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The role of fertility and population in economic growth

Empirical results from aggregate cross-national data

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Abstract. Two recently improved sets of cross-country panel data are combined in order to re-examine the effects of population growth and fertility on economic growth. Using a 107 country panel data set covering 1960–85, we find that high birth rates appear to reduce economic growth through investment effects and possibly through "capital dilution", although classic resource dilution is not evident in the data. Most significantly, however, birth rate declines have a strong medium-term positive impact on per capita income growth through labour supply or "dependency" effects.

1. Introduction

The human species is currently going through a period of remarkable expansion. World population is thought to have been approximately 300 million in the year 1 A.D., after which it required about 1700 years to double to 600 million (see Collins 1982). By contrast, world population doubled from 2.5 billion to 5 billion in the 37 year period 1950–87, and, at current growth rates, would double again to 10 billion by about 2030. While the growth rate of population has actually fallen slightly since its peak in about 1970, the absolute increase in world population continues to grow every year and in 1992 was roughly 92 billion.

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data made available by Summers and Heston (1991), and demographic data from *United Nations World Population Prospects* (United Nations, 1992), allowing a large consistent data set (covering the period 1960–85) to be used. We derive a model specification that demonstrates the importance of birth rates in addition to population growth per se, and that allows us to distinguish several different possible mechanisms through which fertility might affect the growth of per capita real income.

The time series nature of our data is particularly important for at least two reasons (in addition to simply expanding the size of the data set). First, time series data allows more reliable treatment of "country-specific" effects that might be significant in explaining economic growth. We are also able to address important issues related to simultaneity discussed by Blanchet (1988), among others. Specifically, it seems likely that rising per capita incomes cause declines in fertility. If so, then fertility and population growth rates might be affected by income growth while income growth is simultaneously being influenced by fertility, leading to identification problems. We are able to test for and deal with this possible endogeneity of demographic variables.

In contrast to recent surveys, our analysis favours a "neo-Malthusian" interpretation: decreases in fertility tend to promote growth of per capita real income. Using production function based modelling, we clearly observe the "relative labour supply effect" of declining birth rates articulated by Coale and Hoover (1958): as birth rates fall, there is a period in which entry into the labour force rises more rapidly than the dependent population, yielding higher output per capita. This result is consistent with the findings of Coale (1986) and Bloom and Freeman (1988) that declining fertility produces a transitional increase in per capita income growth. In addition, we find that for high birth rate countries, birth rate declines tend to promote investment, although investment appears to be positively related to birth rates in low birth rate countries. There is also an apparent "capital dilution" effect of high fertility (but the role of possible "resource dilution" remains highly speculative). Overall, our results show more robust transitional effects than previous work and imply some effects that would also apply to comparisons across steady states.

We might also emphasize that in simple regressions, using birth rates (either crude or net of infant mortality) rather than population growth as a regressor for income growth tends to give stronger results. We also confirm, as found by Bloom and Freeman (1988), United Nations (1988), and Blanchet (1991 b) that more recent periods (i.e. 1980–85) exhibit a stronger negative correlation between population growth and per capita output growth than earlier periods (such as 1960–65).

We do not provide a full set of references to previous work on fertility and economic development, but several of the surveys cited earlier contain fairly complete bibliographies. Widely cited studies include Easterlin (1967), Kuznets (1967), Pitchford (1974), Rodgers (1984), Chesnais (1985), McNicoll (1984) and Hazledine and Moreland (1977). Two valuable collections of papers examining the relationship between demographic change and economic development are Salvatore (1988) and Johnson and Lee (1987). The "investment effect" that we investigate is related to the "savings effect", which has itself been the subject of considerable disagreement. Leff (1969, 1980) found that high youth dependency rates depress savings, as have Mason (1981), and Fry and Mason (1982), while Ram (1982) and Kelley (1986) have argued that the apparent existence of this effect is very sensitive to various aspects of specification.

Our starting data set was the list of 138 countries covered by Summers and Heston (1991). We omitted countries from this list on three grounds. First, we omitted 19 countries where data was missing for more than 2 years. (When there was only one or two years of missing data, as for Indonesia 1960–61, we extrapolated the time series forward or backward as necessary.) Second, we omitted four additional countries because of their heavy dependence on natural resource extraction. Our rationale is that national accounting techniques do not deal adequately with resource extraction, since no correction is made for the associated depreciation of natural capital. Nor is our supply side analysis able to deal with the substantial variations in output of resources which are controlled by cartels such as OPEC. While these effects are minor for most countries, they create a very serious problem in interpreting the data for a few. (The exact criterion we used was to omit countries for whom over 50% of GDP was accounted for by primary nonrenewable resource extraction in any 5-year period.)

