David vs. Goliath in Growth: 
On the Historically Changing Impact from Scale*

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Abstract

There appears to be ample evidence that the size of population or stock of human capital acted as a stimulus to growth in historical times. In the post WWII era, however, there is little evidence of such scale effects on growth. If we accept the historical evidence, we are left with an important question: Where did the scale effect go? This paper provides an overlapping generation model which allows for a nonlinear effect from scale on growth: positive at low levels but ultimately levelling off and turning negative at sufficiently high levels of the labor force. Using cross country data, covering the 1960-1990 period we find strong support for a nonlinear scale effect.

Keywords: Overlapping Generations, Endogenous Growth, Scale Effects

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1 Introduction

An important theoretical issue in economic growth is understanding the historically observed transition from a state of stagnation in terms of income per capita, into modern economic growth where income per capita rises secularly. During the last few years a number of models have been constructed – so-called unified models of growth – which are capable of replicating this fundamental transformation of the economy. Most such models involve scale effects.\(^1\) In fact, the impact on productivity from the size of the population (or the stock of human capital) typically plays an instrumental role in triggering the demographic transition thus enabling the transition into sustained income per capita growth.\(^2\)

The assumption of a positive impact on living standards from an increasing population is in fact supported by historical evidence. In particular, the study by Kremer (1993) provides an ingenious test of scale effects over the very long run. Specifically, Kremer shows theoretically that the growth rate of population should be proportional to the size of the population, if (1) fertility is determined along Malthusian lines and (2) growth in income (technology) is subject to a positive scale effect from the size of population. As Figure 1 shows, this relationship is borne out during most of human existence, but not for recent history where the clear relationship between size of population and its growth rate vanishes.\(^3\) A likely reason is that the Malthusian mechanism is no longer relevant for the post World War II period (Kremer, 1993). However, there is a reason why this explanation may not be fully satisfactory.

Figure 2 shows the coevolution of the same two variables for a subset of countries covered by Kremer’s global analysis, and with focus on 1960-2000 – the period corresponding to the downward sloping segment in Figure 1. Specifically, it shows the co-movement between population size and growth in the 111 poorest economies in the world, according to World Bank classifications. Figure 3 illustrates the same but for 29 countries all of which had a level of income per capita below 1000 PPP\$ in 1985.\(^4\) Remarkably, the global pattern visible from

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\(^1\) See e.g. Galor and Weil (2000), Jones (2001) and Lagerlöf (2003).

\(^2\) There are exceptions: A unified model where scale (in the sense of the size of population) is not a key driving force behind the transition is Galor and Moav (2002).

\(^3\) Some sense of time scale can be obtained by noting that the 1 billion mark is reached somewhere between 1800 and 1850. 80 years later 2 billion individuals inhabited the globe and by 1960 the world population had risen to 3 billion.

\(^4\) Since China is “special”, due to its strict population control policies, we have omitted it from the illustration in Figure 3. Adding China does not, however, change the pattern identified in any substantial way.
Figure 1: World population vs. the population growth rate, 1 Mio B.C. to 1990. Source: Kremer, 1993, p. 682.

Figure 1 still holds if we focus on the bottom segment of the global distribution of income per capita. Undoubtedly, within this group of countries most are comparable in terms of labor productivity (and growth rates thereof) to OECD countries 100 years ago.\footnote{Clark (2001) provides estimates of UK GDP per capita as far back as 1300, and compares them with today’s poor economies. It is interesting to observe that Clark finds UK Anno 1760 to be a richer place than Egypt in 1992. In the sample of countries underlying Figure 2 Egypt’s GDP per capita in 1992 was nearly 50% higher than the median level. Incidentally, 1760 is about the time where most current-day industrial economies started to emerge from “the Malthusian epoch” (Galor and Weil, 2000).} Moreover, from Figures 2 and 3 it becomes clear that the evolution of population and population growth in Figure 1 to a large extend is driven by what occurred in the poorest economies on earth; places where the Malthusian model arguably continues to be a reasonable approximation.\footnote{According to prevailing UN population projections this pervasive reduction in fertility is expected to continue for the next half century.}

Thus, if a (complete) departure from the Malthusian mechanism is not a fully satisfactory account for the reversal of time-series correlation between population size and growth, we are necessarily led to consider an alternative explanation: Over time the positive scale effect gradually petered off, and possibly even changed sign.
This interpretation of the global population data is consistent with more direct evidence on scale effects. As mentioned above, numerous historical studies suggest that scale mattered a great deal in historical times. Aside from the well known study by Diamond (1997), the work of Hoffman (1996) provides evidence that productivity was spurred by an expanding population in various regions of France during the middle ages. The influential work of Boserup (1965) also suggest a positive impact from a larger population on productivity. At the same time the lack of time-series evidence in favor of scale effects in modern day societies is well recognized (e.g. Jones, 1995; Dinopoulos and Thompsen, 1999). Clearly there is a tension between pre-industrial and post World War II evidence in this respect. But what could explain “a reversal” of impact from scale?

Indeed, this finding led to a large literature on how to eliminate the scale effect from otherwise standard endogenous growth models. See e.g. Young (1998), Dinopoulos and Thompson (1998), Peretto (1998), Howitt (1999) and Dalgaard and Kreiner (2001).
We begin by examining this issue theoretically using an overlapping generations (OLG) model featuring endogenous growth. For ease of exposition the analysis invokes an externality from the stock of capital yielding a simple “AK” production technology in reduced form.\(^8\) This technology will, if nested in an infinite horizon model, yield an unambiguously positive scale effect on growth. A standard infinite horizon model (exhibiting endogenous growth) will therefore not be able to rationalize a historically changing impact from scale on growth. But the same technology nested in the OLG framework holds very different implications. Within the OLG model the impact of an increasing labor force on growth is shown to be ambiguous.

