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Land and population growth in the Solow growth model: Some empirical evidence

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ABSTRACT

The Solow model with land predicts that the effect of population growth on the growth rate of income per capita decreases with the share of agriculture. This paper shows that the empirical evidence is consistent with this theoretical prediction.

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1. Introduction

It is well known that the Solow model with land differs in subtle ways from the standard Solow (1956) growth model. One of these differences predicts that the effect of population growth on the growth rate of income per capita decreases with the importance of agriculture in the economy.

This paper takes this theoretical prediction seriously and tests it for a set of 152 countries, using data from the 1971–2003 period. The empirical evidence suggests that the effect of population growth on the growth rate of income per capita does vary across countries, and in particular it is decreasing in the country's share of agriculture. This is consistent with the theoretical prediction of the Solow model with land.

Practically, the implication is that exogenous changes in the population growth rate have bigger growth effects in countries with a high share of agriculture.

2. Land in the Solow model

The methodology follows the simple approach of Romer (2006, Chapter 1). Assume that the production function is given by the Cobb–Douglas specification

$$Y_t = A_t K_t^\beta L^\gamma N_t^{1-\beta-\gamma}, \quad (1)$$

where Y is output, K is the capital stock, A captures the level of technology, N is employment, L is land (assumed to be fixed), and $0 < \beta, \gamma < 1$. Exogenous growth rates for N and A are given by: $\dot{N}_t / N_t = n$ and $\dot{A}_t / A_t = a$, where a dot above a variable indicates a time derivative. Standard assumptions of the Solow model are that there is a constant saving rate, s ($0 < s < 1$), and a constant depreciation rate, δ ($0 < \delta < 1$).

Capital accumulation then is given by $\dot{K}_t = sA_t K_t^\beta L^\gamma N_t^{1-\beta-\gamma} - \delta K_t$, and denoting capital per capita by $k_t = K_t / N_t$, it follows that

$$\dot{k}_t = sA_t k_t^\beta L^\gamma N_t^{-\gamma} - (n + \delta)k_t. \quad (2)$$

Let y denote income per capita, $y_t = Y_t / N_t$. Along a balanced growth path, the growth rates of k and y , g_k and g_y respectively, are equal. It is straightforward to show that here the balanced growth path determines the growth rate

$$g_y = g_k = \frac{a - n\gamma}{1 - \beta}. \quad (3)$$

There are several interesting observations to make regarding Eq. (3). *First*, even with $a > 0$, the long-run growth rate is not guaranteed to be positive: it might well be negative if the detrimental effects of population growth are not made up by sufficiently rapid technological progress. *Second*, an increase in the population growth rate reduces the balanced growth rate of income per capita. These first two implications are well known and unsurprising.

A *third* noteworthy implication of Eq. (3), is that the effect of population growth on long-run income growth depends on the importance of land in the production process. Specifically, a given

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Table 1
Model (4): No interaction term.

$growth(i) = \phi_0 + \phi_{pop}pop(i) + \theta_1y_{1971}(i) + \theta_2inv(i) + \nu(i)$		
ϕ_0	0.873** (0.103)	1.438** (0.381)
ϕ_{pop}	-0.205** (0.055)	-0.143** (0.055)
θ_1	-	-0.160** (0.041)
θ_2	-	0.042** (0.007)
R^2	0.142	0.321
N	152	152

Notes. Estimated heteroskedasticity-consistent (White, 1980) standard errors in parentheses.

** Significant at 1%,
* Significant at 5%.

increase in n is predicted to reduce the income growth rate by more if γ is large, than if γ is small.¹

This *third* implication, which has been much less (if at all) investigated in the literature, is the focus of the present paper. The goal of the paper is to test whether this implication is empirically supported by the cross-country evidence.

3. The data

The dataset consists of 152 countries, for which annual data exist for all variables for each of the years 1971–2003.

All data except the share of agriculture in value added, are obtained from the Penn World Table (PWT, Mark 6.2), documented in Heston et al. (2006; see also Summers and Heston, 1991).