Third, we omitted eight additional countries for which the United Nations estimate of annual population growth rates and the PWT5 population growth rates (derived from World Bank data) differed by more than one percentage point (e.g. 2.5% as opposed to 3.5%). For most countries agreement was very close, but a few (e.g. Afghanistan in 1981–85) produced very different estimates, suggesting that the data for these countries is unreliable and that the match between PWT5 and United Nations data may not be very good. In the case of Taiwan, there is simply no recent United Nations data.[2] Appendix 1 lists the 107 countries left in our sample in ascending order of their 1961–65 real GDP per working age person. Appendix 2 lists the countries omitted according to the three criteria just described. Our overall data set is a balanced panel of $1077 \times 5 = 535$ observations.

Before making use of this panel data set, however, we undertake some preliminary analysis comparable to that of many previous studies. Specifically, we begin by using full period aggregates (1961–85) for each country (i.e. 107 observations) and run simple cross-sectional regressions of economic growth on population growth and birth rates. At the suggestion of a referee we use "net" or "adjusted" birth rates as our birth rate variable. Adjusted births are simply crude or gross births net of infant mortality. Roughly speaking, the adjusted birth rate "counts" only the number of newborn children expected to reach their first birthday. In fact, whether one uses crude or adjusted birth rates makes little difference to the results. Adjusting birth rates for infant mortality reduces the overall dispersion in birth rates, but preserves the general ordering of countries.

Comparing the results obtained here with previous work allows us to see how much of the difference between our findings and previous work is due to the new data we are using, rather than to the innovations of exploiting the panel structure of the data and using the production-function based estimation procedure developed in Sects. 3 and 4 of the paper.

In Table 1 we report the results of simple OLS regressions of per capita GDP growth versus population growth and versus (adjusted) birth rates. A recent study by Kelley (1992) suggests, however, that statistical measures of correlations such as these may be sensitive to the treatment of heteroscedasticity and to systematic differences between sub-samples. We therefore report four additional estimates making different adjustments for possible heteroscedasticity. Each adjustment

2 Taiwan has been omitted from United Nations data since the early 1970s as a political concession to China.

Table 2. Per capita output growth vs. adjusted birth rates. Regression coefficients (*t*-statistics) [White-adjusted]

Period/Method	Whole sample ($n = 107$)	Less developed ($n = 40$)	More developed ($n = 67$)
1961–85			
OLS	−0.69 (−4.6) [−4.9]	−0.51 (−0.7) [−0.6]	−0.32 (−2.0) [−2.4]
Weight = population	−0.86 (−5.1)	−2.30 (−5.9)	−0.16 (−0.9)
Weight = RGDP p.c.	−0.43 (−3.3)	−0.60 (−0.7)	−0.23 (−1.4)
Weight = GDP	−0.31 (−2.2)	−2.30 (−6.4)	−0.09 (−0.5)
1961–65			
OLS	−0.95 (−3.3) [−3.7]	−2.04 (−1.6) [−1.9]	−0.42 (−1.5) [−1.5]
Weight = population	−1.55 (−4.7)	3.87 (4.1)	−0.76 (−2.7)
Weight = RGDP p.c.	−0.47 (−2.3)	−1.94 (−1.8)	−0.21 (−0.9)
Weight = GDP	−1.08 (−4.4)	4.51 (4.8)	−0.44 (−1.5)
1981–85			
OLS	−0.75 (−2.7) [−2.8]	−1.97 (−1.9) [−2.4]	−1.43 (−4.7) [−4.2]
Weight = population	−1.76 (−4.6)	−0.38 (−8.8)	−1.67 (−5.9)
Weight = RGDP p.c.	−0.95 (−4.1)	−1.99 (−2.3)	−1.38 (−4.7)
Weight = GDP	−0.74 (−2.3)	−3.75 (−9.2)	−1.45 (−5.6)

the Sudan replace Egypt, Sri Lanka and the Congo.) In Tables 1 and 2 we report the regression coefficients within each sub-sample as well as across the whole sample and we repeat the exercise for the beginning and ending 5-year periods. SHAZAM 6.2 (see White et al., 1990) was used for these regressions.

