A NONSCALE GROWTH MODEL WITH R&D AND HUMAN CAPITAL ACCUMULATION

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No 574

WARWICK ECONOMIC RESEARCH PAPERS

THE UNIVERSITY OF WARWICK

DEPARTMENT OF ECONOMICS

A Nonscale Growth Model with R&D and Human Capital Accumulation

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November 2000

Abstract

This paper aims to contribute to the new growth theory with a model in which the engine of growth is human capital growth. Building on Romer's [1990] model, two new functions are introduced: (1) A speci…cation for the production of new designs that assumes no externalities and no inventions before time zero; and (2) A speci…cation for the accumulation of human capital technically similar to that in Lucas [1988]. As opposed to Romer's model, the scale-e¤ects prediction is eliminated because technological growth does not depend on the number of researchers, but instead on the rate of growth of human capital. Moreover, the model introduced carries a new prediction: Growth depends positively on the ratio of …nal-good workers to researchers.

JEL Classi…cation: O0; O3; O4; D5.

Keywords: endogenous growth; research and development; human capital accumulation; scale-e¤ects prediction; …nal-good workers to researchers ratio.

* I wish to thank Sayantan Ghosal for his encouragement, involvement and intellectual stimulation and Marcus Miller for his insightful comments. I am also grateful to Paul Romer for his enlightenment to a doubt of mine. Financial support from Universidade do Minho-Portugal and Fundação Ciência e Tecnologia-Portugal are gratefully acknowledged. The usual disclaimer applies.

1 Introduction

Idea-based[1] growth models share with the neoclassical model the result that technological progress can overcome diminishing returns to physical capital and thus deliver sustained positive per-capita growth in the long-run. However these two kinds of model offer very different predictions about the determinants of growth. While Solow's [1956] model accepts the rate of technological progress as exogenous to the model, idea-based growth models determine the rate of technological progress within the model, which implies that in the latter models national growth rates are sensitive to national characteristics such as tastes, technology and policies.

The latest empirical research has found strong evidence of differences in levels and/or rates of growth across countries, which firmly suggests that both policy and institutions matter for economic growth (Temple, 1999)[2]. Endogenous growth models should therefore prove to be more appropriate than the neoclassical model to explain the observed diversity of growth rates.

The first-generation of idea-based growth models, due to Romer [1987, 1990], Grossman and Helpman [1991] and Aghion and Howitt [1992] come however with a scale-effects prediction which is very much at odds with the 20th-century empirical evidence, as highlighted by Jones [1995]. These models predict that the growth rate is proportional to the number of researchers and thus to the size of the population of the economy, given the assumed constant share of researchers in total population. Such prediction makes the models unable to explain why the United States and OECD countries have failed to grow faster despite substantially increased numbers of researchers in these economies.

Starting with Jones [1995], many growth economists have been active trying to eliminate the scale-effects prediction of the first-generation of idea-based models.

As defined by Jones [1999], these models fall into two groups. In the first group of nonscale growth models lie the model of Jones [1995], Kortum [1997] and Segerstrom [1998], which obtain the result that the growth rate of output per-capita is proportional to the growth rate of the population, instead of the population size. The growth rate of the population is assumed exogenous which means that these models contain the neoclassical model's prediction that neither economic policies, neither changes in tastes have an impact on the economic growth rate. Additionally, in the absence of population growth, exponential economic growth cannot be sustained in this kind of model.

The latest line of research on scale and growth includes the work of Aghion and Howitt [1998 Ch.12], Dinoupolous and Thompson [1998], Peretto [1998] and Young [1998]. These papers eliminate the scale-effects prediction by assuming that an increase in scale increases the number of products available, leaving the amount of research effort per sector (and consequently growth) unaltered. In these models, changes in policy can have effects on the long-run growth rate

[1] These endogenous growth models are also called R&D-based growth models.

[2] Mills and Crafts [1999] show that the recent OECD experience shows no tendency for the equalisation of long-run growth rates.

and in addition, they obtain exponential growth in the absence of population growth.