This result is fairly robust. In the main text we demonstrate this inherent

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\(^8\) More generally, however, our argument pertains to a larger class of endogenous growth models that have the AK-structure as their ultimate form. For example, it is straightforward to show that a Romer (1987) model, featuring growth due to increasing specialization, can be reduced to an AK-model. See also the R&D driven endogenous growth model developed in Barro and Sala-i-Martin (1995, Ch. 6).
ambiguity within a two periods, one sector, OLG model featuring intergenerational transfers. We also develop a two-sector version with publicly funded R&D where the result carries over. But the fundamental intuition for the result is most readily explained in the limiting case of the model developed below; the Diamond (1965) model where preferences are Cobb-Douglas.

In this particular setting the all-important driving force behind capital accumulation is the wage rate, since the savings rate is independent of the real rate of return. Raising the labor force entails diminishing marginal returns on labor which works so as to reduce the wage rate, savings and capital accumulation. At the same time, however, increasing the labor force implies that more individuals are saving resources for old age which stimulates capital accumulation. As a result, the impact on growth from an increasing population depends on which of these two effects dominate. The condition for the absence of scale effects is simply that the elasticity of labor demand is equal to one. If, moreover, the aggregate production technology is CES (featuring an elasticity of substitution below one) the scale effect may turn negative after a critical size of the labor force has been attained. This (plausible) case, which carries over when bequests are present as well as to the two-sector framework, motivates a hump shaped relationship between scale and growth.

If the nonlinear scale effect is a pervasive phenomena we ought to be able to detect it in a broad cross-section of countries. In the empirical analysis we measure scale as the "effective" labor force. That is, the size of the labor force multiplied by the average skill level. The latter is defined as (the exponential of) a fixed Mincer return multiplied by average years of schooling in total population. With this measure in hand we investigate whether the 1960 effective labor force exhibits a nonlinear relationship with the growth rate of income per capita for the 1960-90 period. Consistent with the predictions of the model we find an inverted U-shaped relation in a cross section of 85 countries. This finding is also qualitatively consistent with the global trends discussed above.

Our work is related to several strands of literature. On the theoretical side it is related to the, by now, rather large literature on scale effects. A common feature of all these contributions is that they are cast within the infinite horizon model, in contrast to the analysis conducted here. This difference in choice of theoretical framework is crucial. In the infinite horizon model, the rate of return on capital is alone pivotal in determining the rate of growth, as it drives

\[9\] See footnote 7 for selected references.
the consumers’ desire to accumulate capital. Since the key feature of endo-
genous growth is that the tendency for diminishing returns to capital (sometimes “broadly” defined) is curbed, and since labor and capital are complements in the production function, the implication that higher employment levels lead to more growth is an inherent feature of such models, unless suitably modified. In the OLG analysis the ambiguousness is inherent to the framework.

Our empirical analysis is related to a recent strand of literature which explores an alternative (or rather complementary) hypothesis to the one pursued here: that the extent of trade openness limits the size of the scale effect (Alesina, Spolaore and Wacziarg, 2000; Alcalá and Ciccone, 2003). In very outward oriented economies "the world is the market" and for this reason domestic market size (scale) is of the second order. From an empirical standpoint this hypothesis can be examined by adding an interaction term to the growth regression, involving trade and a proxy for market size. Both Alesina, Spolaore and Wacziarg (2000) and Alcalá and Ciccone (2003) find such an interaction effect to be significant and negative. The empirical strategy followed in the present paper is heavily inspired by Alcalá and Ciccone (2003). In pursuing the hypothesis of a nonlinear effect from the scale of the economy we also allow for an interaction effect in the empirical model. Although we apply a different measure for "scale" (Alcalá and Ciccone use the size of population) and a slightly different measure for trade, we also find the interaction effect to be significant and negative, in addition to the nonlinear effects from the effective labor force.

Finally, the empirical study by Papageourgjou (2002) also reports a nonlinear relation between growth and scale. However, the scale variable used by Papageourgjou (2002) includes only an influence from schooling, not from the size of the labor force. In addition, the cross-section regression performed by Papageourgjou (2002) controls only for this variable (and its square), and not for other plausible growth determinants.

The next section lays out the theoretical model. Section 3 presents the empirical results, and Section 4 contains concluding remarks.

2 Theory

Consider a closed economy where activity extends infinitely into the future, but where each individual live for only two periods. Time is discrete, and denoted by

\[ t = 0, 1, 2, \ldots \]

Specifically, Papageourgjou (2002) uses the variable: 0.1*average years of primary schooling + 0.2*average years of secondary schooling + 0.3*average years of higher education.
The economy produces a homogenous good that is either consumed or saved/invested. The markets for output and factors of production, labor and capital, are competitive. The size of the population is assumed to be exogenously given and constant.

The representative firm produces output, $Y_t$, by combining capital, $K_t$, and labor, $L$:

$$ Y_t = F\left(K_t, K_t L\right), $$

(1)

$K_t$ is an externality which will equal the aggregate stock of capital in equilibrium. This technological assumption is what usually (i.e. in an infinite horizon context) will lead to a scale effect in a strong sense: increasing the labor force entails a higher growth rate of income per capita.\(^{11}\) As we shall see, even this strongest of scale predictions, may be eliminated in the OLG framework.