Table 1 is reasonably consistent with the traditional result that the empirical link between population growth and economic growth is somewhat tenuous, particularly for the less developed countries. Looking, for example, at the six OLS white-adjusted *t*-statistics for the stratified samples, only one shows a statistically significant relationship between population growth and per capita output growth. Nevertheless, almost all of the coefficient estimates in Table 1 are negative, creating at least a suggestion of a negative relationship. Table 2, showing the link between (net) birth rates and economic growth, contains stronger negative effects. In the most recent period, all relationships estimated are significantly negative, and for the full period, both the whole sample and the more developed countries exhibit significant negative relationships. The overall inference arising from inspection of Table 2 is that the correlation between fertility and economic growth is negative, particularly in the most recent period. It remains to be seen, however, whether we can find persuasive evidence of a causal connection running form fertility to economic growth. Drawing reasonable inferences would seem to require more detailed structural modelling, which we seek to do in the following sections.

In addition, one cost of doing simple cross-sectional regressions of the type reported here is that information contained in the time-varying behaviour of any one country is ignored: only cross-sectional variation is used to derive inferences. Exploiting time series variation by constructing panel data based on 5-year intervals allows more complete use of the information contained in the data.

parents, especially mothers, to devote more time to producing market output. Letting the relation between effective labour per capita and w be denoted $h = h(w)$, we can write:

$$\hat{h} = \hat{w}(1+\lambda) \ , \tag{4}$$

where $\lambda = h'(w)w/h$, the elasticity of effective labour per capita with respect to the working age share.[3]

We must also impose some structure on the nature of technical progress. Recent work (including Abramovitz 1986; Romer 1986; Dowrick and Nguyen 1989; Dowrick and Gemmell 1991) suggests that there may be systematic variations in rates of technical progress over time and according to level of development. In particular, the benefits of technical progress may be difficult to realize if infrastructure in human and physical capital is below some threshold level. Thus the link between level of development and technical progress may be nonlinear. Accordingly, we specify technical progress as a quadratic function of some index of development, z, and include a vector of dummy variables, one for each period of observation (after the first), yielding the following technical progress function

$$\theta = \theta_{01} + \theta_{0t}D_t + \theta_1 z + \theta_2 z^2 \ . \tag{5}$$

The final term in (2), ϕ, is a residual representing "random error" and any other source of unmodelled variation. Some of these factors might be specific to particular countries, such as institutional or political factors. Accordingly, we specify two components to the error term: a country specific component and a white noise component. Indexing countries by i and periods by t, this yields:

$$\phi_{it} = \mu_i + \varepsilon_{it} \ . \tag{6}$$

Substituting (3), (4), (5), and (6) into (2), we obtain an equation suitable for estimation

$$\hat{y} = \alpha_0 + \alpha_1 \mathrm{IS}_{it} + \alpha_2 \hat{w}_{it} + \alpha_3 \hat{P} + \alpha_4 z_{it} + \alpha_5 z_{it}^2 + \alpha_6 D_t + \mu_i + \varepsilon_{it} \ , \tag{7}$$

where $\alpha_0 = \theta_{01} - a_K\delta$, $\alpha_1 = Y_K$, $\alpha_2 = a_H(1+\lambda)$, $\alpha_3 = (a_s - a_R - a_K)$, $\alpha_4 = \theta_1$, $\alpha_5 = \theta_2$, and $\alpha_6 = \theta_{0t}$. Estimation of Eq. (7) does not allow separation of the independent effects of returns to scale, resource depletion, and capital shallowing. Nor does it allow us to distinguish between the output-employment elasticity (a_H) and the effective labour elasticity (λ). Nevertheless, it does allow estimates of the net direct effect of population growth on per capita income growth. In addition, we can write the following equation for investment and for the rate of change, $\hat{w}$, in the working age share of population

3 We use the working age population as our primary variable representing "effective labour". One could argue that it would be better to work with "labour force" but data quality issues make the working age population a much better variable for our purposes. Note, however, that some countries have experienced an increase in female labour force participation over the period, with the result that increases in the working-age share might understate the actual increase in effective labour. Partially offsetting this is the possibility that women made significant indirect contributions to measured GDP without being counted in the labour force, in which case the working-age share would be a more reliable measure even apart from data quality issues.