This paper aims to contribute to the new growth theory with a model that o¤ers an alternative mechanism through which positive growth is sustained in the long-run and that provides an alternative explanation for the observed diversity of growth rates across countries and through time.

The model proposed is a nonscale growth model which does not fall into any of the two groups analysed by Jones [1999] and above described. It is an idea-based model that contemplates human capital growth.

Human capital is de…ned here as an individual's capacity to observe, comprehend and act accordingly upon his/her environment. Accumulation of this capacity is done by the whole population either by taking extra courses; through self instruction, or learning with their family or peers.

In this framework the ultimate engine of growth is human capital growth, which is determined by the market forces originated in the R&D monopolistic competition setting.

The model's speci…cation builds on the idea-based structure of Romer's [1990] model and introduces two functions: (1) A speci…cation for the production of new designs that assumes no externalities and no inventions before time zero; and (2) A speci…cation for the accumulation of human capital technically similar to that in Lucas [1988]. It obtains a balanced growth path equilibrium with exponential growth in the absence of population growth, although a balanced growth path can equally be obtained with a growing population.

The scale-e¤ects prediction is eliminated in the new model because technological growth does not depend on the number of researchers, but instead on the rate of growth of human capital.

The new model carries the theoretically surprising result that growth depends positively on the ratio of …nal-good-workers to researchers. It explains the diversity of growth rates across countries and through time as a result of the di¤erent ratios of …nal-good-workers to researchers, and not the di¤erent numbers of researchers, as in the …rst-generation of idea-based models. Consequently, and as opposed to those models, the model introduced here is able to o¤er a possible solution to the puzzle that the developed nations's 20th-century experience posed to growth economists. It predicts that a rise in the number of researchers will lower the growth rate unless it is accompanied by a rise in the …nal-good-workers in at least the same amount as the new researchers.

As an endogenous growth model in all its essence, the new model allows for e¤ects of economic policy and trade on the economic growth rate. Namely, it is found that a subsidy to the research sector ; and trade of capital goods enhance the value of the …nal-good-workers to researchers ratio, thus leading to a higher long-run growth rate.

The paper is organised as follows. After this Introduction, Section 2 follows with the speci…cation and results of the new model. Section 3 analyses the model's implications in terms of economic policy, trade and welfare. Section 4 closes the present study with final considerations.

2 Specification of the Model

The preference structure is the standard one[3]. Infinitely lived homogeneous consumers maximise the discounted value of their representative utility:

$$\text{Max} \int_0^{\infty} e^{-\rho t} U(C_t) dt \quad ; \quad U(C) = \frac{C^{1-\sigma}}{1-\sigma};$$

where variable C_t is consumption in period t, ρ is the rate of time preference and $\frac{1}{\sigma}$ is the elasticity of substitution between consumption at two periods of time. Whatever his budget constraint is, a consumer facing a constant interest rate r, chooses to have consumption growing at the constant rate g_c given by the familiar Euler equation:

$$g_c = \frac{\dot{C}}{C} = \frac{1}{\sigma}(r - \rho) \tag{1}$$

Equation 1 expresses a positive relationship between the interest rate and the growth rate. In the $(r; g)$ space it is represented by an upward sloping curve that unites pairs $(r; g)$ that constitute balanced growth paths determined by the savings decisions of households. It is called the Preferences curve.

As in Romer [1990], the production side can be understood as having three sectors. The final goods sector, the capital goods sector and the research and development sector. The specification of the production technology for the final goods sector is the one used by Romer [1990] in the version presented by Jones [1995] and Aghion and Howitt [1998], and is adapted so as to substitute labour for effective labour, in a Lucas's [1988] fashion. The final good, Y, is produced using as inputs labour devoted to final output, L_Y, and a number A of differentiated durable capital goods, i, each produced in quantity $x(i)$. All capital goods have additively separable effects on output:

$$Y = (uhL_Y)^{1-\alpha} \int_0^{A} x(i)^{\alpha} di; \tag{2}$$

where $L_Y^e = uhL_Y$ is the effective contribution of labour to final goods production, variable u represents time devoted to working and variable h stands for a worker's level of human capital ranging from 0 to infinity.