We assume that $F$ is twice differentiable in both arguments, and exhibits constant returns to scale in $K_t$ and $L$. Moreover, let $F\left(1, \frac{K_t L}{K_t}\right) = f\left(\frac{K_t L}{K_t}\right)$. Then total output of the representative firm becomes

$$ Y_t = K_t f\left(\frac{K_t L}{K_t}\right). $$

The producers will acquire capital and hire labor until the (private) marginal products equals the gross rate of return, $r_t + \delta$, and the real wage, $w_t$:

$$ r_t + \delta = f\left(\frac{K_t L}{K_t}\right) - f'\left(\frac{K_t L}{K_t}\right) \frac{K_t}{K_t / L} = \partial Y / \partial K, $$

$$ w_t = f'\left(\frac{K_t L}{K_t}\right) - \partial Y / \partial L. $$

For the sake of brevity, we will assume that capital depreciates fully during a period: $\delta = 1$.

In equilibrium, where $K_t = \bar{K}_t$, it follows that

$$ r = f\left(\bar{L}\right) - L f'\left(\bar{L}\right) $$

(2)

$$ w_t = f'\left(\bar{L}\right) K_t. $$

(3)

Accordingly, the aggregate production function simplifies to $Y_t = f\left(\bar{L}\right) K_t$. Note that the real rate of interest is increasing in the size of the labor force, since $f''\left(\bar{L}\right) < 0$ whereas the wage rate is decreasing in $L$. The latter is simply due to diminishing returns.

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\(^{11}\) See Barro and Sala-i-Martin (1995, ch. 4).
Next, consider the consumers. In their first period of life, individuals supply one unit of labor in-elasticly for which they receive a wage, \( w_t \). They also receive bequest from their parents, \( b_t \). On this basis the consumers divide their first period income between consumption today, \( c^1_t \), and savings \( s_t \). In the second period of life, individuals divide their capital income, \( (1 + r) s_t \), between consumption and bequest for the offspring. That is \( c^2_{t+1} = (1 + r) s_t - b_{t+1} \).

We assume preferences are CES, and that parents derive utility from the amount of bequest they pass on:\(^{12}\)

\[
U(c^1_t, c^2_{t+1}, b_{t+1}) = \frac{(c^1_t)^{1-\theta} - 1}{1-\theta} + \frac{1}{1+\rho} \left[ \frac{(c^2_{t+1})^{1-\theta} - 1}{1-\theta} + \kappa \frac{b^{1-\theta}_{t+1} - 1}{1-\theta} \right].
\]

The parameters fulfill: \( \theta > 0, \rho > 0 \) and \( \kappa \geq 0 \). Whereas \( \theta \) and \( \rho \) has the usual interpretations, \( \kappa \) parametrizes the strength of the joy-of-giving motive. In particular, if \( \kappa = 0 \) the model collapses to the familiar Diamond (1965) framework.

Standard computations lead to the following closed form solution for the savings of the young, and thus total savings

\[
S_t = s_t w_t L + s^r (1 + r) K_t
\]

where \( s^r \equiv \kappa^{1/\theta} / (1 + \kappa^{1/\theta}) s^w \) and

\[
s^w \equiv \frac{(1 + \kappa^{1/\theta}) (1 + r)^{1-\theta}}{(1 + \rho)^{1/\theta} + (1 + r)^{1-\theta}}.
\]

As can be verified, \( \partial s^w / \partial r \geq 0 \) when \( \theta \geq 1 \). Note also, for future reference, that when \( \kappa > 0 \) the savings rate out of capital income, \( s^r \), is always smaller than the savings rate out of wage income, \( s^w \).

The capital stock at time \( t + 1 \) is given by the total savings of the young in period \( t \). Thus, inserting from equation (3) and equation (2) (along with the assumption that \( \delta = 1 \)), we obtain – after some rearrangements – the following expression for the growth rate of the capital stock

\[
g_K = s^w \left\{ f(L) \frac{\kappa^{1/\theta}}{1 + \kappa^{1/\theta}} + \frac{1}{1 + \kappa^{1/\theta}} f'(L) L \right\},
\]

where \( g_K \equiv (K_{t+1} - K_t) / K_t \). The previous observations form the basis of the following result:\(^{12}\) The "joy-of-giving" approach is supported empirically by Altonji, Hayashi and Kotlikoff (1997).
Theorem  Scale effects in the OLG model with bequest and CES preferences. The effect on the long-run growth rate from an increase in the labor force will be positive, zero, or negative, depending on whether

$$\varepsilon_{s,L} \cdot \frac{\partial w}{\partial L} \left( \frac{L}{s} \right) + \frac{1}{\theta} \left( 1 + \frac{\kappa^{1/\theta}}{1 - \alpha_K} \right) \left( 1 + \alpha_K \frac{\kappa^{1/\theta}}{1 - \alpha_K} \right) \leq 0.$$  \hspace{1cm} (8)

$$\varepsilon_{s,L} = (\partial w/\partial L) (L/s) \geq 0 \text{ for } \theta \leq 1, \sigma \equiv -f''(L)/(f'(L)) \text{ is the elasticity of substitution, while } \alpha_K \equiv (f(L) - LF(L))/(f'(L)) \text{ is capital’s share of total income.}$$

Proof. See the appendix. □

A special case of considerable interest is where preferences are Cobb-Douglas:

Corollary If \( \theta = 1 \) the effect on the long-run growth rate from an increase in the labor force will be positive, zero, or negative, depending on whether

$$1 + \kappa \geq \frac{-f''(L)}{f'} = \frac{\alpha_K}{\sigma}.$$ \hspace{1cm} (9)

The reason why the implication of the OLG model differs so markedly from those of the infinite horizon model is the fundamentally different determinants of aggregate savings in the models.