The variable *growth* is constructed as the average growth rate of real GDP per capita measured in PPP terms, *pop* is defined as the average population growth rate, and *inv* as the average investment rate (investment as a fraction of GDP); these are all averaged over 1971–2003.

The importance of land in the production function is proxied by the variable *agr*, measured by the share of agriculture in value added, again averaged for each country over the 1971–2003 period. The source is the Main Aggregates Database of the UN National Accounts.²

An Appendix with the full data set is omitted because of space considerations, but the data set (available on request) includes both developed and developing countries and a wide range for the share of agriculture. The *agr* variable in the data set ranges from 0.1% in Kuwait to 62% in Somalia.

4. Empirical results and discussion

We begin with simple cross-sectional regressions of the real income per capita growth rate (*growth*) on population growth (*pop*):

$$growth(i) = \phi_0 + \phi_{pop} \cdot pop(i) + \mathbf{x}'(i) \cdot \boldsymbol{\theta} + \nu(i), \quad (4)$$

where i is indexing over countries; ϕ_0 , ϕ_{pop} , and the elements of the vector $\boldsymbol{\theta}$ are parameters to be estimated; \mathbf{x} is a vector of other standard control variables that include the starting level of income and investment rate (*inv*); and ν is the error term. Note that Eq. (4) is similar to the influential Mankiw et al. (1992) specification and imposes the restriction that the effect of population growth on income growth is the same for all countries: ϕ_{pop} does not vary by i . This restriction is imposed not because we think that it holds, but in order to use Eq. (4) as a benchmark and facilitate comparisons with the existing literature.

¹ Put differently, the *second* implication says $\frac{d\phi_{pop}}{dn} < 0$, while the *third* says $\frac{\partial d\phi_{pop} / dn}{\partial \gamma} > 0$.
² Country selection has been dictated by data availability.

Table 2
Model (5): Linear interaction term.

$growth(i) = \phi_0 + \phi_{pop}pop(i) + \theta_1y_{1971}(i) + \theta_2inv(i) + \nu(i)$		
$\phi_{pop} = \psi_0 + \psi_{agr}agr(i)$		
ϕ_0	0.877** (0.085)	3.602** (0.521)
ψ_0	-0.132* (0.066)	-0.044 (0.049)
ψ_{agr}	-0.004* (0.002)	-0.009** (0.002)
θ_1	-	-0.383** (0.059)
θ_2	-	0.031** (0.006)
R^2	0.192	0.455
N	152	152

Notes. See Table 1.

Table 1 reports two versions of Eq. (4)—one with and one without the controls in \mathbf{x} . Results are as expected: the coefficient of population growth, ϕ_{pop} , is negative in both specifications; the coefficient of the starting level of income per capita, θ_1 , is also negative, indicating (conditional) convergence; and the coefficient of investment, θ_2 , is positive. All coefficients are highly statistically significant. The estimated values of ϕ_{pop} suggest that an increase in the population growth rate by 1% (such as from 1% to 2%; or from 2% to 3%) will reduce the growth rate of GDP per capita by 0.14% (or 0.2% in the bivariate specification), but this effect is constant across countries.

Next, we relax the restriction that ϕ_{pop} is the same for all countries. Instead, as suggested by Eq. (3), ϕ_{pop} is allowed to vary across countries as a function of *agr*, the share of agriculture: $\phi_{pop}(i) = \psi(agf(i))$. Recall that the theoretical prediction is that $\psi' < 0$. To implement this empirically, we first try a simple linear specification for the ψ function, $\phi_{pop}(i) = \psi_0 + \psi_{agr}agr(i)$, and then a logarithmic specification, $\phi_{pop}(i) = \psi_0 + \psi_{agr} \ln agr(i)$.³ So, the estimated equation becomes

$$growth(i) = \phi_0 + (\psi_0 + \psi_{agr}agr(i))pop(i) + \mathbf{x}'(i) \cdot \boldsymbol{\theta} + \nu(i) \quad (5)$$

with the linear interaction term, or

$$growth(i) = \phi_0 + (\psi_0 + \psi_{agr} \ln agr(i))pop(i) + \mathbf{x}'(i) \cdot \boldsymbol{\theta} + \nu(i) \quad (6)$$

with the logarithmic specification. Note that ψ_{agr} captures the effects of the share of agriculture on the relationship between population growth and the growth rate per capita income.