[3] Helpman [1992] discusses the implications of using such a preference structure, namely the resulting positive relationship between the interest rate and the growth rate, which is not observed empirically. The reason why the existing growth models treat consumption in a simple way is that they are designed to analyse supply-side mechanisms of economic growth. For alternative preference structures, see Weil [1990] and Epstein and Zin [1989].

A worker with skill level h, and endowed with one unit of time per unit of time, devotes the fraction u of his non-leisure time to current production, and the remaining $1 - u$ to human capital accumulation. The model implicitly assumes that the amount of leisure is fixed exogenously so that there is no choice about it[4].

Physical capital accumulation is given by:

$$\dot{K}_t = Y_t - C_t;$$

and assuming that it takes one unit of foregone consumption to produce one unit of any type of capital good, K is related to the capital goods by the rule:

$$K = \int_0^A x(i)di;$$

People can choose whether to work in the final goods sector, or in the R&D sector:

$$L = \overline{L} = L_Y + L_A;$$

where total population L (with skill level h) is assumed constant.

In the research and development sector, the production function of designs that is introduced is:

$$A = \varepsilon(uhL_A); \quad (3)$$

where $0 \leq \varepsilon < 1$:

This specification is made upon the assumption that there is no exogenous discovery before time 0. That is, without R&D activities, the number of designs is zero.

Notice also that this specification assumes that the productivity of researchers is independent of the stock of designs. That is, in this model there are no externalities across time in the R&D process. The zero external returns assumption is adopted here, once Romer [1990] argues that whether there are increasing or decreasing returns to R&D is a philosophical question, and Jones [1995] adds that if on the one hand some discoveries like calculus are most likely to increase the productivity of the following researchers, on the other hand it is also likely that the most obvious ideas are discovered first, making it more difficult for the following researchers to discover new ideas.

According to equation 3, in a balanced growth path A will be growing at the same rate as the population's human capital h:

$$g_A = g_h$$

The specification for the human capital accumulation process is now requested in the text. It is assumed that workers can improve their human capital,

[4] See Solow [2000] for an analysis of Lucas's model with leisure.

h, by dedicating, each period, the amount of time u to working and the amount of time $1 - u$ to accumulating human capital. Human capital is defined in this model as an individual's capacity to observe, comprehend and act accordingly over his/her environment. Total population, who is assumed skilled, can increase their human capital by taking extra courses, learning by themselves, or learning with their peers or family. The human capital accumulation equation assumes a Uzawa's [1965] form:

$$\dot{h}_t = h_t \gamma (1 - u_t); \quad (4)$$

where γ is a constant reflecting the efficiency with which an individual's time spent absorbing new information translates into his/her accumulation of human capital.

Equation 4 makes it clear that a balanced growth path requires a constant u. That is, in a balanced growth path, infinitely lived people will dedicate each period a constant amount of time working and a constant amount of time learning and human capital will grow by the same constant proportion each period, up to infinity[5]. The idea is that there is always something new to learn. Skilled individuals (intentionally) keep on absorbing new information, attending formation activities, in short, accumulating human capital. This human capital benefits the productivity of workers in whatever the sector they choose to work[6].

As mentioned before, total labour in this economy is assumed skilled. To include unskilled labour in the final good production function wouldn't change the main results of the model[7]. Besides, this is a model that describes a developed economy's growth process, so Cohen's [1998] view that unskilled individuals are bound to be excluded from the economy is taken up: "a worker who does not participate in the task-upgrading efforts of society as a whole is left behind."

Moving on to the capital goods sector. Final good producers rent each capital good according to the profit maximisation rule:

$$\frac{dY}{dx(i)} = R(i);$$

which gives the inverse demand curve faced by each capital good producer:

$$R(i) = \alpha (uhL_Y)^{1-\alpha} x(i)^{\alpha - 1} \quad (5)$$

[5] If we prefer to think in terms of finitely lived individuals and infinitely lived familes, we have to assume that altruistic parents leave everything to their children, including their knowledge, which is not difficult to accept if we observe that the better educated the parents are, the greater the level of knowledge showed by their children from as early as birth.