With infinitely living agents savings will, at a balanced growth path, equal a constant fraction of capital income.\(^{13}\) Since the real rate of return is increasing in \( L \), an unambiguously positive scale effect will result.

Consider next the extreme case of a Diamond (1965) model. This corresponds to the case described in the corrolary augmented by the assumption \( \kappa = 0 \). In this model savings stem solely from labor income (cf equation (5)); the polar opposite of the infinite horizon case. Raising the labor force entails diminishing marginal productivity on labor and lowers the wage rate and savings. At the same time, increasing the labor force also implies that more individuals are saving resources for old age. The net effect therefore depends on which of these two effects dominate, and is in general ambiguous. But insofar as \( -f''(L)/f''(L) = 1 \), that is, if the elasticity of labor demand is unit elastic, the two counteracting forces on the growth rate exactly off-set one another, and the model exhibits no scale effects from the size of the labor force.

Allowing for bequest, \( \kappa > 0 \), while maintaining \( \theta = 1 \) (the case highlighted in the corrolary exactly) implies that savings is in part determined by capital

\(^{13}\)See Bertola (1993). This conclusion, of course, assumes that preferences are homothetic since only then will the savings rate be constant for a constant rate of interest.
income, partly by wage income (see equation (5)). As a result, it is not surprising that the tendency for diminishing returns to labor needs strengthening for a positive scale effect to be absent. The required increase in the elasticity of labor demand is determined by \( \kappa \), since the weight attached to capital income in determining total savings is increasing in this parameter (the weight attached to bequest in the utility function).

When moving to the more general OLG case \( (\theta \neq 1, \kappa > 0) \), the condition becomes more complex, since changes in \( L \) affects the real rate of interest, and therefore the savings rate. Since the real interest rate, is increasing in the size of the labor force \( (\partial r/\partial L = -f''(L)L > 0) \), the sign of \( \partial s/\partial r \) will determine whether the first term in (8) works so as to promote or retard the scale effect. In general the scale effect is dampened when \( \theta > 1 \).

While assuming \( \theta > 1 \) is often standard in the literature on economic growth, available evidence suggest that changes in real rates of interest lead – at best – to only minor changes in the savings rate.\(^{14}\) The finding that \( \frac{\partial s}{\partial r} \approx 0 \) is (in the present case) consistent with Cobb-Douglas preferences: \( \theta = 1 \). As a result, in what follows we shall focus on the Cobb-Douglas setting which leads to the “no scale-effect condition” stated in the corollary.

On this basis one may provide an example of how the sign of the scale effect may change as the size of the population increases. This example directly motives our empirical work below:

**Example: Nonlinear Scale Effects** Consider the CES technology

\[
Y = \left( \beta K^{\frac{1}{\sigma-1}} + (1 - \beta) (\bar{K}L)^{\frac{1}{\sigma-1}} \right)^{\sigma/(\sigma-1)}
\]

It now follows that the condition \( (1 + \kappa) \sigma \gg \alpha_K \) can be written (for \( \bar{K} = K \))

\[
\sigma > \frac{1}{1 + \kappa} \frac{\beta}{\beta + (1 - \beta) L^{\frac{1}{\sigma-1}}} \tag{10}
\]

Assume \( 1 > \sigma > \beta / (1 + \kappa) \) (= \( \beta / \left[ (1 + \kappa) \left( \beta + (1 - \beta) L^{\frac{1}{\sigma-1}} \right) \right] \)) for \( L = 1 \). In this case it follows that the right hand side of equation (10) is monotonically increasing in \( L \). As long as \( \alpha_K < (1 + \kappa) \sigma \) the scale effect will be positive. But if population keeps expanding, the positive scale

\(^{14}\) Modigliani (1986) states in his Nobel lecture that “... despite a hot debate, no convincing general evidence either way have been produced, which leads me to the provisional view that \( s \) [the savings rate] is largely independent of the interest rate. (p. 304, emphasis in original). Arestis and Demetriades (1997) surveys the literature and reaches a similar conclusion.
effect eventually vanishes since by monotonicity of $\beta/(\beta + (1 - \beta) L \overset{\beta}{\sim})$, there must exist $L = \hat{L}$ such that $\sigma(1 + \kappa) = \beta/(\beta + (1 - \beta) \hat{L} \overset{\beta}{\sim})$.

Beyond this point a further expansion of the population harms growth.

The relationship between growth and the labor force is thus hump shaped.

Before we explore the implications of this finding in the context of the historical growth record and the global population patterns discussed in the Introduction, we briefly provide a generalization of the model to a two-sector environment. Specifically, we will consider an economy where growth is fueled by capital accumulation and R&D. This will allow us to illustrate how the model’s implications have bearing on the more recent growth record of major individual economies like the US.

2.1 On the Modern Growth Regime

In this section we continue to assume that consumers derive utility from consumption during youth, old age, and from bequest. Moreover, we assume $\theta = 1$. Consequently, savings of the young – determined by wages and bequest – fuel capital accumulation.

The first new element to the model above is that we modify the production side of the economy. Specifically, we assume the production function of the representative firm is

$$Y_t = F(K_t, A_t, L).$$

Hence, the externality is replaced by $A_t$, technological knowledge. When maximizing profits the firm takes $A_t$ as given. This leaves us with two factor demand equations

$$r_t = f(x_t L) - x_t L f'(x_t L)$$

$$w_t = f'(x_t L) A_t,$$

where $x_t \equiv A_t/K_t$.

