Without Scale Effects, Does Population Growth Matter?

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Abstract

The use of the R&D-based endogenous growth models that emerged in the early 1990s subsequently declined because their scale-effect conclusion that a larger population leads to a higher per-capita GDP growth rate could not be supported empirically (see Jones 1995). However, the prediction of Jones' modified model—that the per-capita GDP growth rate would be related linearly and positively to the population growth rate—also contradicts some empirical evidence because these two variables are usually negatively correlated. In this paper, we reconstruct an R&D-based growth model that accounts for possible diminishing returns to the factor inputs of both researcher strength and per-capita technology level, thereby overcoming the counterevidence issues of first- and second-generation R&D-based endogenous growth models. The empirical evidence presented herein shows that the growth rate of R&D researcher strength has to be sufficiently higher than that of the population to guarantee a positive per-capita GDP growth rate.

Keywords: Scale effects; R&D; Endogenous growth

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I. Introduction

The term "scale effect" in the literature of economic growth suggests that an economy with more workers would generate more ideas and hence achieve a higher growth rate. Theoretical R&D-based models such as Romer (1990), Aghion and Howitt (1992), and Grossman and Helpman (1991) are representative studies concluding that scale effects exist. These models all agree that the returns to the inputs of both technology level and researcher strength in the R&D sector are equal to unity because of the standing-on-the-shoulder-of-giants effect and so guarantee endogenous growth. In a balanced growth path, the per-capita GDP growth rate can be determined by the number of researchers in an economy, which is proportional to the total population level.

The above-mentioned first-generation R&D-based endogenous growth models have been applied to many theoretical and empirical studies. For instance, Funke and Strulik (2000) and Arnold (2000) developed an endogenous multi-sector growth model that includes accumulation of physical capital, human capital, and product variety and discuss the dynamical properties of the system. Borensztein *et al.* (1998) empirically estimated the contribution of foreign direct investment to the economic growth rates in OECD countries by following Romer's (1990) theoretical framework. These theoretical and empirical applications of the first-generation R&D models, however, were later proved invalid by Jones (1995).

Jones (1995) claimed that the implication of scale effects in any R&D growth model is inconsistent with the macroeconomic data of any country. An exponential growth in population level cannot be the cause of a business-cycle-like per-capita GDP growth rate. Therefore, the first-generation R&D models need fundamental revision. Instead of non-diminishing returns to technologies in the R&D sector, Jones (1995) reckoned that past discoveries make it increasingly difficult to discover new ideas. Therefore, Jones (1995) broke down the key R&D equation in the first-generation models and reached plausible results with no scale effects. His ideas thereafter became a caution for other researchers constructing R&D-based endogenous growth models and inspired many subsequent studies. For instance, Sequeira (2011) revised the theoretical framework constructed by Funke and Strulik (2000) and Arnold (2000) that took into account the de-scaling effects in the R&D sector so that the returns to the input of technology is diminishing.

Jones (1995) removed the scale effects from the R&D-based models. However, in his modified model, the ratio of per-capita GDP growth rate to population growth rate is constant and positive. Such a positive correlation between these two variables still contradicts some empirical data, especially in developing countries. This means that the technological accumulation process needs more re-consideration, especially the returns to accumulable factors.

In this paper, such re-consideration advances Jones' R&D-based model and gives us more convincing and consistent theoretical results based on empirical facts. The next section reviews Jones' model, discusses its inconsistencies with data, re-considers the nature of the R&D sector, and then modifies his work. Section III demonstrates how the revised model in Section II fits the US macro data, and Section IV concludes this paper.

II. Review and Revision of R&D-based Growth Models

The R&D-based endogenous growth models in early 1990s were generalized by Jones (1995) in the following reduced-form equations:

$$Y = K^{1-\alpha}(AL_Y)^{\alpha},\ \alpha \in (0,1) \text{ and} \tag{1}$$

$$\dot{A} = \delta L_A A,\ \delta > 0. \tag{2}$$

In equations (1) and (2), Y, A, and K represent respectively output, technology, and capital stock and δ is a constant efficiency parameter in upgrading technology levels. Both the production sector (equation (1)) and R&D sector (equation (2)) require labor inputs. The total labor level, L, in the economy is allocated to either producing final output (L_Y) or innovating new technologies (L_A), so $L = L_Y + L_A$. Because of non-diminishing returns to factor inputs (L_A and A) in the R&D sector, technology levels grow at the following steady-state constant rate:

