On the Effectiveness of Growth-Enhancing Policies in a Model of Growth Without Scale Effects

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Abstract. Standard R&D growth models have two disturbing properties: the presence of scale effects (i.e., the prediction that larger economies grow faster) and the implication that there is a multitude of growth-enhancing policies. Recent models of growth without scale effects, such as Segerstrom’s (1998), not only remove the counterfactual scale effect, but also imply that the growth rate does not react to any kind of economic policy. They share a different disturbing property, however: economic growth depends positively on population growth, and the economy cannot grow in the absence of population growth. The present paper integrates human capital accumulation into Segerstrom’s (1998) model of growth without scale effects. Consistent with many empirical studies, growth is positively related not to population growth, but to investment in human capital. And there is one way to accelerate growth: subsidizing education.

1. INTRODUCTION

Two robust properties of standard R&D growth models (see Romer, 1990; Grossman and Helpman, 1991; Aghion and Howitt, 1992) are the presence of scale effects and policy efficacy: growth rates depend positively on the scale of the economy (measured by population size) and on various policy instruments. Both of these predictions are at odds with the empirical facts. Backus et al. (1992) demonstrate the non-existence of scale effects. And fostering long-run economic growth does not appear to be an easy task (which country would choose not to do so?).

In response to these peculiarities, the literature on growth without scale effects, originating from Jones (1995), has appeared on the scene. Non-scale growth models eliminate the scale effects by assuming that, since technological change becomes more difficult to sustain as technology progresses, long-run growth is not feasible with a constant level of inputs in R&D. Rather economic growth depends on the rate of change of the factors used in R&D. The precise conditions necessary for ongoing growth are by now well understood (see...
Eicher and Turnovsky, 1999; Jones, 1999; Li, 2000). In most of these models, the only input in R&D is labor, so that the pace of technological change depends positively on population growth, and the economy cannot grow in the absence of population growth. Another important implication is that the long-run growth rate is independent of policy measures. A notable example of this strand of the literature is Segerstrom’s (1998) quality-upgrading model. However, some Western industrial economies with stagnating population do grow, and the coefficient of population growth in cross-country productivity growth regressions tends to be negative (see, e.g., Levine and Renelt, 1992).

The present paper offers a straightforward way to deal with this problem: we replace population growth with human capital accumulation in Segerstrom’s (1998) model of growth without scale effects. Economic growth does not presuppose population growth in the resulting model. Consistent with cross-country growth regressions (e.g. Levine and Renelt, 1992), economic growth depends positively on investment in human capital. We demonstrate that the policy-infficacy result of the Segerstrom-type models has to be qualified in one respect: education subsidies strengthen the incentives to invest in education and thereby spur growth. We wish to emphasize, however, that this policy-efficacy result should be regarded with the necessary caution. In standard R&D growth models with scale effects, all that is needed to speed up growth is a reallocation of labor from production to R&D. In the model considered here, an increase in the long-run rate of growth requires heavier investment in education, which enables workers to improve their performance in leading-edge R&D. Both the involved time lags and the practical difficulties encountered in improving educational attainments are obvious. Moreover, the model ignores additional obstacles to growth-enhancing policies, such as low marginal returns to human capital in R&D and international knowledge spillovers (on this see Arnold, 1999).

Section 2 introduces the model. In Section 3, the steady-state equilibrium is derived. Section 4 concludes.

1. In the first volume of the German Economic Review, Eicher et al. (2000) have presented an interesting application of this non-scale growth model to international capital flows.

2. Young (1998) and Howitt (1999) offer an alternative explanation for why growth is independent of the scale of the economy. There are two kinds of R&D: product improvement and product development. The former drives growth. When the labor force grows, product variety increases, but growth does not accelerate because R&D aimed at quality improvements is not affected.

3. A similar analysis in a model with horizontal innovation can be found in Arnold (1997, Chs. 17–19; 1998; 2000) and in Blackburn et al. (2000). Related studies of the interaction of human capital and R&D are in Eicher (1996) and Lloyd-Ellis and Roberts (2000).