[6] Notice that the accumulation of knowledge cannot be assumed to happen through learning-by-doing, as it would imply two different kinds of knowledge.In this model we assume that there is only a common base of knowledge which is used by workers in whatever sector they are employed.

[7] This can be seen in Romer's [1990] model by reinterpreting variable L as unskilled labour and variable H as skilled labour.

Faced with given values of L_Y and r, the capital good producer that has already incurred the fixed cost investment in a design, P_A., and has the patent on it, will choose x that maximises its revenue minus variable cost at every date:

$$\pi = \max_x R(x)x - rx$$

With a constant marginal cost and a constant elasticity demand curve, this monopolistic competitor solves his problem by charging a monopoly price which is a mark-up over marginal cost. The mark-up is determined by the elasticity of demand[8]:

$$R(i) = \frac{r}{\alpha}$$

The idea is that a firm incurs a fixed cost when it produces a new capital good. It recovers this cost by selling its good for a price that is higher than its constant marginal cost.

The decision to produce a new capital good depends on a comparison of the discounted stream of net revenues that the patent on this good will bring in the future, and the cost P_A of the initial investment in a design. The market for designs is competitive, so at every date t the price for designs will be equalised to the present value of the revenue that a monopolist can extract. This means that capital good producers earn zero profits in a present value sense. The zero-profit/free-entry condition is then:

$$\begin{aligned} P_A &= \int_0^{\infty} e^{-rt}\pi dt \qquad (6) \\ &, \\ \dot{P}_A &= rP_A - \pi; \end{aligned}$$

where the second equation is obtained assuming that there are no bubbles.

The model is solved for its balanced growth path - an equilibrium in which the variables h, A, K, C and Y grow at constant exponential rates. In a balanced growth path, the interest rate is constant. Therefore so is $R(i)$. Then the demand function faced by each capital good producer is rewritten, having in consideration the fact that the symmetry of the model implies that $R(i) = \overline{R}$ and $x(i) = \overline{x}$, to get:

$$x(i) = \overline{x} = (uhL_Y)\left[\frac{\alpha^2}{r}\right]^{\frac{1}{1-\alpha}} \qquad (7)$$

In this model x is growing at the rate:

$$g_x = g_h \qquad (8)$$

Moving now to the equilibrium in the labour market. In equilibrium, the remuneration of labour has to be the same in both the final good and the

[8] The elasticity of demand is equal to $\alpha - 1$.

R&D sectors. In the final goods sector the respective wage is equal to labour's marginal productivity:

$$w_Y = \frac{dY}{dL_Y} = (1-\alpha)uh(uhL_Y)^{-\alpha}Ax^{\alpha};$$

and in the research sector, labour's remuneration is:

$$w_A = \frac{dA}{dL_A}P_A = \varepsilon uhP_A$$

Equality implies:

$$P_A = \frac{1-\alpha}{\varepsilon}(uhL_Y)^{-\alpha}Ax^{\alpha} \tag{9}$$

Differentiation of equation 9 shows that in a balanced growth path, P_A is growing at the rate:

$$g_{pa} = g_h \tag{10}$$

So the zero-profit condition 6 now becomes:

$$g_h = \left(r - \frac{\pi}{P_A}\right) \tag{11}$$

Total physical capital, $K = Ax$ grows at:

$$g_k = 2g_h; \tag{12}$$

and output:

$$Y = (uhL_Y)^{1-\alpha}Ax^{\alpha}$$

grows at the same rate as capital. The physical capital accumulation equation guarantees that the growth rate of consumption per-capita is growing at the same rate as output and capital per-capita[9]. Then equation 11 gives:

$$g_y = 2\left(r - \alpha\frac{L_Y}{L_A}\right) \tag{13}$$

Equation 13 links pairs $(r; g)$ that constitute balanced growth paths resulting from the equilibrium conditions in the production side of the economy. It expresses a positive relationship between the interest rate and the growth rate and is called the Technology curve. It is upward sloping in the space $(r; g)$.