$$\gamma_A = \dot{A}/A = \delta s^* L, \tag{3}$$

where s^* is the steady-state share of labor devoted to R&D sector, (L_A/L); γ_x denotes the growth rate of variable x henceforth. If we re-write equation (1) in per-worker form and take log-differentiation, the steady-state per-capita output growth rate (γ_y) will be equal to γ_A in equation (3). This implies that a larger population level with more workers leads to a higher growth rate in both per-capita output and aggregate technology levels. Such scale effects contradict empirical evidence because the population level of an economy always grows exponentially but per-capita GDP growth rates fluctuate around some constant level (one to two percent on average in high-income western countries). Thus, the assumption of non-diminishing returns to factor inputs in the R&D sector imposed by Romer (1990), Aghion and Howitt (1992), and Grossman and Helpman (1991) is not plausible and invokes the following alternative R&D equation of Jones:

$$\dot{A} = \delta L_A A^{\phi}, \ \phi \in (0,1). \tag{4}$$

Equation (4) demonstrates that technological progress gets harder with more and more advanced innovations, and therefore the marginal returns of technology input, A, get diminished in the R&D sector. With non-unitary production elasticity, the steady-state growth rate of A and per-capita output, y, is constant and equals

$$\gamma_y = \gamma_A = \frac{n}{1-\phi}, \tag{5}$$

where n is the population growth rate. In equation (5), the numerator on the right-hand side should be the growth rate of the number of scientists (γ_{L_A}), n replaces it because on page 520 in Jones (1995), it is stated that "in the steady state the growth rate of the number of scientists can be no greater than the rate of population growth." In the next section, we will empirically show that this statement is incorrect. In addition, the per-capita GDP growth rate cannot be some positive and linear function of population growth (given that $\phi \in (0,1)$), especially in developing countries. For instance, using a sample of 43 developing countries, Dyson (2010) found that the per-capita GDP growth rate is linearly and negatively dependent on population growth. By definition, the per capita output growth rate equals the growth rate of the aggregate output minus the population growth rate; that is, $\gamma_y = \gamma_Y - n$. Therefore, equation (5) holds only when the growth rate of the aggregate output, γ_Y, equals $(2-\phi)/(1-\phi)$ multiplied by the population growth rate. For example, if $\phi = 0.5$, $\gamma_Y = 3n$ validates equation (5). The more close ϕ gets to unity, the more close the ratio of γ_Y to n gets to infinity, and the more difficult for the results in equation (5) to hold.

Just like empirical observations did not support the existence of scale effects, the positive correlation between the per-capita GDP growth rate and population growth rate proposed by Jones (1995) is also unconvincing and needs some further modification. An alternative setting and explanation of his R&D equation can be considered as follows:

$$\dot{A} = \delta L_A^{\psi} \left(\frac{A}{L}\right)^{\phi}, \text{ where } \psi, \phi \in (0,1). \tag{6}$$

In equation (6), the increment of A shows diminishing returns to the input of researchers, L_A. This is because in order to invent a new product or upgrade existing technology, an economy will need more input of researchers than for previously invented less-complicated products. For instance, the number of scientists devoted to inventing the light-emitting diode (LED) light bulbs must be greater than Thomas Edison’s crew who created the first long-lasting electronic light bulb.

An accumulation of A also shows diminishing returns to the stock of knowledge per person, (A/L), instead of an economy’s existing level of A. This slightly modifies Jones’ idea that past discoveries (the aggregation of technology, A) make it more difficult to obtain new ideas. Instead, it is more likely that new products will be invented in an economy if each person’s access to modern technology becomes easier. If only a few people possess smart phones in an economy, for instance, technology advancement would be slower than in an economy where the smart phone penetration rate is almost 100% and 3G networks are widespread. In other words, each person's possession of technology is more dominant for technological advancement in an economy than the giant stock of technology possess by a small group of people or firms.