Table 2 reports two versions of Eq. (5), following the format of the last table. Once again the estimated θ 's are unsurprising, so we focus on the ψ 's. The estimated ψ_0 is negative, as expected, though statistically significant only in the model of the first column. More interestingly, however, the estimated ψ_{agr} is negative and statistically significant in both models. This means that not only does ϕ_{pop} , the effect of population growth on the growth rate of income per capita, vary across countries, but also that it varies in a way that is consistent with the prediction of the Solow model with land. In particular, ϕ_{pop} is shown to be decreasing with the share of agriculture.

Table 3 repeats the exercise for the logarithmic specification of Eq. (6), and the results are qualitatively very similar (indeed the estimated θ 's are virtually unchanged). Once again, the estimated ψ_{agr} is negative, though now statistically significant in the second column only. As expected, the estimated ψ_0 is again negative.

³ Several other nonlinear specifications were also considered, including *agr* squared or the square root of *agr*, but without changing the main findings.

Table 3
Model (6): Logarithmic interaction term.

$$growth(i) = \phi_0 + \phi_{pop}pop(i) + \theta_1y_{1971}(i) + \theta_2inv(i) + \nu(i)$$

$$\phi_{pop} = \psi_0 + \psi_{agr} \ln agr(i).$$

ϕ_0	0.880** (0.085)	3.385** (0.605)
ψ_0	-0.263** (0.057)	-0.431** (0.099)
ψ_{agr}	-0.024 (0.023)	-0.088** (0.032)
θ_1	-	-0.365** (0.065)
θ_2	-	0.037** (0.007)
R^2	0.155	0.403
N	152	152

Notes. See Table 1.

6. Conclusions

The Solow growth model with land predicts that the effect of population growth on the growth rate of income per capita depends negatively on the importance of agriculture in the economy. This paper showed that the empirical evidence is consistent with this theoretical prediction.

What is the quantitative importance of the negative values that we obtained for ψ_{agr} ? To assess this, Fig. 1 graphs the estimated relationship between ϕ_{pop} and ψ_{agr} according to our three models: (4), (5), and (6). The solid line comes from model (4) which assumes that the effect is independent of agr , and thus it is a horizontal line. The dashed lines of models (5) and (6) not only show a negative slope—they also indicate that the range of this relationship is quantitatively substantial. Using the estimates from the linear specification, for

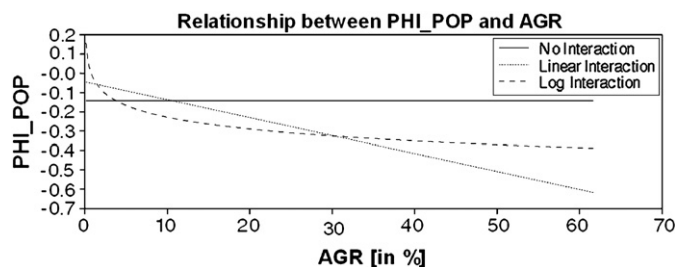


Fig. 1. $PHI_POP = \phi_{pop}$ (effect of population growth on per capita income growth) $AGR = agr$ (share of agriculture in value added).

example, a 1% (exogenous) change in population growth in Somalia ($agr = 62\%$), Afghanistan ($agr = 54\%$), or Uganda ($agr = 51\%$) will change the annual growth rate of income per capita by 0.5% or more. On the contrary, the same 1% (exogenous) change in population growth in Singapore ($agr = 0.7\%$) or Kuwait ($agr = 0.1\%$) will have virtually no effect on the growth rate of income per capita.

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