[9] Remember that L is constant which means that variables grow at the same rate as their per-capita counterparts.

The equilibrium balanced growth rate for this economy is found by solving the system of two equations and three endogenous variables, r, g and $\frac{L_Y}{L_A}$.

$$g = 2\left(r - \alpha\frac{L_Y}{L_A}\right) \wedge g = \frac{1}{\sigma}(r - \rho) \qquad (14)$$

There are many solutions to this system[10], as for any value of $\frac{L_Y}{L_A}$ the system determines corresponding values of r and g. For each given value of $\frac{L_Y}{L_A}$ the system's solution is represented in the space (r, g) as the point where the Technology curve and the Preferences curve cross and is equal to:

$$g = \frac{2}{2\sigma - 1}\left[\alpha\frac{L_Y}{L_A} - \rho\right] \qquad (15)$$

Notice that whether the equilibrium growth rate varies positively or negatively with the ratio $\frac{L_Y}{L_A}$; depends on the value of σ being greater than or smaller than 0.5, respectively. In fact, all the subsequent analyses about policy and trade effects on growth depend on the value of the elasticity of marginal utility.

The restriction $\sigma > 0.5$ is imposed here, having in consideration that Blanchard and Fisher [1989] state that $1/\sigma$ has been observed as normally below or close to unity, and for instance Barro and Sala-i-Martin use values of $\sigma = 2$ or 3 in their empirical studies on growth. The diagrammatic visualisation of this model is possible via Figure 1. Under the imposed restriction, the Preferences curve is steeper than the Technology curve[11].

Notice that whereas in Romer's [1990] model, the growth rate depends positively on the number of researchers which is determined by the labour and output equilibrium conditions, in this model the growth rate depends on the decision to accumulate human capital. Along a balanced growth path, the economy grows forever at an exponential rate which is determined by the whole population's choice in terms of human capital accumulation. This human capital is homogeneous and benefits the productivity of all the workers in the economy.

Diversity of growth rates across countries or through time can be explained by the diverse values of the ratio $\frac{L_Y}{L_A}$ for every other variables held constant.

3 Implications of the Model

3.1 No scale-effects prediction

Equation 15 shows that the economic growth rate does not depend on the size of the population. Indeed doubling L would correspond to doubling both L_Y and L_A, given the constant share of each on total labour in a balanced growth path, thus leaving the growth rate unaltered.

[10] Provided parameter values are chosen so as to ensure that the growth rate is not greater than the interest rate, as otherwise present values will not be finite and the integral that defines consumers utility diverges.

[11] Note that this restriction implies that $\alpha\frac{L_Y}{L_A}$ is greater than ρ.

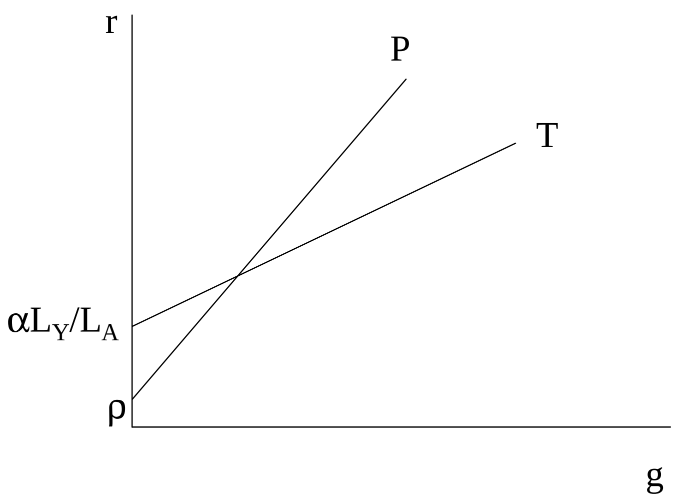

Figure 1:

The elimination of the scale-effects prediction is an important result, because this prediction characterises Romer's [1990] model and virtually all the first-generation idea-based models and it is not empirically supported, as highlighted by Jones [1995] and referred to in the Introduction.