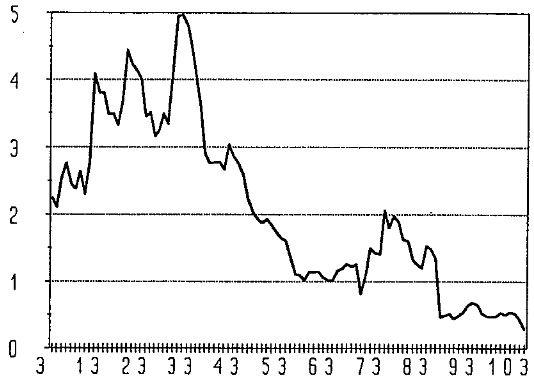

Fig. 1. Sequential Chow test for subdividing sample

We have again divided the sample into two subsamples based on level of development. In this case we ordered the countries by 1961–65 real GDP per working age adult, as given in Appendix 1. (Countries were ranked by GDP per working age person rather than GDP per capita because the former measure is normally taken as a better measure of "level of development", especially when a technology catch-up term is to be included in the regression.) Sequential Chow tests were then applied to estimates of production equation (7). The structural break is most pronounced between the least developed 31 countries and the rest. This defines the groupings that we use throughout the rest of the paper. By comparison with earlier work, the "cutoff" between more and less developed countries is somewhat unorthodox, at it is more common to stratify the sample be separating the top third from the bottom two-thirds, whereas we have the converse. Figure 1 shows the sequential Chow test statistic (distributed $F(10, 515)$ under the null hypothesis of no structural break) as a function of the break-point. The strongest break appears clearly at about the 31st country, and is highly significant.

Table 4 provides data summary statistics for the whole sample and for the two sub-samples.

An observation is a 5-year period for a given country. Table 4 shows that there is remarkably wide variation across the observations in income growth rates, population growth rates, and birth rates (among other things). It is perhaps also of interest that the strongest crude correlation involving income growth is with investment.

As already noted, the longitudinal panel structure of our data allows investigation of possible unmodelled country-specific factors. Following Greene (1990), and using the associated procedures in the LIMDEP 5.1 econometrics package (as described in Greene 1989), we were able to test for country specific effects and carry out appropriate estimation in their presence. For each equation the "error" term is of the form $\varepsilon_{it}+\mu_i$, where i refers to the country and t refers to the period. μ is the country specific term. Running a simple pooled OLS regression assumes that $\mu_i = 0$. A fixed effects model assumes that μ_i is a fixed constant (across time periods) for each country, in which case an appropriate estimation techniques is least squares with country specific dummies. The third possibility is that μ_i is itself a random variable, yielding an error components model, referred to as a "random effects", model, that can be estimated using generalized least squares. We report all three possibilities.

Table 5. Per capita GDP growth – whole sample ($n = 535$). (t-statistic) [White-adjusted t-stat]

Variable	OLS	Fixed effects	Random effects	IV: $n = 428$
$\hat{w}$	0.85 (2.9) [2.7]	0.31 (0.9)	0.79 (2.7)	1.35 (3.2)
$\hat{P}$	0.02 (0.1) [0.1]	−0.33 (−1.0)	0.02 (0.1)	−0.17 (−0.7)
IS	0.10 (5.5) [3.9]	0.09 (2.3)	0.10 (5.2)	0.11 (5.2)
LRP	−0.45 (−0.8) [−0.7]	−1.61 (−0.8)	−0.50 (−0.8)	−0.58 (−0.8)
LRP^2	−0.14 (−1.0) [−0.8]	−0.86 (−1.8)	−0.16 (−1.0)	−0.08 (−0.8)
summary stats				
adj. R^2	0.196	0.152		0.191
s.e.	3.06	3.51		3.16

Diagnostics: Hetero: ***; Reset (2)-; Endogeneity: $P = 0.054$*.
Model selection: FE vs OLS: F: $P = 0.13$, X^2: $P = 0.02$**; RE vs OLS: $P = 0.50$; FE vs RE: $P = 1.0$.
*** Indicates significance at $P = 0.01$ level, ** at $P = 0.05$, * at $P = 0.1$.
"Endogeneity" reports the significance of the Hausman test for endogeneity of the two demographic variables.

variables for each period to capture period fixed effects, but we do not report the coefficients here. Full sample results are reported in Table 5. We find that the country-specific fixed effects are not significant on the F-test, but are significant at the 0.05 level on the likelihood ratio test. The random effects model is preferred to the fixed effects model, so we report both.