The second new element relates to the evolution of $A_t$ over time. Following Antinolfi, Keister and Shell (2001), we assume that $A_t$ expands as the result of public investments in R&D. Antinolfi et al (2001) assume that these investments are funded by a tax on the income of the young. In their model this is
equivalent to a tax on wage income. In our model, in contrast, period 1 income also comprises bequests. As a result, budget balance then implies that

$$A_{t+1} = I_{A,t} = \tau (w_t + b_t) L,$$

where \( \tau > 0 \) is the (constant) tax rate on total period 1 income. This specification is consistent with a “fishing out” view of the research process; a given relative increase in the stock of knowledge gradually becomes more expensive as the stock of knowledge, \( A_t \), expands.

Given log preferences, and the presence of a tax on first period income, aggregate savings (and thereby capital in period \( t + 1 \)) is given by

$$K_{t+1} = S_t = s_t L = (1 - \tau) \frac{1 + \kappa}{\kappa + 2 + \rho} [w_t + b_t] L.$$

As should be clear, under this set of assumptions the ratio of the stock of knowledge to that of physical capital, is constant at all points in time. Specifically

$$x_t = \bar{x} \equiv \frac{\tau}{1 - \tau} \frac{(2 + \kappa + \rho)}{(1 + \kappa)}.$$

Consequently, it can be shown (by substituting for \( b_t L = \frac{\kappa}{1 + \kappa} (1 + r_{t+1}) s_{t-1} L = \frac{\kappa}{1 + \kappa} (1 + r_{t+1}) K_t \) and using equilibrium factor prices) that the growth rate of the economy will be given by

$$g_A = g_K = (1 - \tau) s \left[ \frac{\kappa}{1 + \kappa} f'(\bar{x} L) + f''(\bar{x} L) \bar{x} L \frac{1}{1 + \kappa} \right],$$

where \( s \equiv \frac{1 + \kappa}{2 + \rho + \kappa} \). Comparing this equation with equation (7) (for \( \theta = 1 \)) reveal that they are identical save for the presence of \( \bar{x} \) – the constant \( A/K \) ratio. Observing that \( \bar{x} \) is independent of \( L \) it is clear that the Corollary carries over to the present model featuring endogenous R&D.

**Quantitative implications** While we believe scale effects stimulated growth in historical times, a case can be made that the "no-scale" condition might be approximately satisfied for major modern day economies, like the US.

To see this, we begin by noticing that the OLG model predict the following relationship between the current income of parents, \( (1 + r) s_t \), and the amount of bequest, \( b_{t+1} \), passed on to the offspring:

$$b_{t+1} = \frac{\kappa}{1 + \kappa} (1 + r) s_t.$$

Accordingly, reducing the (current) income of the parent by 1 unit entail a reduction in bequests by \( \frac{\kappa}{1 + \kappa} \) units. Using the 1969-89 Panel Study of Income
Dynamics, Antonji et al (1997) estimate that a reduction in the current income of parents leads to a reduction in transfers by a mere 4 cents. In the present context this could be taken to imply that a value for $\kappa$ of 0.04 is about reasonable. In US national accounts $\alpha K$ is roughly 1/3. As a result, for the “no-scale effect” condition to be fulfilled a value for $\sigma$ of about 0.32 is required. Interestingly, this is in the ball park of what the recent study by Chirinko, Fazzari and Mayer (2002) find on the US data; their point estimate for $\sigma$ is .39 with a standard deviation of .11 (Chirinko et al, 2002, Table 3). This (approximate) fulfilment of the “no-scale effect condition” is broadly consistent with the observation that average US growth has remained remarkably stable over the last 50 years or more, in spite of an increasing size and education of the labor force (Jones, 2002).

Next we turn to the historical record and the patterns identified in figures 1-3.

2.2 On the Historical Record: Kremer (1993) Revisited

A slightly modified version of Kremer’s (1993) argument follows. Suppose output is given by

$$Y_t = A(L_t) K_t,$$

where $A(L)$ summarizes the positive influence from population on productivity. In general is could reflect the idea generating process, gains for specialization, or some other mechanism. In these cases we would assume $A'(L) > 0$ for all $L$. Assume that population is adequately described by the following (very stylized) Malthusian model:

$$L_t = \Sigma^{-1} Y_t \Rightarrow \frac{Y_t}{L_t} = \Sigma, \Sigma > 0. \quad (11)$$

That is, the size of population adjusts (instantaneously) such that income per capita, $Y_t/L_t$, is always at the level of subsistence, $\Sigma$. Finally, assume that investments, $I_t$, are determined as

$$I_t = \Delta \cdot Y_t, \Delta > 0, \quad (12)$$

where $I_t = K_{t+1}$, thus assuming full depreciation from one period to the next. Combining these three equations immediately tells us that the following holds:

$$g_L = \ln L_t - \ln L_{t-1} = \ln A(L_t) - \ln A(L_{t-1}) + \ln (\Delta \cdot A(L_t)), \quad (13)$$

which is similar to the key equation in Kremer’s analysis.
As pointed out in the introduction: given (1) the Malthusian mechanism, and (2) a positive scale effect \( A'(L) > 0 \), the growth rate of the labor force, \( g_L \), exhibits a positive association with the size of population. One interpretation of the 1960 "breakdown" of this simple association, is that equation (11) is replaced by, say, 

\[
g_L = g_L(y),
\]

where \( g_L'(y) < 0 \). Increases in income per capita is ultimately associated with declining fertility.\(^{16}\)

But an alternative interpretation is that for a large fraction of the globe's population, the Malthusian model is still roughly accurate. In this case we need to assume, that \( A'(L) \) eventually turns negative, in order to explain the movements in Figure 1 -3. The simplest way to provide microfoundations for the switch from \( A'(L) > 0 \) to \( A'(L) < 0 \) is to consider the Diamond version of the model developed above, augmented by the Malthusian link (equation (11)).

