On "Scale Effects": Further Evidence

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Abstract

One of the main issues associated with recent R&D-based growth models is their prediction concerning "scale effects". That is, these models ask the question as to whether economic growth is a function of the level *or* the growth rate of human capital at steady state. This note presents some cross-country and historical time series evidence that supports scale effects in the early stages of development and non scale effects in the long-run.

JEL Classification Numbers: O15, O40.

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1 Introduction

This note contributes to the investigation of "scale effects" in models of economic growth. Most R&D-based model predict that economic growth – as measured by real GDP per capita growth – is positively related to the level of human capital – as measured by an index of the average years of education or the number of scientists and engineers (S&E). Jones (1995a) examined this relationship for a sample of developed countries and found that the scale effects prediction is not supported by the data; more precisely Jones' work shows that real GDP growth is insensitive to changes in the number of S&E.

This note empirically investigates scale effects under a wider sample of countries that include both developed and developing countries. The analysis here, which employs cross-sectional and time-series data, finds some evidence that support a hump-shape relationship between growth and human capital. More precisely, at low levels of human capital, growth is shown to be increasing in human capital. After a certain threshold, it is found that higher levels of human capital are associated with slower economic growth. Eventually, at high human capital levels, growth is found to be insensitive to changes in human capital. This result is consistent with both the transitional path and the steady state prediction of Jones (1995b) model.

2 Empirical evidence on "scale effects"

The aim of this section is to further investigate the scale effects prediction of many growth models (such as Romer (1990), Grossman and Helpman (1991), Aghion and Howitt (1992) and Jones (1995a,b) just to name a few) by examining the relationship between economic growth and the stock of human capital. This note extends Jones' work by investigating scale effects for a wider sample of countries; developed countries that grow primarily through innovation, and also developing countries that grow primarily through the adoption of existing technologies.

In investigating the relationship between growth and human capital, I first undertake a simple cross-country analysis. As a proxy for per capita output I use Summer and Heston (1991) data on per capita GDP, and as a proxy for human capital I use a modification of the Barro and Lee (1993) data on cross-country educational levels. Barro and Lee provides data on the average number of years in primary, secondary, and higher education.[1] An interesting feature of the plot in figure 1

[1] The data, which contains 6 observations for the years 1960, 1965, 1970, 1975, 1980, 1985 for a sample of 104 countries, is a weighted index of the Barro and Lee (1993) data as follows: $0.1 * (avg.\ yrs.\ in\ primary) + 0.2 * (avg.\ yrs.\ in\ secondary) + 0.3 * (avg.\ yrs.\ in\ higher)$. Persson and Tabellini (1994), and Tallman and Wang (1994) use similar indexing techniques to construct human capital proxies. A sensitivity analysis on different weighting schemes of the Barro and Lee data shows no change in the results of the cross-country analysis.

<u>Note to Referee:</u> *See Appendix (not for publication) for the sample of countries used in the cross-country analysis.*