The IV regression (for instrumental variables) is an attempt to correct for possible endogeneity of birth rates. As noted in the introduction, Blanchet (1988, 1991 b), among others, has emphasized that birth rate and population variables might be endogenously influenced by changes in income. If demographic variables are simultaneously affected by changes in per capita income, then simply regressing income growth on demographic variables using ordinary least squares or related techniques will not produce meaningful results. The first line of defence, noted by Blanchet, is that demographic variables seem to be closely related to the level of income rather than to income growth. If it is the level of income that is important, the regressing income growth on demographic variables is not necessarily a problem.

This would be a complete defence if the data were based on very short time periods. If one uses 5-year or 10-year periods, however, then variation in growth rates across countries over the period can lead to significant variations in the level of income and hence birth rates within the period. This problem is obviously much less severe with 5-year periods (as we have) than with 10-year periods, but it certainly requires some attention, and can be addressed by the time series aspect of the data. We test for endogeneity using Hausman's test for exogeneity (as described in Beggs 1988). As indicated in note 4 in Table 5, there is only modest evidence of endogeneity. We do, however, report the results from an associated instrumental variables regression in column 4 (IV) of Table 5 that uses strictly predetermined birth rates as instruments.

The notes following the table require some explanation. First, the "diagnostics" are carried out just for the OLS regressions. The three asterisks following "Hetero" means that the null hypothesis of homoscedasticity can be rejected at the 0.01 level of significance using Shazam 6.2 diagnostics. Shazam 6.2 actually carries out eight separate tests for heteroscedasticity. We report

Table 6. Per capita production function – less developed countries (n = 155). (t-statistic) [White-adjusted t-stat]

Variable	OLS	Fixed effects	Random effects
$\hat{w}$	1.57 (1.9) [2.1]	1.00 (1.0)	1.46 (1.7)
$\hat{P}$	−0.12 (−0.3) [−0.2]	−0.74 (−1.1)	−0.22 (−0.5)
IS	0.06 (1.4) [1.1]	0.07 (0.7)	0.06 (1.4)
LRP	5.48 (1.1) [1.0]	−10.8 (−1.4)	3.05 (0.6)
LRP^2	0.75 (0.9) [0.7]	−2.43 (−1.6)	0.32 (0.3)
summary stats			
adj. R^2	0.104	0.152	
s.e.	3.61	3.51	

Diagnostics: Hetero: **, Reset(2)-; Endogeneity: $P = 0.76$.
Model selection: Fixed eff. vs OLS: F: $P = 0.18$, X^2: $P = 0.04$**; Random effects vs. OLS, $P = 0.91$; Fixed vs Random, $P = 1.0$.
The IV estimates are not reported as endogeneity is not significant.

Table 7. Per capita production function – more developed countries (n = 380). (t-statistic) [White-adjusted t-stat]

Variable	OLS	IV: $n = 304$
$\hat{w}$	0.67 (2.3) [2.0]	1.28 (3.1)
$\hat{P}$	−0.09 (−0.6) [−0.5]	−0.27 (−1.2)
IS	0.08 (4.4) [3.2]	0.09 (4.0)
LRP	−1.99 (−2.4) [−2.9]	−1.91 (−2.0)
LRP^2	−0.95 (−3.2) [−3.6]	−0.88 (−2.5)
summary stats		
adj. R^2	0.328	0.326
s.e.	2.64	2.73

Diagnostics: Hetero: ***; Reset(2)-; Endogeneity: $P = 0.012$**.
Fixed Effects vs OLS: F: $P = 0.60$, X^2: $P = 0.27$; Random Effects vs OLS, $P = 0.33$; Fixed vs Random, $P = 1.0$.
Neither the fixed effects nor the random effects estimates are reported as neither is significantly preferred to OLS.

ables are endogenous with respect to income growth rates. The coefficients on population growth are negative, but of little statistical significance. Overall, the regression has little explanatory power. We conclude that for these countries we have not been able to estimate a reliable systematic relationship between factor inputs and output growth. We suspect this may reflect the relatively poor level of data quality for these countries. Even so, the favoured (OLS-White adjusted) regression for this set of 31 very poor countries does show an economically large and statistically significant positive effect of increases in the working age population share on per capita income growth, suggesting that declines in fertility would boost per capita growth for this set of countries.

