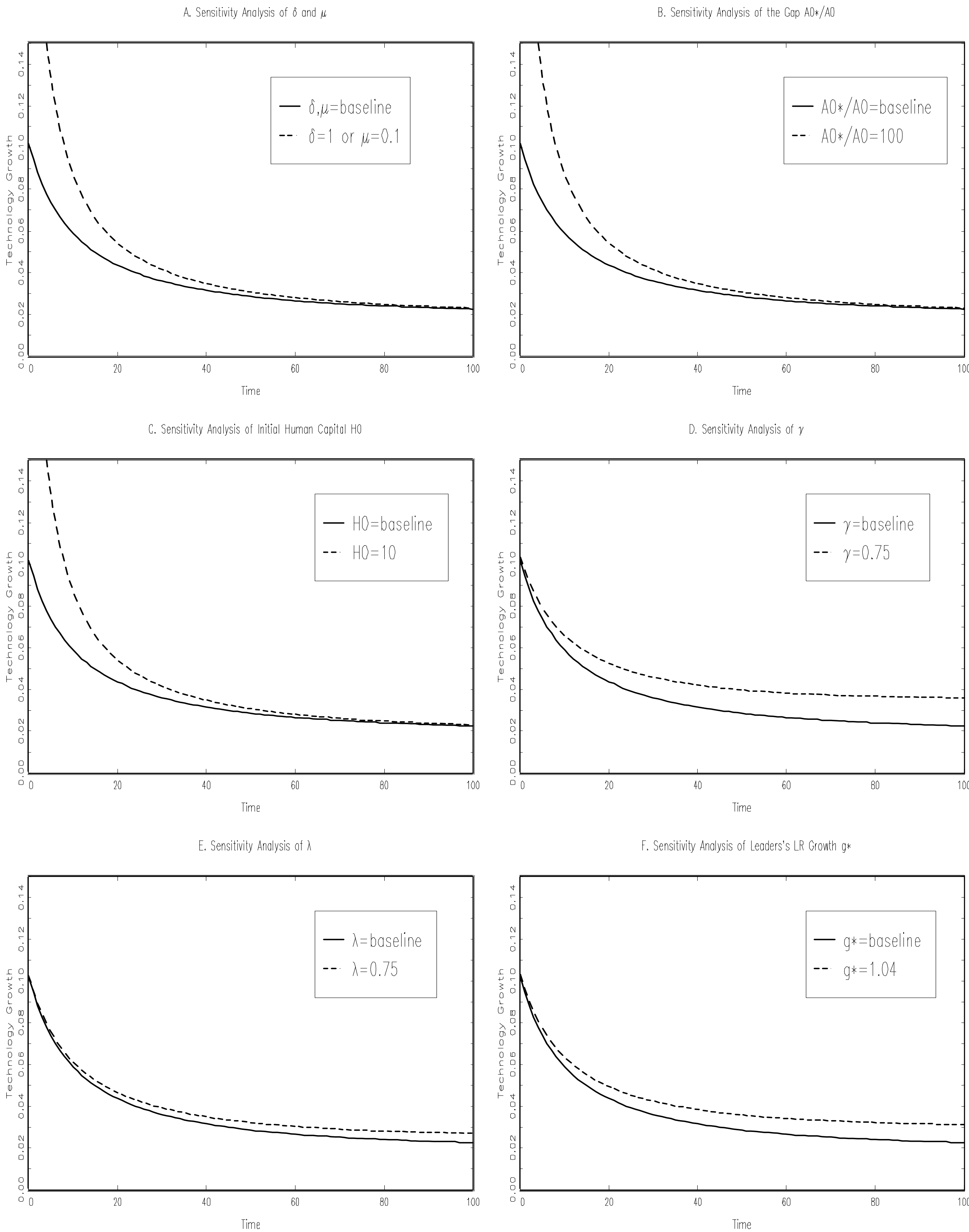


the simulation exercise. A noticeable feature of figure 1 is that the transitional growth of the follower is much faster than that predicted by Jones (1995a) model. This is expected since the follower's technological accumulation is now subject to two external effects (rather than one in Jones): the first is due to the existing domestic technology and the second is due to existing foreign technology.

To better understand the properties of the modified R&D equation, we examine how changes in relevant parameters affect the transitional growth path. Sensitivity analyses, on the parameters δ (or μ), γ, λ, the initial technology gap A_0^*/A_0, the initial level of labor L_0, and the leader's steady state growth g_{A^*}, reveal some interesting insights.

Figure 2A illustrates that a uniform increase in the domestic innovation parameter δ (or a proportional increase in the foreign adoption parameter μ), would result in much higher transitional growth path. Figure 2B reveals the importance of technological gap in this model. It shows that, everything else being equal, the wider the technology gap between the follower and the leader, the higher the transitional growth. This suggests that the further away the follower is from the technological frontier (i.e. the larger the ratio $\frac{A^*}{A}$) the greater its potential to grow rapidly by taking advantage of existing foreign technologies. Figure 2C shows that the initial level of labor is crucial in determining the ability of a country to adopt existing technology. The role of labor in this model is more important than that in Jones

Figure 2: Sensitivity analysis of baseline simulation



(1995a) in the sense that it enhances both innovation *and* imitation. Notice that changes in δ, μ, A_0^*/A_0, and L_0 can affect only the transitional growth and not the long-run growth rate.

Figures 2D, 2E, and 2F show how changes in γ, λ, and g_A^* influence transitional growth. Figure 2D reveals that a positive deviation from the baseline technological share parameter γ results in higher transitional and steady state growth. Figure 2E shows that the same is true when the duplication parameter λ increases. Finally, figure 2F illustrates how an increase in the steady-state growth of the leader results in higher transitional and steady-state growth for the follower.[8]

3. Conclusion

The most important feature of the modified R&D-based model examined above is its emphasis on technological transfers as a major determinant of growth in developing countries. The model predicts that developing economies possessing sufficiently high levels of labor can take advantage of existing technologies through the process of technological adoption and grow rapidly for a long time. However, as they continue to exploit the growth potential from technological transfers, at the same time they narrow down their technological gap with the leader which makes adoption less feasible. Another favorable features of the model is its simplicity. A single law of motion of technical change incorporates both the processes of innovation\re-invention and imitation. The models' steady-state predictions retain the favorable property of the non-scale effects while its transitional dynamics account for faster convergence to the steady state due to the imitation technology.

[8] Experiments with a large number of alternative sets of parameters do not change the results qualitatively.

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