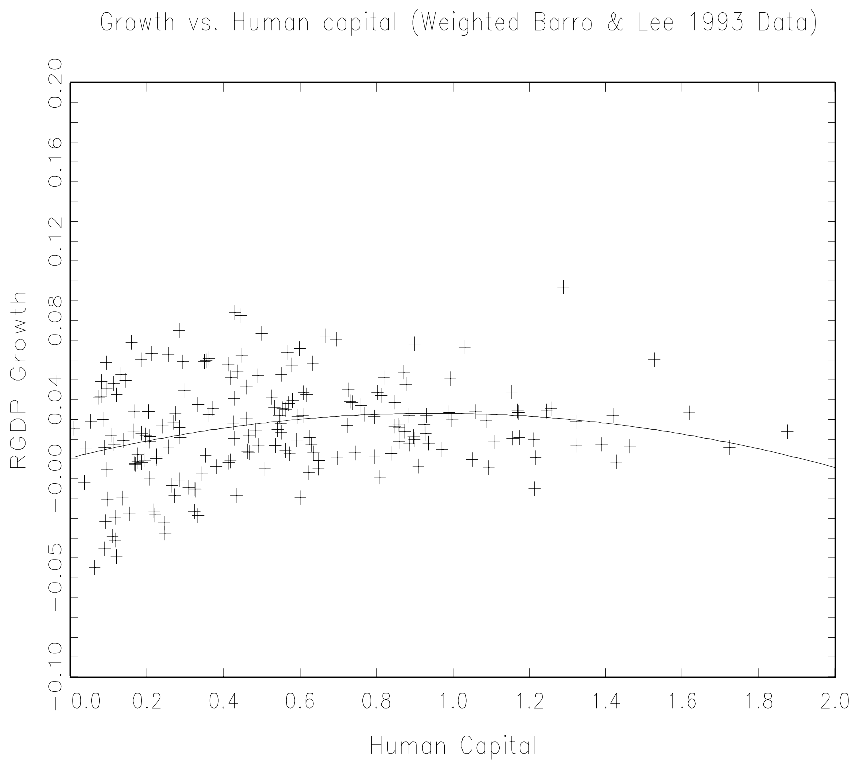

Figure 1: The figure above presents a cross-country relationship between growth and human capital. Each point corresponds to the geometric growth rate and the average human capital level for a given country for each decade. The sample includes 104 countries, and there are 2 observations for each country. The solid line is the fitted quadratic regression equation.

is that there is no apparent positive relationship between growth and human capital predicted by *most* R&D-based models prior to Jones (1995a,b). Even though weak, one actually might notice a hump-shape pattern. It seems that growth is positively related to human capital until the latter reaches the level of 0.8 to 1.0. Beyond this threshold, there are signs of slowing growth associated with higher human capital. In order to, more formally, investigate the hypothesis of a hump-shape relationship I run a quadratic regression and fit it to the cross-country plot. The regression yields the equation

$$Gy = \underset{(2.45)}{0.010691} + \underset{(3.36)}{0.047250H} - \underset{(-2.69)}{0.024875H^2}, \quad R^2 = 0.07, \tag{1}$$

where Gy denotes real GDP per capita growth and H denotes human capital. Both variables are significant at the 1 percent level, with the predicted signs. The continuous solid line in figure 1 is the fitted quadratic function of equation (1).[2]

I further examine the relationship at hand under an income-segmented-sample. The 4 plots of figure 2 are constructed by ordering the sample of 104 countries by per capita GDP and dividing it into 4 classes (low-income, low-middle-income, middle-income, and high-income) by using break points similar to those used in the literature.[3]

Income Class	*Coefficient*	*Test-Statistic*	*Signif. Level*
Low	0.049014	2.79	1 percent
Low-Middle	0.034894	3.12	1 percent
Middle	0.021214	1.11	
Hi	-0.000448	-0.047	

Table 1: The table above gives regression estimates and their corresponding t-statistics for the income-segmented-sample exercise.

Linear regression estimates on the 4 income classes presented in table 1 reveal some interesting findings. OLS estimates suggest that there exists a positive and significant relationship between growth and human capital for the low- and low-middle-income countries. Further, there is a positive but not statistically significant relationship between the variables of interest for the middle-income countries. Finally as shown in figure 2 and table 1, hi-income countries experience slower growth at higher levels of human capital; however this relationship is not statistically significant. The income-segmented-sample exercise presented above supports positive scale effects in early development that, however, disappear with higher human capital levels.

Time series evidence provide additional support to a nonlinear relationship between growth and human capital. In the following exercise we use historical time series data from Maddison (1982, 1989) to examine how per capita GDP growth evolved over a period of about 120 years for a sample of 15 OECD countries.

[2]The estimated coefficients of a cubic regression provide further support for a nonlinear relationship:

$$Gy = \underset{(0.84)}{0.005031} + \underset{(2.71)}{0.087776H} - \underset{(-1.89)}{0.087693H^2} + \underset{(1.38)}{0.025502H^3}, \qquad R^2 = 0.08.$$

The first two variables are significant at the 1 percent and 10 percent levels respectively, and with the predicted signs. The third variable is insignificant, which is consistent with the hump-shape hypothesis.

A piecewise-linear regression is also designed to attain its maximum near the maximum of the quadratic regression ($H = 0.95$). The resulting regression is given by

$$Gy = \underset{(4.17)}{0.015055} + \underset{(3.24)}{0.023132H} - \underset{(-2.09)}{0.012641H_{0.95}}, \qquad R^2 = 0.06,$$

where $H = H_{0.95}$ if $H \geq 0.95$, and $H = 0$ if $H < 0.95$. The first variable H is significant at the 1 percent level and the second variable $H_{0.95}$ is significant at the 5 percent level. Both variables have the predicted sign.

[3]More precisely, the 4 income classes have been determined by using break points similar to those used by the World Bank (...-$2000 low-income, $2001-$5500 low-middle-income, $5501-$9000 middle-income, and $9001- ... high-income).