The results for the more developed countries (reported in Table 7) are much clearer. The regression explains one-third of the variance in growth rates and the coefficients are estimated with reasonable precision. Neither specification of country effects – fixed or random – is statistically significant, but there is clear

Table 9. Investment: less developed economies (31 countries $\times 5 = 155$ observation). Reporting the coefficients and (t-statistic) [White t-stat] from regressions of IS

	OLS			Fixed effects		Random effects	
Birth rate	−15.1	(−3.2)	[−3.0]	−8.9	(−1.5)	−9.3	(−1.9)
(Birth rate)^2	1.8	(3.2)	[3.1]	1.2	(1.6)	1.2	(1.9)
LPI	−12.7	(−12)	[−13.0]	−8.2	(−4.3)	−10.7	(−7.6)
y	0.66	(4.0)	[4.1]	0.93	(3.5)	0.81	(3.9)
y^2	−0.07	(−0.2)	[−0.2]	−0.63	(−1.3)	−0.35	(−0.8)
adj. R^2	0.710			0.845			
s.e.	4.59			3.36			

Diagostics: Hetero: ***; Reset: OLS: ***; Fixed effects ***; Random effects ***.
Model selection: Fixed effects vs OLS: $P = 0.000$ ***; Random effects vs OLS: $P = 0.000$ ***; Fixed vs Random: $P = 1.0$.
The coefficients on y and y^2 have been multiplied by 100 and 10^6 respectively. Period dummies are included but not reported here.

Table 10. Investment: more developed countries (76 countries $\times 5 = 380$ observation). Reporting the coefficients and (t-statistics) [White t-stat] from regressions of IS

	OLS			Fixed effects		Random effects	
Birth rate	−0.91	(−0.5)	[−0.5]	12.9	(4.3)	7.05	(3.0)
(Birth rate)^2	−0.05	(−0.2)	[−0.2]	−2.1	(−5.0)	−1.17	(−3.5)
LPI	−10.7	(−13)	[−13]	−9.7	(−6.1)	−9.8	(−9.0)
y	0.18	(3.7)	[3.7]	0.34	(5.1)	0.25	(4.6)
y^2	−0.12	(−4.1)	[−4.4]	−0.14	(−3.7)	−0.13	(−4.1)
adj. R^2	0.541			0.800			
s.e.	5.81			3.84			

Diagnostics: Hetero: -; Reset: OLS ***; Fixed effects -; Random effects -.
Model selection: Fixed effects vs OLS: $P = 0.000$ ***; Random effects vs OLS: $P = 0.000$ ***; Fixed vs Random: $P = 1$.

significant coefficient in the entire sample and in the sub-sample of 76 more developed countries. Fertility might in turn have an effect on investment and therefore an indirect effect on economic growth in addition to the direct effect already estimated. Tables 9 and 10 report regression results for investment using birth rates, the (logged) price of investment, LPI, and income as explanatory variables. (Using the log of price rather than the level does not significantly affect the other coefficients, but it does provide a better fit to the data and is therefore favoured by specification tests.)

For the less developed countries, we find a quadratic birth rate effect that is negative over the region covered by the data (i.e. higher birth rates reduce investment). This effect is, however, only of marginal significance in the models with country-specific effects. The price effect is large, significant, and negative, as expected, and there is a significant positive and essentially linear income effect. The preferred estimates are provided by the random effects model.

In the more developed countries we find, as expected, that price effects are important, and that the income effect is non-monotonic. Country effects are very years when increases in old age dependency relative to new labour force entrants begin to become significant. This potential negative "rebound" effect depends very much, of course, on retirement practice, public policy toward old age, and the precise dynamics of the model structure, and is not a necessary implication of falling fertility.