4. Of course, growth also depends positively on the quality of education, as pointed out by Hanushek and Kimko (2000) and Barro (2001).
2. MODEL

Consider a closed economy inhabited by a continuum of constant length \( l > 0 \) of identical households. \( l \) measures the scale of the economy. Each individual owns \( h(t) \) units of human capital. By devoting \( h_\delta(t) \) units of human capital to education at time \( t \) individuals raise their human capital by an amount

\[
\dot{h}(t) = \delta h_\delta(t)
\]

(\( \delta > 0 \) and \( h(0) > 0 \)). This is the Uzawa–Lucas education technology. The aggregate supply of human capital at \( t \) is \( L(t) \equiv lh(t) \). Households maximize the intertemporal utility function \( \int_0^\infty e^{-\rho t} \log(u(t)) dt \), where \( \rho > 0 \) is the subjective discount rate and \( u(t) \) is the instantaneous utility function (in what follows, the time argument is suppressed). Education is subsidized: the government pays households a constant fraction \( s_\delta \) of the forgone income \( wh_\delta \) (\( w \) is the wage rate per unit of human capital). There is a continuum of industries indexed by \( \omega \in [0, 1] \). In each industry different qualities \( j \) can be produced (\( j \geq 0 \) takes on integer values only). The highest quality producible in industry \( \omega \) is denoted \( j(\omega) \). Instantaneous utility \( u \) is given by

\[
\log u = \int_0^1 \log(\sum_{j=0}^{j(\omega)} \lambda d(j, \omega)) d\omega,
\]

where \( d(j, \omega) \) denotes consumption per capita of quality \( j \) produced in industry \( \omega \). It is assumed that \( \lambda > 1 \). Hence, the higher the quality of a unit of goods from industry \( \omega \), the greater its contribution to instantaneous utility. One unit of goods of each known quality \( j \) in each industry \( \omega \) is obtained from one unit of human capital. Producers of different qualities in an industry compete in prices. Firms employ human capital in R&D so as to invent new qualities. If the state-of-the-art quality in industry \( \omega \) is \( j(\omega) \), a firm that accomplishes an invention learns to produce quality \( j(\omega) + 1 \) and receives a patent which makes it a monopolist for the newly invented quality. The instantaneous probability of a quality improvement in industry \( \omega \) in a short time interval \( dt \) is denoted \( I(\omega)dt \). The arrival rate \( I(\omega) \) depends on \( L_\omega(\omega) \), the amount of human capital engaged in R&D aimed at industry \( \omega \), and on \( X(\omega) \), the difficulty of R&D in industry \( \omega \):

\[
I(\omega) = \frac{AL_\omega(\omega)}{X(\omega)}
\]

(\( A > 0 \)). The difficulty of R&D increases with current R&D efforts:

\[
\frac{\dot{X}(\omega)}{X(\omega)} = \mu I(\omega)
\]
(with \( \mu > 0 \) and \( X(\omega) > 0 \) for all \( \omega \) at \( t = 0 \)). The government pays a constant fraction \( s_R \) of each firm’s R&D costs. There is free entry into R&D. Risk is diversified completely in a perfect stock market. All markets always clear.

3. EQUILIBRIUM

In equilibrium, expenditure is distributed evenly across industries; quality leaders set the limit price \( \lambda w \) for their quality \( j(\omega) \); producers of lower qualities are inactive. Hence, per capita consumption equals \( d(\lambda w) = c/(\lambda w) \), where \( c \) denotes expenditure per capita. Quality leaders earn profit \( \pi^L = (\lambda - 1)cI/\lambda \). Because profits are the same in each industry, we can assume that R&D efforts are spread evenly across industries, so that the arrival rate \( I \) is the same in all industries. For future reference, notice that the number of quality jumps in a short interval \( dt \) is equal to the uniform probability of a quality jump in a single market: \( d[\int_0^1 j(\omega)d\omega] = I dt \). Instantaneous utility can be rewritten as

\[
\log u = \log c - \log w - \log \lambda + \log \lambda \int_0^1 j(\omega)d\omega
\]

(4)