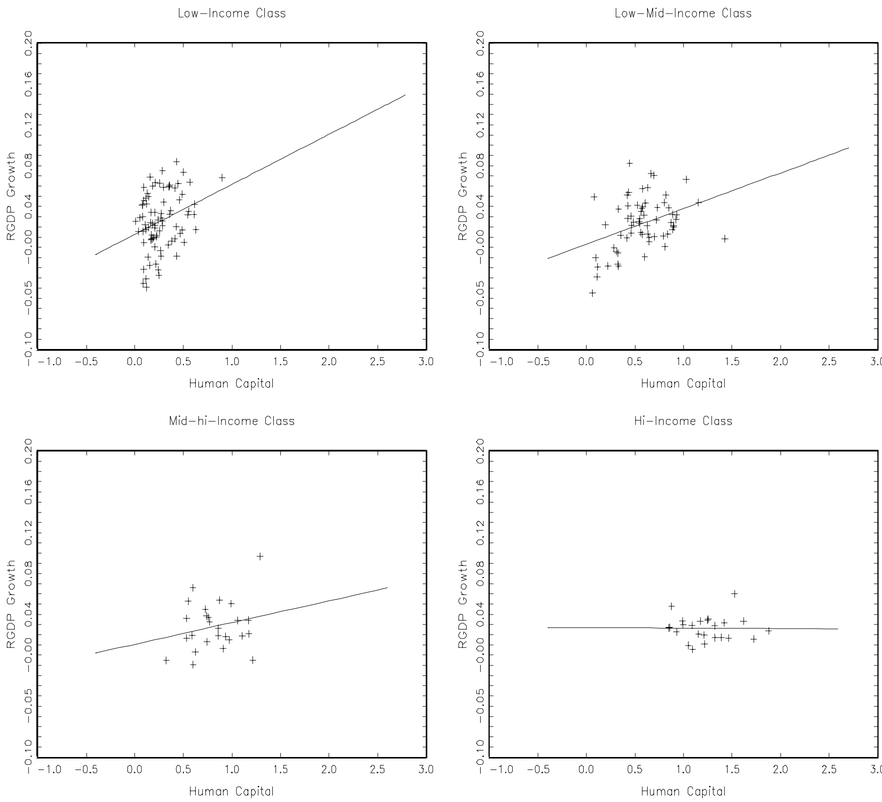

Figure 2: Plots of the relationship between growth and human capital in 4 income groups of countries. The solid lines are the fitted linear regression equations.

A time segmented trend test is applied here. Observations for the period 1871-1987 are segmented into two epochs, by using a predetermined break point. The first epoch is the prewar period that covers the years 1871-1949 (excluding the years of WWII), and the second epoch is the postwar period that covers the years 1951-1987. As shown in table 2, most of the 15 countries had positive and statistically significant growth rates in the first epoch where as in the second epoch most countries experienced slowing growth rates, but only a few of these have estimates that are statistically significant.[4] Making the assumption that the existing positive relationship between human capital (as measured by S&E) and time observed in OECD countries holds across

[4]Jones (1995b) used the Summer and Heston data set to run a time trend test for the period 1950-1988. As shown in columns 3 and 4 of table 2, our results are similar to those of Jones.

the period examined here, suggests that our result is consistent with the hypothesis of hump-shape relationship between growth and human capital.[5]

Country	*Time Trend* 1871-1949	*Time Trend* 1950-1987	*Jones Time Trend* 1950-1988
Australia	-0.000011	-0.001283	-0.001100
	(2.59)	(-3.63)	(-2.53)
Austria	0.000864	-0.000056	-0.000100
	(-0.03)	(-0.21)	(-0.15)
Belgium	0.000189	-0.000431	-0.000320
	(0.74)	(-1.30)	(-0.68)
Canada	-0.000596	0.000050	0.000200
	(-0.79)	(0.13)	(0.38)
Denmark	0.000338	-0.000254	-0.000290
	(1.87)	(-0.66)	(-0.41)
Finland	0.000879	-0.000433	-0.000360
	(1.25)	(-1.05)	(-0.63)
France	0.000855	-0.000834	-0.000870
	(1.92)	(-3.57)	(-2.38)
Germany	0.001045	-0.001721	-0.001530
	(1.67)	(-5.18)	(-3.26)
Italy	0.000872	-0.001184	-0.000950
	(2.94)	(-3.78)	(-2.63)
Japan	0.001238	-0.001915	-0.001820
	(2.07)	(-4.17)	(-3.07)
Netherlands	0.002955	-0.00801	-0.000750
	(2.45)	(-2.20)	(-1.40)
Norway	0.000533	0.000196	-0.000250
	(2.57)	(0.57)	(0.73)
Sweden	0.000856	-0.000531	-0.000330
	(1.86)	(-1.74)	(-1.00)
U.K.	-0.000055	-0.000171	0.000020
	(-0.29)	(-0.41)	(0.06)
U.S.	-0.000511	-0.000092	0.000013
	(-1.58)	(-0.22)	(0.10)

Table 2: The table above presents coefficient estimates (and their corresponding t-statistics in parentheses) for a segmented time trend test for 15 OECD countries.