These calculations do not presume any dynamic feedback effects in which higher incomes induce a further decline in fertiliy. Such effects would tend to increase the apparent gain from a fertility decline. A "complete" structural dynamic system can be obtained by specifying birth rates and population growth rates as a function of income. Estimated random effects equations for birth rates and population growth follow (t-statistics are in parentheses).

$$\text{br} = 11.6 - 1.05\ (25.7)\log(y) \qquad R^2 = 0.31\ \text{(Random effects)}$$

$$\text{Pop. growth} = 5.7 - 0.46\ (8.04)\log(y) \qquad R^2 = 0.31\ \text{(Random effects)}$$

Birth rates show a remarkably close relationship to (the log of) income. The corresponding relationship of population growth to income is mitigated both by mortality and by migration (as is consistent with Tables 1 and 2), but is also strongly significant. It would be possible to take the estimates of (7), (8), (9), (10) and (11) and run a dynamic simulation for a country (assuming particular starting values). The behaviour and properties of this dynamic system are highly sensitive to particular estimates and specifications. While we feel that the basic pattern in the data is fairly clear, there is substantial uncertainty over precise specification and actual estimation, and the effects we capture explain only a modest amount of total variation. Therefore, we would not regard the dynamic properties of the system as appropriate for presentation as "empirical" results at this stage. It is, however, important to emphasize that one type of behaviour that can emerge is a dynamic demographic transition in which income growth plays a role. More elaborate analysis of this dynamic system is, however, beyond the scope of this paper. See Blanchet (1988) for some interesting dynamic simulations of this type.

5. Concluding remarks

We have recently observed a striking and unprecedented variation across countries in per capita income growth. Variation in investment rates is highly significant but explains only a modest share of total variation. We offer evidence that variation in fertility, especially variation in the extent to which birth rates have fallen, might also be an important contributing explanation.

Our analysis is not undermined by the concern that birth rate changes might be an endogenous response to income growth. Even when birth rate changes are strictly predetermined in income growth regressions, the effect of birth rates on income growth remains at least equally significant. In other words, birth rate declines precede income growth increases. Nevertheless, as already discussed, the effects we estimate might well be part of a self-reinforcing demographic transition with feedback effects.

While the most striking effect of birth rate changes arises through the labour supply (or "negative dependency") effect, there are also effects in high birth rate countries arising from the impact of birth rates on investment. In addition, there may be a "factor crowding" effect of increased population which we attribute to

Appendix 1

Countries in sample order

Number	Country	y/w 1961–65	Number	Country	y/w 1961–65
1	U.R. Tanzania	531	28	Cote d'Ivoire	2204
2	Ethiopia	547	29	Egypt	2225
3	Uganda	741	30	Congo	2326
4	Rwanda	770	31	Cape Verde	2330
5	Lesotho	772	32	Sierra Leone	2372
6	Gambia	826	33	Ghana	2515
7	Zaire	868	34	Papua New Guinea	2574
8	Malawi	879	35	Mauritania	2701
9	Myanmar	907	36	Mozambique	2772
10	Guinea	995	37	Liberia	2868
11	China	1055	38	Pakistan	2872
12	Botswana	1220	39	Angola	2903
13	Mali	1238	40	Senegal	2920
14	Nepal	1269	41	Rep. of Korea	2994
15	Central Africa	1331	42	Honduras	3003
16	Kenya	1332	43	Sudan	3027
17	India	1403	44	Swaziland	3078
18	Indonesia	1426	45	Nigeria	3134
19	Cameroon	1597	46	Philippines	3387
20	Haiti	1679	47	Bolivia	3641
21	Gabon	1783	48	Turkey	3698
22	Benin	1865	49	Sri Lanka	3838
23	Madagascar	1943	50	Paraguay	3990
24	Bangladesh	1979	51	Yugoslavia	4423
25	Chad	2026	52	El Salvador	4468
26	Zimbabwe	2063	53	Marocco	4473
27	Thailand	2146	54	Ecuador	4767

Appendix 2

Countries omitted from the sample

Missing data	*Resource dependent*
Burkina Faso	Zambia
Comoros	Trinidad & Tobago
Guinea Bissau	Kuwait
Seychelles	Saudi Arabia
Bahamas	
Dominica	*Population discrepancy*
Grenada	
St. Lucia	Burundi
St. Vincent & Grenada	Niger
Bahrain	Somalia
Oman	Togo
United Arab Emirates	Guyana
Yemen	Afghanistan
Hungary	Taiwan
Poland	Malta
Solomon Islands	
Tonga	
Vanuata	
Western Samoa	

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