A slight complication is that we need to allow for growth in the labor force. Given the reduced form production technology and the law of motion for \( K_t \) derived above, growth in total income is:

\[
\sum \equiv \ln Y_t - \ln Y_{t-1} = \ln f(L_t) - \ln f(L_{t-1}) + \ln \hat{s} + \ln(f'(L_t)L_t).
\]

Consider an exogenous increase in \( L_t \) for \( L_{t-1} \) given (which amounts to an increase in \( g_{L_t} \)). Then it is straightforward to prove that \( \frac{\partial g_Y}{\partial L_t} \geq 0 \) iff

\[
\sigma + \frac{L_t}{\sigma + L_t} \geq \alpha K_t.
\]

Now notice that as long as \( \sigma < 1 \) and constant (as in the example above), the left hand side of the inequality will be decreasing in \( L_t \), whereas \( \alpha K_t \) is increasing. Hence for a CES technology we may obtain the hump shaped pattern. In the end the model gives us a reduced form relationship

\[
g_L = g_Y = B(L_t) + \ln \hat{s},
\]

which mirrors "Kremers equation", equation (13), almost exactly.

The model thus suggest that scale may have spurred growth for an epoch of human existence. Slowly, however, the positive influence from population

\(^{16}\)Of course, if scale effects are present this would also be associated with a deacceleration of economic growth. As long as income growth remains positive this matters little, however, for the implied relationship between \( g_L \) and \( L_t \).
wore off as the size of population expanded. Today it may have disappeared altogether – or perhaps even been turned into a detriment to growth. This simple story is consistent with the historical evidence on positive scale effects from population, and with the lack of evidence of the same for modern day industrialized economies.

3 Empirics

So far the analysis has focused on global patterns. That is, the growth experience of the world economy, or the world's leading economy. In this section we examine whether cross-country data support the predicted hump shaped relation between scale and growth. Clearly if such a relationship hold at the country level, it will have bearing on the global growth performance (whereas the opposite does not follow). From an empirical angle, Barro-style growth regressions may be invoked to examine the validity of a nonlinear scale effect.

The underlying logic of the “Barro-regression” is that growth depends on initial income and determinants of long-run productivity. The latter involves investment rates of various kinds (in physical capital, human capital, R&D and so on), which the analysis above suggests are affected by scale at a deeper level. Hence, in addition to various other possible “deep” determinants of investment effort, we include scale and scale squared in the regression equation. This is the strategy pursued in the remaining.

3.1 Regressions

Formally we estimate the following model:

$$g_y = \beta_0 + \beta_1 hL60 + \beta_2 (hL60)^2 + Z'\gamma + \varepsilon,$$

where $g_y$ is growth in per capita GDP 1960-90, $hL60$ is the effective labor force in 1960, $(hL60)^2$ is its square and $Z$ denotes a vector of additional controls. We define the effective labor force as

$$hL60 = e^{\psi u_{60}} L60,$$

where $u_{60}$ is average years of schooling in 1960 and $L60$ is the size of the labor force in 1960. The "Mincer return", $\psi$, it fixed at 10 percent for all countries (Pritchett, 2001). The effective labor force variable is centered around its mean value in the sample. This implies that the sum of the point estimates for $hL60$
and \((hL60)^2\) gives the growth impact from scale, measured at the mean value for \(hL60\) in the sample.

In addition to these variables we also include a set of other controls, contained in \(Z\); other likely determinants of long run prosperity. The problematic issue is which controls to add. Inspired by the empirical strategy in Alcalá and Ciccone (2003) we approach this issue by including the 11 variables deemed robust in Doeppelhofer, Miller and Sala-i-Martin (2000), along with measures of institutions and a scale/trade interaction variable. The inclusion of a control for the interaction between trade and scale is inspired by the work of Alesina, Spolaore and Wacziarg (2000) and Alcalá and Ciccone (2003), whereas the importance of controlling for institutions is stressed in Hall and Jones (1999) and Acemoglu et al (2001).

More specifically, the eleven variables taken from Doeppelhofer et al are: The log of initial GDP per capita in 1960 (LGDP60), number of years the economy has been open from 1950-94 (YrsOpen), life expectancy in 1960 (LifeE60), Fraction of population that follows the Confucian religion (CONFUC), Fraction of GDP in mining (Mining), primary school enrollment in 1960 (P60), continent dummies for Sub-Sahara Africa and Latin America (Safrica and Laam, respectively), Fraction of population protestant (Prot), Fraction of population Muslim (MUSLIM) and fraction of primary export in total exports in 1970 (PRIM). To this list we add either the index for government anti-diversion policies (GADP) developed by Hall and Jones (1999) or the rule of law variable (RLAW). The purpose is to control for institutions. Finally, we also allow for an interaction effect between \(hL60\) and trade \((hL60*LFR)\). The trade variable used is the log trade share of GDP derived from a gravity equation in Frankel and Romer (1999) (LFR). That is, the fraction of total trade in GDP as predicted solely by demographic variables and measures of geographical location.