Households thus maximize \( \int_0^\infty e^{-\rho t} \log c dt \) subject to (1) and their budget constraint \( a = ra + w(h - h_\delta) + s_\delta wh_\delta - c \), where \( a \) is per capita asset holdings and \( r \) is the safe interest rate realized in the stock market. The current value Hamiltonian for this problem is \( \mathcal{H} = \log c + \theta_a[ra + w(h - h_\delta) + s_\delta wh_\delta - c] + \theta_\delta \delta h_\delta \), where \( \theta_a \) and \( \theta_\delta \) are the co-state variables associated with the budget constraint and (1), respectively. The necessary and sufficient conditions for an interior maximum are:

\[
\frac{\partial \mathcal{H}}{\partial c} = \frac{1}{c} - \theta_a = 0
\]

(5)

\[
\frac{\dot{\theta}_a}{\theta_a} = \rho - 1 \frac{\partial \mathcal{H}}{\partial a} = \rho - r
\]

(6)

\[
\frac{\partial \mathcal{H}}{\partial h_\delta} = -\theta_a(1 - s_\delta)w + \theta_\delta \delta = 0
\]

(7)

\[
\frac{\dot{\theta}_\delta}{\theta_\delta} = \rho - 1 \frac{\partial \mathcal{H}}{\partial h} = \rho - \frac{\theta_a}{\theta_\delta} w
\]

(8)

Conditions (5) and (6) yield the Ramsey rule for an optimal expenditure profile: \( \dot{c}/c = r - \rho \). Differentiating (7) with respect to time gives \( \dot{w}/w = \dot{\theta}_\delta/\theta_\delta - \dot{\theta}_a/\theta_a \). Inserting \( \theta_\delta/\theta_\delta = \rho - \delta/(1 - s_\delta) \) (from (7) and (8)) and \( \theta_a/\theta_a = \rho - r \) (equation (6)), one obtains
The stronger future income is discounted (i.e. the greater \( r \)), the lower the effectiveness of education \( \delta \), and the lower the education subsidy \( s_\delta \), the higher the growth rate of wages required to induce investment in human capital. Having solved the households’ optimization problem, we are already in a position to determine the steady-state growth rate of the economy.\(^6\) We normalize the wage rate such that \( w_h = 1 \). Consider a steady state in which the shares of human capital in its different uses (production, R&D, and education) are constant. Human capital per capita devoted to production is \( h_d = w^* \). It follows that \( w_h = \hat{c} = \frac{\delta}{1-s_\delta} \). Since \( h \) grows like \( h^* \), we have \( \hat{h}/h = \frac{\delta}{1-s_\delta} - \rho \)

\[
\frac{\hat{h}}{h} = \frac{\delta}{1-s_\delta} - \rho
\]  

(10)

This expression also gives the growth rate of aggregate human capital: \( \frac{\dot{L}}{L} = \frac{\dot{h}}{h} \). In order to have an interior solution (\( 0 < h_k < h \)), it is assumed that \( s_k/(1-s_k) < \rho/\delta < 1/(1-s_k) \). Equation (3) implies that \( I \) is constant in a steady state. Using (2) and the fact that \( L_1/L \) is constant if the shares of human capital in its different uses are constant, we have \( \hat{I} = X/X = L_1/L_1 = \hat{L}/L = \frac{\hat{h}}{h} \) and, using (10),\(^7\)

\[
I = \frac{1}{\mu} \left( \frac{\delta}{1-s_\delta} - \rho \right)
\]  

(11)

Differentiating (4) with respect to time gives \( \dot{u}/u = \dot{c}/c - \dot{w}/w + I \log \lambda \). Inserting \( \dot{c}/c = 0, \dot{w}/w = \rho - \delta/(1-s_\delta), d\int_0^1 j(\omega) d\omega = I dt \), and the expression for \( I \) in (11), we obtain

\[
\frac{\dot{u}}{u} = \left( 1 + \frac{\log \lambda}{\mu} \right) \left( \frac{\delta}{1-s_\delta} - \rho \right)
\]

Steady-state utility growth depends positively on the effectiveness of education \( \delta \) and on the size of the quality improvements \( \lambda \). It depends negatively on the discount rate \( \rho \) and the parameter \( \mu \), which measures the impact of current

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R&D on the difficulty of future R&D. The steady-state growth rate is independent of the scale parameter \( l \). Contrary to Segerstrom (1998), positive population growth is not a necessary condition for utility growth; the economy grows despite the fact that population is constant. Importantly, \( \dot{u}/u \) is independent of the R&D subsidy \( s_R \), but increases in the education subsidy \( s_e \) raise the steady-state growth rate.