With diminishing returns to the inputs of both L_A and (A/L) in equation (6), along a balanced growth path, the technology (as well as per-capita GDP) growth rate level must be constant and equals

$$\gamma_y = \gamma_A = \frac{\psi\gamma_{L_A} - \phi\gamma_L}{1-\phi}. \qquad (7)$$

From equation (7), we can reasonably assume that the amount of labor force is proportional to the total population, so that $\gamma_L = n$. In an extreme case with zero increase in number of researchers ($\gamma_{L_A} = 0$), a high population growth rate would harm per-capita GDP growth; this was demonstrated by Dyson (2010) as consistent in developing countries. If both γ_{L_A} and γ_L are positive, the sign and magnitude of γ_y will depend on the relative size of γ_{L_A} and γ_L, as well as on the parameters, ψ and ϕ. In countries with a large number of skilled migrants, such as the United States and Australia, the increase in γ_{L_A} would be much higher than the increase in γ_L. In this case, an empirical study may show that there exists a positive correlation between γ_L and γ_y, although such a correlation might be stronger between γ_{L_A} and γ_y.

If we further assume that the R&D sector exhibits constant returns to the inputs of L_A and (A/L), that is, $\psi = 1 - \phi$, equation (7) can be re-written as

$$\gamma_y = \gamma_A = \gamma_{L_A} - \frac{\phi}{1-\phi}\gamma_L, \qquad (8)$$

and we can reach the following two propositions.

<u>**Proposition 1**</u>: If the number of researchers is proportional to the total employment level, $\gamma_{L_A} = \gamma_L = n > 0$, then $\gamma_y = \gamma_A = \frac{1-2\phi}{1-\phi}n$. The growth rates of technology level and per-capita GDP are negatively correlated with the population growth rate when $\phi > 0.5$.

Proposition 2: To guarantee positive growth rates of technology level and per-capita GDP, $(1-\phi)\gamma_{L_A} > \phi\gamma_L$ must be satisfied. For instance, if $\phi = 2/3$, then $\gamma_{L_A} > 2\gamma_L$ is necessary for $\gamma_y = \gamma_A > 0$. That is, the growth rate of number of researchers should be twice the total labor/population growth rate.

III. Theoretical Implication on US Macro Data

Equation (8) and the two propositions that follow it need to be empirically supported in terms of relation between the growth rates of per-capita GDP, number of researchers, and labor, as show in Table 1.

Table 1: Compounded Annual Growth Rates of GDP per Worker, Total Employment, and Number of Researchers: 1995–2007

GDP per Worker	Total Employment	Number of Researchers	Implied ϕ
1.93%	1.28%	2.94%	0.44

* Implied ϕ is calculated based on equation (8). Data source: Science and Engineering Indicators 2010 and Penn World Table version 7.1.

As L denotes the employment level in an economy in the model, Table 1 consistently fits equation (8) and helps us calculate the magnitude of the share of stock of knowledge per person (ϕ) in the R&D equation. $\phi = 0.44$ is in a reasonable range, and it confirms that the positive per-worker GDP growth rate resulted from the fact that the number of researchers grew faster than the total employment level during the period 1995–2007. This observation does not differ greatly when L represents the total population level in an economy, as shown in Table 2.

Table 2: Compounded Annual Growth Rates of GDP per Capita, Population, and Number of Researchers: 1995–2007

GDP per Capita	Population	Number of Researchers	Implied ϕ
2.18%	1.03%	2.94%	0.43

* Implied ϕ is calculated based on equation (8). Data source: Science and Engineering Indicators 2010 and Penn World Table version 7.1.

The revised R&D-based growth model with the diminishing returns to factor inputs shown in equation (6) is consistent with the empirical observations for US data. In addition, both Tables 1 and 2 disagree with the statement of Jones (1995) that "in the steady state the growth rate of the number of scientists can be no greater than the rate of population growth." Therefore, in our revised R&D equation proposed in this paper, we provide one possible modification when constructing growth models with endogenous technology advancement.

IV. Concluding Remarks

In order to eliminate the scale effects in the R&D-based growth models of the early 1990s, Jones (1995) modified the key R&D equation in the model and provided a plausible explanation for the equation. However, the prediction of a positive correlation between the population and per-capita GDP growth rates in his modified model still contradicts some empirical facts, especially in developing countries. Thus, Jones' modification of the R&D-based growth model was not complete.

The merits of this paper lie in our further modification of Jones' R&D equation by taking into account the possible diminishing returns to the inputs of both number of researchers and per-capita technology level in the R&D sector. This consideration not only removes the scale effects but also explains the multiple relationships between the population and per-capita GDP growth rates. This alternative model is also found to fit US data well. The estimated share of per-capita technology in the US R&D sector is between 0.43 and 0.44.

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