Table I reports the results from estimating the equation above by least squares. Column 1 provides a regression without the scale variables. The controls are the 5 most robust determinants according to Doeppelhofer et al. In column 2 we add the effective labor force in 1960 and its square. Both are significant and the signs are consistent with the hump shaped relationship be-

17All variables, except for the GADP index which comes from Hall and Jones (1999), derive from Sala-i-Martin (1997). The complete data set can be downloaded from http://www.columbia.edu/~xs23/data/millions.htm
between growth and scale, predicted by the model above. In Column 3 and 4 we examine a fuller model where all of the 11 robust variables are added. The point estimates for $hL60$ and $hL60^2$ only change to a minor extent, and they remain significant, albeit at the 10 percent level. Column 5 adds the GADP variable, and Column 6 reveals the impact on the key parameters of interest in the present context. As is clear, the only consequence of adding the institutional variable is that the parameters are estimated somewhat more precisely.\textsuperscript{18} Finally, in Column 7 we report the results from adding an interaction effect between trade and effective labor force, as well as the exogenous trade variable. As seen, we also find the interaction effect to be negative and significant consistent with the "extent of market" hypothesis. The nonlinear effect from $hL60$ also remains significant, now at the 1% level of significance.

An immediate cause for concern is that the institutional measure is endogenous. Table II therefore reports the results from 2SLS regressions.

The instruments used for GADP are the ones suggested by Hall and Jones (1999): the fraction of population speaking one of the five primary European languages at birth (EuroFrac), Fraction of population speaking English at birth (EngFrac) and the absolute latitude (Latitude). In this exercise we concentrate on the full model with and without the "extent of market" variables added. As seen $hL60$ continues to display a hump shaped relation to growth. In all cases we are unable to reject orthogonality of our instruments, and the instruments used are generally significant in explaining institutions as seen from the reported F-statistics. It is also noteworthy that the interaction between scale and trade is significant at conventional levels throughout, consistent with the empirical work of Alcalá and Ciccone (2003) and Alesina, Spolaore and Wacziarg (2000).

A final issue to be addressed is whether "heterogeneity" of impact from scale is present. That is, do the above regressions suggest that scale has a positive impact in some places, zero impact in other countries and perhaps a detrimental impact in a third group of countries? This would be the pattern suggested by the analysis above.

To address this issue we begin by noting that in the IV regressions of the full model (Table 2, reg #2 and #4) we include an interaction term between exogenous trade and our measure of scale, in addition to the variables related to

\textsuperscript{18}OLS regressions involving rule of law are very similar, and are available upon request.
scale and scale squared. As already mentioned, the interaction term is included in response to the empirical findings in Alesina, Spolaore and Wacziarg (2000) and Aláca and Ciccone (2003). This means that the marginal impact on growth is given by

$$\frac{\partial g_y}{\partial hL60} = \beta_1 + 2\beta_2 \cdot hL60 + zT,$$

(14)

where $T$ is the log(Frankel/Romer) trade variable, as explained above. The parameters $\beta_1, \beta_2$ and $z$ are the parameters of the regression model related to the scale effect, the scale effect squared and the interaction effect, respectively. Thus the critical level of the effective labor force, where scale turns into a detriment to growth, $hL60(T)$, is a function of the trade variable:

$$hL60(T) = \left(\frac{\beta_1 + zT}{2\beta_2}\right).$$

The graph below plots this relationship, based on the estimates from Table II, regression (2). It also provides a confidence interval, where the standard errors are appropriately calculated using the delta method. In addition, each of the 81 country observations of scale and exogenous trade, included in Regression II.2, are plotted. For all countries within the band we can not reject a "no-scale effect" hypothesis. Whereas we will have to accept the alternative (negative) if above the upper confidence band, and positive below.

As can be seen, our regressions show that for a considerable group of countries the scale effect is zero. In addition, a few countries have a negative scale effect under our results. Only two, India and USA, have statistically significant negative scale effects, but a number of others are above (or at) the critical scale level, given trade. Finally, our results suggest that scale has a positive influence on growth in another large group of countries.

The finding of a negative scale effect for the US may seem troubling. It is important to recognize, however, that the implied value for $\frac{\partial g_y}{\partial hL60}$ is small. If we plug in US values for $hL60$ and $T$ in equation (14) we find $-0.003$. This estimate implies that if US scale is increased by 1 relative to the mean in the sample the growth rate (possibly only on impact) falls by 0.3 percentage points. The mean for $hL60$ is about 12600. So if US scale increases solely due to a larger labor force, the experiment above amounts to increasing the labor force by almost 13 million people; or nearly 18 percent (based on US 1960 labor force). Accordingly, increasing the US labor force by 1 percent, would correspond to a growth de-acceleration of only 0.02 percentage points (1/50 of a percent), which
Figure 4:

is far from earth shattering.\textsuperscript{19}

Overall we view these results as consistent with our model. The model predicts positive, zero and negative scale effects, depending on the size of $hL60$ – *ceteris paribus*. At the same time these findings are not easily reconciled with existing theoretical models in the literature since they tend to imply either positive or zero scale effects, and never negative ones.

4 Concluding Remarks

According to UN projections global population growth will continue to decline in the years to come. Indeed, according to some projections global de-population can be expected after 2040. What will be the implications for economic growth?

Existing research on scale effects have focused more or less exclusively on the

\textsuperscript{19}Moreover, this finding can easily be consistent with our calibrations in Section 2.1. The critical value for $\sigma$ is about 0.32, and available estimates fall in the interval $0.39 \pm 0.11$. If we think about a $\sigma = 0.28$ for the US as being appropriate, our conditions suggest a negative impact from scale.
growth record of the 20th century. This might be problematic insofar as scale historically have had a different growth impact than what was the case in the last century. Hence, models’ consistent with the evidence over longer periods of time may be more appropriate for making educated guesses about what the future might bring in this context.