The source of scale-effects in the first-generation of idea-based models lies in their specification of the R&D equation. In Romer [1990] that equation is:

$$\dot{A} = \delta A L_A \qquad (16)$$

With such a specification, the growth rate of designs is $g_A = \delta L_A$. Therefore a balanced growth path solution requires a constant L_A, and the growth rate is proportional to the number of workers engaged in research. In Romer [1990] the equilibrium growth rate is:

$$g_y = g_A = \frac{\alpha\delta\bar{L} - \rho}{\alpha + \sigma} \qquad (17)$$

With a constant share of total labour dedicated to R&D, the economic growth rate is proportional to the size of the labour force of the economy.

Jones [1995] writes that this scale-effects prediction is easily empirically rejected. The labour force has grown immensely in the developed economies over the last 25 to 100 years, and average growth rates have been relatively constant or have even declined. Jones also writes that evidence against the R&D equation is also compelling. In the United States, for instance, the number of workers engaged in R&D grew by more than a factor of 5 from 1950 to 1988 and the average growth rate has remained relatively constant or has even declined. He adds that even accounting for lags associated with R&D wouldn't reverse the rejection of the scale-effects prediction.

Jones [1995] proposes to find a way to preserve the idea-based structure of Romer's model, while eliminating the prediction of the scale-effects. He transforms the original R&D equation 16 into:

$$\dot{A} = \delta A^{\phi} L_{A}^{\lambda\; -1}; \tag{18}$$

where $0 < \lambda \leq 1$ and $\phi < 1$. Equation 18 implies that a balanced growth path solution requires that:

$$g_A = \frac{\lambda g_{LA}}{1 - \phi} \tag{19}$$

The share of L_A in L is fixed, so $g_{LA} = g_{LY} = g_L$. And the growth rate of the population is taken as exogenous to the model. Jones's [1995] equilibrium growth rate of output per-capita is:

$$g_y = \frac{\lambda g_L}{1 - \phi} \tag{20}$$

In making the growth rate of output per-capita dependent on an exogenously determined variable, Jones's model places the engine of economic growth outside of the model, returning to the neoclassical exogenous growth model in terms of its implications for long-run growth, namely that neither policy nor changes in tastes are capable of increasing economic growth.

Jones's [1995] prediction that population growth is the fundamental engine of per-capita growth is also easily rejected empirically. Moreover in Jones's model there is no economic growth in the absence of population growth.

By contrast, the model introduced in Section 2 preserves the structure of an idea-based model[12] and has the advantage of not displaying the scale-effects prediction. Moreover, and as opposed to Jones's [1995], it is an endogenous growth model in all its essence. The engine of growth, which is the growth of human capital, is determined within the model by the existing market forces and is thus influenced by economic policy and other national characteristics.

3.2 Policy Effects on Growth

An increase in $\frac{L_Y}{L_A}$ shifts the Technology curve to the left leading to a new balanced growth path with a higher growth rate and a higher interest rate, as represented in Figure 2, below.

The model delivers the theoretically surprising result that output per-capita growth depends positively on the ratio $\frac{L_Y}{L_A}$, meaning that the higher the proportion of workers engaged in final good production relative to those dedicated to research, the higher the growth rate of the economy. Although surprising,

[12] Jones [1995] praises R&D-based models for being intuitively very appealing and having strong microfoundations.