[5] Time series evidence for the period 1960-1993, mainly from the Basic Science and Technology Statistics OECD (1993), show that for most OECD countries there exists a one to one relationship between human capital (measured in S&E) and time.

3 Conclusions

This note has extended the investigation of the scale effects prediction. The main findings of the paper are:

1. The whole-sample and segmented-sample cross-country analyses reveal a hump-shape relationship between growth and human capital. More precisely positive scale effects – positive relationship between real GDP per capita growth and the stock of human capital – appear to exist in the early stages of development. Subsequently, slower growth seems to be associated with higher levels of human capital. Historical times series evidence on developed countries leads to similar in spirit result.

2. This result is consistent with both the transitional path as well as the steady state prediction of the model proposed in Jones (1995b). More precisely, our finding supports Jones' hump-shape transitional path as well as *Jones Critique* that at steady state there are no scale effects.

One concern associated with finding (2) is that the model proposed in Jones (1995b) allows only for technological innovation and not imitation. Therefore given our extended cross-country sample which includes developing countries that primarily imitate, it might be argued that Jones' model is not applicable. However, it has been shown by Papageorgiou (1998) that we can easily modify Jones' R&D equation to allow for imitation without changing any of its qualitative results.[6]

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[6] Papageorgiou (1998) proposed a modified R&D equation that allows for technological innovation and imitation, yet preserving the qualitative predictions of Jones (1995b). The alternative specification takes the form $\dot{A} = [\delta H_A^\lambda A]^\gamma [\mu H_A^\lambda (\frac{A^*}{A})]^{1-\gamma}$,where A is the stock of domestic technology, A^* is the stock of foreign technology (leader's stock of technology), $\gamma \in (0,1)$ is the technology share, $\delta \in (0,1)$ is an innovation parameter, $\mu \in (0,1)$ is an imitation parameter and $\lambda \in (0,1)$ is a parameter that allows for the possibility of duplication. The first term of the right hand side the specification, $[\delta H_A^\lambda A]^\gamma$, represents the ability of a country to grow by innovating/re-inventing new varieties. The second term, $[\mu H_A^\lambda (\frac{A^*}{A})]^{1-\gamma}$, captures the potential for a country to absorb foreign technologies.

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Appendix (Not for Publication)

Barro and Lee (1993) Data and Modifications

Table A shows the sample of countries used in this paper from the Barro and Lee (1993) data. The data used in this paper is a weighted index of the Barro and Lee data given by:

$$0.1 * (avg\, yrs\, in\, primary) + 0.2 * (avg\, yrs\, in\, secondary) + 0.3 * (avg\, yrs\, in\, higher).$$

Persson and Tabellini (1994), and Tallman and Wang (1994) use similar indexing techniques to construct human capital proxies. A sensitivity analysis on different weighting schemes of the Barro and Lee data shows no change in the results of the cross-country analysis.

Table A

Algeria	Togo	Guyana	Austria
Benin	Tunisia	Paraguay	Belgium
Botswana	Uganda	Peru	Cyprus
Cameroon	Zaire	Uruguay	Denmark
Central Afr. R.	Zambia	Venezuela	Finland
Congo	Zimbabwe	Bangladesh	France
Egypt	Barbados	Myanmar	W. Germany
Gambia	Canada	Hong Kong	Greece
Ghana	Costa Rica	India	Hungary
Guinea-Biss	Dominican Rep.	Indonesia	Iceland
Kenya	El Salvador	Iran	Italy
Lesotho	Guatemala	Iraq	Malta
Liberia	Haiti	Israel	Netherlands
Malawi	Honduras	Japan	Norway
Mali	Jamaica	Jordan	Poland
Mauritius	Mexico	Korea Rep.	Portugal
Mozambique	Nicaragua	Malaysia	Spain
Niger	Panama	Nepal	Sweden
Rwanda	Trinida & Tab.	Pakistan	Switzerland
Papua Guine	USA	Philippines	Turkey
Senegal	Argentina	Singapore	UK
Sierra Leone	Bolivia	Sri Lanka	Yugoslavia
South Africa	Brazil	Syria	Australia
Sudan	Chile	Taiwan	Fiji
Swaziland	Colombia	Thailand	Ireland
Tanzania	Ecuador	Yemen	New Zealand