This paper has examined the hypothesis that the growth rate is not monotonically related to scale. Specifically, scale may only be advantageous up to a point. If the labor force is expanded beyond this level, growth may suffer. This prediction flows quite naturally from the OLG framework featuring endogenous growth, and is consistent with the 1960-90 growth record, as Section 3 demonstrated. The hump shaped pattern may also explain why scale spurred growth in historical times but appears to be of the second order in modern times. Such a framework may therefore represent a useful framework for the analysis of demographically induced changes in future growth. Conducting such an analysis remains an important topic for future research.

At the more general level the analysis emphasizes the need for further research on the determinants of aggregate savings. As stressed in the text, the two key work horse models in the literature on economic growth – the infinite horizon (/Ramsey-Cass-Koopmans) model and the OLG model – hold radically different implications in this respect. Previous research has shown that these differences are at the heart of the two model’s markedly different implications with respect to the convergence process (Galor, 1996). The present paper demonstrates another important implication of the different savings functions: whereas a monotonically positive scale effect applies to the Ramsey-Cass-Koopmans model (unless modified in some fashion), the OLG model imply that scale has an ambiguous effect on long-run productivity. Hence, assessing which savings function is more appropriate might yield important insights into the growth process.

A Proof of the Theorem

Differentiation of equation (7) yields

$$\frac{\partial s^w}{\partial L} \left[ f(L) \frac{\kappa^{1/\theta}}{1 + \kappa^{1/\theta}} + \frac{1}{1 + \kappa^{1/\theta}} f''(L) L \right] - s^w f'(L) \left[ \frac{1}{1 + \kappa^{1/\theta}} - \frac{f''(L) L}{f(L)} - 1 \right] \geq 0$$

which is equal to the condition

$$s^w f'(L) \left\{ \frac{\partial s^w}{\partial L} \left[ f(L) \frac{\kappa^{1/\theta}}{1 + \kappa^{1/\theta}} + \frac{1}{1 + \kappa^{1/\theta}} \right] - \left[ \frac{1}{1 + \kappa^{1/\theta}} - \frac{f''(L) L}{f(L)} - 1 \right] \right\} \geq 0$$

21
Now, notice that:
\[
\frac{f'(L)}{f(L)} \cdot \frac{f'(L)}{f(L) - Lf'(L)} = \frac{f(L)}{f(L) - Lf'(L)} = -\frac{\sigma}{\alpha_K}, \quad \text{since } \sigma \equiv \frac{\alpha_K}{L} = \frac{f(L)}{f'(L)},
\]

and \( \alpha_K \equiv \frac{\epsilon K}{rK} \equiv \frac{f(L)}{f'(L)} \). Thus the condition can be restated to yield
\[
\frac{\kappa^{1/\theta}}{1 + \kappa^{1/\theta}} \left\{ \varepsilon_{s,L} \left[ \frac{\kappa^{1/\theta}}{1 - \alpha_K} + 1 \right] - \left[ \frac{\alpha_K}{\sigma} - \left( 1 + \kappa^{1/\theta} \right) \right] \right\} \leq 0,
\]
from which the above stated condition is easily obtained.

References


### TABLE I. LEAST SQUARES regressions.

*THE DEPENDENT VARIABLE IS GROWTH IN GDP PER CAPITA, 1960-1990*

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**Notes:** a) all regressions include a constant b) t-static’s (absolute value) based on robust standard error in parenthesis. (*) significant at 10%, (**) 5 %, (***) 1 %.
## Table II: 2SLS Regressions.

The dependent variable is growth in GDP per capita, 1960-1990

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<td>-0.002 (0.52)</td>
<td>-0.002 (0.39)</td>
<td>-0.01 (1.22)</td>
<td>-0.01 (1.21)</td>
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<tr>
<td>GADP</td>
<td>0.05*** (2.85)***</td>
<td>0.05*** (2.76)***</td>
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<tr>
<td>RLAW</td>
<td>0.02 (2.12)***</td>
<td>0.02 (1.86)***</td>
<td>0.02 (1.86)***</td>
<td>0.02 (1.86)***</td>
</tr>
<tr>
<td>HL60</td>
<td>0.002*** (2.43)***</td>
<td>0.004*** (3.27)***</td>
<td>0.001 (1.73)</td>
<td>0.004*** (2.31)***</td>
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<tr>
<td>HL60^2</td>
<td>-0.0001*** (2.91)***</td>
<td>-0.0002*** (3.79)***</td>
<td>-0.0001*** (2.04)***</td>
<td>-0.0002*** (2.71)***</td>
</tr>
<tr>
<td>HL60*LFR</td>
<td>-0.001*** (2.59)***</td>
<td></td>
<td>-0.001*** (1.99)***</td>
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</table>

<table>
<thead>
<tr>
<th>No. Obs.</th>
<th>81</th>
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<td>R^2</td>
<td>0.86</td>
<td>0.87</td>
<td>0.83</td>
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<tr>
<td>Hansen J static (p-value)</td>
<td>3.21 (0.20)</td>
<td>3.99 (0.14)</td>
<td>2.81 (0.25)</td>
<td>3.08 (0.21)</td>
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<tr>
<td>F-static (p-value)</td>
<td>3.26 (0.02)</td>
<td>2.28 (0.09)</td>
<td>4.16 (0.01)</td>
<td>2.93 (0.04)</td>
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</tbody>
</table>

Notes: a) all regressions include a constant; b) absolute t-static’s (robust) in parenthesis. Instruments used throughout are: EngFrac, EuroFrac and Latitude, all from Hall and Jones (1999). c) The R^2 reported refers to the centred R^2. (*) denotes significance at 10%, (**) 5 %, (*** ) 1 %.