We now complete the description of the steady-state equilibrium. Let \( v \) denote the value of a patent, i.e. the expected present value of the stream of monopoly profits \( \pi^L \). Free entry into R&D implies \( v = (1 - s_R)WL_I \) or, using (2) and \( wh = 1 \), \( v = (1 - s_R)wX/A = (1 - s_R)X/(hA) \). It follows that \( \dot{v}/v = X/X - h/h = L/L - \dot{h}/h = 0 \). Absence of arbitrage opportunities entails \( v = \pi^L/(r - \dot{v}/v + I) = [(\lambda - 1)/\lambda]c\{\rho + [\delta/(1 - s_\delta) - \rho]/\mu\} \). Taken together, free entry and absence of arbitrage opportunities thus yield

\[
(1 - s_R)x = \frac{\lambda - 1}{\lambda}c \frac{\rho}{\mu \left(1 - s_\delta - \rho\right)}
\]

where \( x \equiv X/(hl) \equiv X/L \). Equilibrium in the market for human capital requires \( l(h - h_\delta) = L_I + lh_\lambda \) or, using (1), (10), (2), (11), and \( h_\lambda = c/(\lambda w) \equiv ch/\lambda \),

\[
- \frac{s_\delta}{1 - s_\delta} + \frac{\rho}{\delta} = \frac{1}{\mu A} \left( \frac{\delta}{1 - s_\delta - \rho} \right) x + \frac{c}{\lambda}
\]

These two equations determine the equilibrium levels of \( x \) and \( c \). A unique solution exists, with the property that \( x \) increases with \( s_R \). As \( L_I/L = XI/(AL) = [\delta/(1 - s_\delta) - \rho]x/\mu A \), the steady-state ratio of human capital in R&D to total human capital increases with the R&D subsidy, but the growth rate of the economy is unaffected.

Parameter changes that raise investment in human capital, as measured by the steady-state ratio of human capital in education to total human capital \( L_e/L \), also raise the steady-state R&D intensity \( I \) and the steady-state growth rate of instantaneous utility \( \dot{u}/u \). To see this, notice that the steady-state ratio of human capital in education to total human capital equals \( L_e/L = h_e/h = (h/h)/\delta = 1/(1 - s_\delta) - \rho/\delta \). \( L_e/L \) increases if \( \delta \) rises, \( \rho \) falls, or \( s_\delta \) rises. These parameter changes are also associated with increases in \( I = [\delta/(1 - s_\delta) - \rho]/\mu \) and \( \dot{u}/u \). Hence the model is capable of explaining the positive correlation between investment in human capital and growth.

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8. The growth rate is independent of many other policy measures, including flat-rate labor income taxes, flat-rate capital income taxes, production subsidies, and basic research.

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4. CONCLUSION

Recent non-scale growth models, such as Segerstrom’s (1998), have accomplished a valuable task by removing the counterfactual scale effects present in the first generation of R&D growth models and by putting into perspective the potency of economic policies in raising long-run growth rates. A disturbing property of many non-scale growth models, including Segerstrom’s (1998), is that positive growth is not sustainable in the absence of population growth. The present paper offers a straightforward solution to this problem: replacing population growth with human capital accumulation. In the resulting model, economic growth does not presuppose population growth. Consistent with the data, the rate of productivity growth is positively related to investment in human capital. Contrary to Segerstrom (1998), there is one way to speed up long-run growth: subsidizing education. We are eager to remark that we do not consider this finding as a rehabilitation of the implication of the first-generation R&D models that it is rather easy to boost growth. For one thing, education policy is the only kind of policy that has growth rate effects. For another, the impact of education policy on growth is indirect and naturally subject to significant time lags.9 What the analysis does is aggravate the concerns of the countries which performed badly in the TIMSS study and the more recent PISA study. Finally, our stylized model ignores the practical difficulties policy-makers encounter in improving educational attainments as well as other obstacles to increasing the long-run growth rate, such as low marginal returns to human capital in R&D and international knowledge spillovers.

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9. I.e., technically speaking, transitional dynamics.