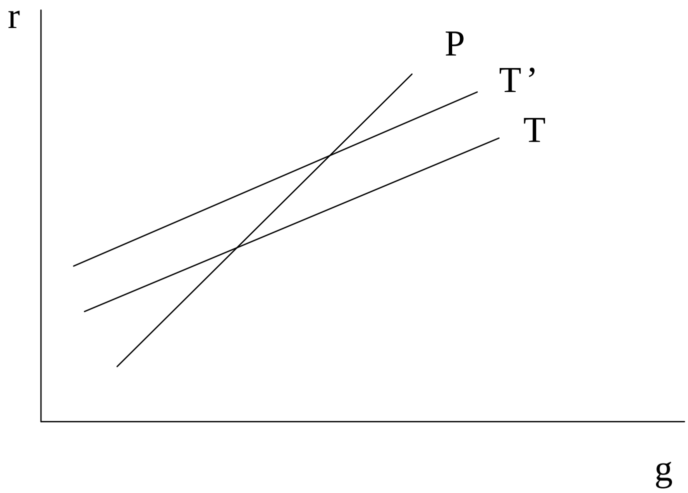

Figure 2:

this result might explain why in many advanced countries average growth rates have not risen or have even declined, despite an increase in their R&D intensity. Notice however, that this economy needs researchers. The solution would be indeterminate if L_A were zero.

Consider a subsidy to the R&D sector financed by lump-sum taxes. It will modify the labour market equilibrium condition 9 into:

$$P_A = \frac{1-\alpha}{(1+s)\varepsilon}(uhL_Y)^{-\alpha}Ax^{\alpha}; \tag{21}$$

which changes the Technology curve into:

$$g = 2\left[r - (1+s)\alpha\frac{L_Y}{L_A}\right]; \tag{22}$$

meaning that the new Technology curve lies to the left of the old one, like in Figure 2. By enhancing the value of the ratio $\frac{L_Y}{L_A}$; the subsidy to the R&D sector influences the growth rate of the economy positively. The subsidy makes the equilibrium in the labour market require a lower patent price. This lower cost relative to capital good producers' profits makes more of them wish to enter the market. The increased demand for credit raises the interest rate, which leads to higher savings and consequently higher growth.

3.3 Trade Effects

Rivera-Batiz and Romer [1991] use Romer's [1990] model to analyse the effects of trade in capital goods on growth, finding that flows of capital goods have no effect on the long-run growth rate unless their are accompanied by flows of ideas. It is shown below that with this new model, trade of capital goods alone does increase the growth rate of the economy.

The assumptions of this exercise are:

(i) Symmetry between the two countries implies that there are no opportunities for intertemporal trade along a balanced growth path;

(ii) There is only one single final consumption good (with price equal to unity). Therefore the only trade that occurs is that of capital goods;

(iii) The two economies are identical, that is, $L = L^*$ and $A = A^*$.

Assuming no redundancy in the production of new designs, trade in capital goods doubles the number of capital goods available to final goods producers:

$$Y^T = (uhL_Y)^{1-\alpha} \int_0^{2A} x(i)^{\alpha} di \qquad (23)$$

Then each capital good producer sees the demand for its good double:

$$x^T = 2(uhL_Y)\left[\frac{\alpha^2}{r}\right]^{\frac{1}{1-\alpha}} = 2x^C; \qquad (24)$$

and consequently:

$$\pi^T = 2\pi^C;$$

where the T-nomenclature stands for the trade economy and the C-letter stands for the closed economy variables.

The marginal productivity of labour in the final goods sector becomes:

$$w^T = \frac{dY^T}{dL_Y} = (1-\alpha)uh(uh2L_Y)^{-\alpha}2A(2x)^{\alpha};$$

and researchers see the demand for their inventions double, so remuneration in the research sector becomes:

$$w^T = \eta uh2P_A$$

Then equilibrium in the labour market means:

$$P_A = \frac{1-\alpha}{\eta}(uh2L_Y)^{-\alpha}A(2x)^{\alpha} \qquad (25)$$

$$\Rightarrow$$

$$P_A^T = P_A^C$$

Now recall the zero-profit condition 11:

$$g_y^C = 2g_h^C = 2\left[r - \frac{\pi^C}{P_A^C}\right]$$

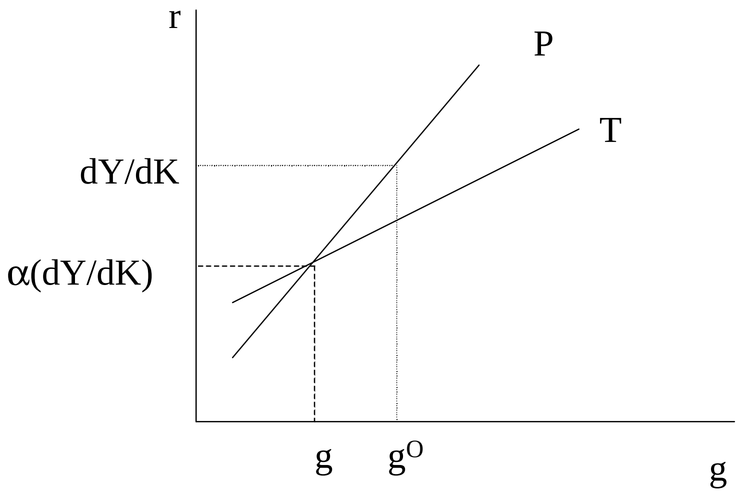

Figure 3:

With trade in capital goods, it becomes:

$$g^T = 2\left(r - 2\frac{\pi^C}{P_A^C}\right); \tag{26}$$

which means, in graphic terms, that the Technology curve with trade lies to the left of the same curve in the closed economy (again like in Figure 2), resulting in an equilibrium balanced growth path with a higher growth rate of output per-capita and a higher interest rate. The equilibrium growth rate in the economy with trade is:

$$g^T = \frac{2}{2\sigma - 1}\left(2\alpha\frac{L_Y}{L_A} - \rho\right) \tag{27}$$

Facing a larger market, capital good producers have higher profits and so more of them will want to enter the market. The higher demand for credit raises the interest rate. A higher interest rate in turn, makes saving more appealing, which translates into a higher growth rate.

3.4 Welfare Properties

Monopolistic competition in the capital goods market is responsible for a higher than marginal cost renting price of each capital good, $R = \frac{r}{\alpha}$. This implies that the equilibrium interest rate is not equal to the marginal productivity of capital, but instead it is equal to $r = \alpha R = \alpha\frac{dY}{dK}$; which is lower than the marginal productivity of capital, as depicted in Figure 3. The optimal solution corresponds to a higher point along the Preferences curve. To achieve this equilibrium, the

Technology curve would have to lie to the left of the decentralised equilibrium one, which means that the decentralised equilibrium has a lower $\frac{L_Y}{L_A}$ ratio than the optimal equilibrium.

4 Final Considerations

A new growth model has been created that brings together into the same framework research and development activities and human capital accumulation. In this framework, the ultimate engine of growth is human capital growth, which is determined by the market forces at play in the R&D monopolistic competition setting.

Human capital is interpreted as the capacity to observe, comprehend and act accordingly upon the (working) environment, influencing positively the worker's productivity. Accumulation of human capital is done in a Lucas's [1988] fashion by the whole population and improves not only researchers' productivity, but also the productivity of workers in the final goods sector.

In this idea-based model, the specification of the production of new designs assumes that there are no externalities from the existing stock of designs into the productivity of researchers, and also assumes that there are no inventions before time zero. With this specification, technological growth does not depend on the number of researchers, but instead it depends on the rate of growth of human capital. As a result, the scale-effects prediction that characterises the first-generation of idea-based models is not present in this model.

This paper contributes theoretically to the recent literature on nonscale growth models, referred to in the Introduction. The model introduced here is structurally distinct from the second group of referred frameworks. Its structure is closer to the first group of nonscale growth models, although its engine of growth is not the exogenously determined population growth, but instead the endogenously determined human capital growth. As a result, growth is influenced by policy decisions. Additionally, the model obtains a balanced growth path equilibrium with exponential growth with or without population growth.

The model predicts that the growth rate of output per-capita depends positively on the ratio of final-good workers to researchers. According to this prediction, raising the number of researchers will have a negative impact on the growth rate unless it is accompanied by a rise in the number of final good workers of no less than the same amount of the new researchers. This might serve as a clue as to why the developed countries have invested so much in human capital and research and development, and have yet failed to experience higher growth rates in the now ending century.

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