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Be fruitful or multiply: On the interplay between fertility and economic development

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Abstract. This paper develops and estimates an empirical model of the interplay between fertility and economic development. Using panel data, this study finds that a one-percent decrease in population growth increases GDP per capita growth by more than three percent. In addition, because families with low levels of human capital choose to have more children, income per capita grows faster in developed countries than in developing countries. Finally, this study shows that the estimates of the interplay between fertility and output obtained from single cross-country regressions are biased downward because that method of estimation is unable to control for unobservable country effects and measurement errors. The neoclassical approach fails to account for these effects. The present study contributes to the now-standard growth model, and provides a better description of international differences in standards of living.

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1. Introduction

This study has two central themes. The first is methodological – to compare the empirical validity of the endogenous fertility growth model (EFGM) pre-

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dictions with that of the standard growth model (SGM). The second is substantive – to evaluate the magnitude of the reduction in income growth per capita resulting from an increase in population growth. Methodologically, this study finds that the EFGM predicts observed patterns of Gross Domestic Product (GDP) per capita better than do SGMs. Thus, by ignoring fertility as a choice variable, SGMs omit an important source of diversity in income growth across time and countries. Substantively, I find that an increase in population growth decreases GDP per capita growth at an increasing rate. This is due to a combination of the following effects: (a) children consume resources, but do not produce, implying that in countries with high fertility, a smaller share of the population works; (b) parents spend time taking care of their children, implying an additional negative impact on the labor supply; (c) the classical physical capital dilution; and (d) reverse causality, meaning that income influences fertility behavior.

The above scenario calls for an extension of the classical theory of growth. In the SGM (e.g., Solow 1956; Lucas 1988; and many others), higher population growth lowers income because physical capital must be spread more thinly over the population of workers (capital dilution). These models assume a constant rate of population growth. Others (Mankiw et al. 1992) allow variations among countries by assuming exogenous heterogeneity in the preference for children. In contrast, EFGMs such as those developed by Barro and Becker (1989), Becker et al. (1990), and Galor and Weil (1996 and 1999) link fertility choices and economic growth by endogenizing both variables.[1] EFGMs also include the assumption that the relative number of the young imposes a productivity cost or dependency effect on the economy, while SGMs ignore this element.

As a consequence of these two differences, the solution to the EFGM includes an additional dynamic equation. Hence, while in the SGM population growth is assumed to be constant, in the EFGM fertility rates are governed by a policy function, which depends on the stock variables in the economy. This policy function may take several forms. For example, Malthus (1965) predicted that fertility would increase as income rose; Barro and Lee (1993) find some evidence that the policy function has an *inverted U-shape*; Becker et al. (1990) predict a negative noncontinuous relationship; and Ahituv (1995) predicts that the policy function can be approximated by a log-linear negative function with physical and human capital as the stock variables.

A considerable amount of empirical work has been done on cross-country sources of economic growth. Much of this work suffers from several weaknesses: (a) most of them employ cross-sectional, single-equation regression analyses; (b) many use average annual GDP growth rates from 1960 to 1985 as the main dependent variable, and therefore examine the sources of growth in a particular period in economic history; and (c) most of them fail to take into account the effects of the population's age structure on a country's labor force participation rate, resulting in confusion between capital per capita and capital per worker. The present study follows Islam (1995) who employs panel data to reexamine cross-country differences, showing that the results obtained by Mankiw et al. (1992) are sensitive to unobserved heterogeneity. Analyzing the data used by Mankiw et al. (1992) and Barro (1991), Islam finds higher rates of conditional convergence and lower values of the elasticity of output with respect to capital.

Studies that examined the interaction between the economy and fertility

(Barro 1991; Meltzer 1992) find that a country's wealth and the level of educational attainment account for most of the variation in cross-country fertility differences. Both these studies, however, find that the effect of fertility on economic growth is insignificant. Due to data limitations, these authors were unable to control for the effects of omitted variables and measurement errors, nor could they explore changes in income and fertility within countries. Barro and Lee (1993) extend these studies by employing a Seemingly Unrelated Regression (SUR) using two data points for each country and arrive at conclusions that are broadly similar to those of Barro (1991). As explained below, I find that their results are subject to unobserved heterogeneity bias. Schultz (1994) and Brander and Dowrick (1994) demonstrate an interesting illustration of the power of panel data in this type of analysis. Schultz (1994) shows that when unobserved heterogeneity is controlled for, the sign on the family-planning activity index coefficient (in fertility regression) is reversed. Brander and Dowrick (1994) examine the effects of population growth on economic growth. Unlike their results, the present study shows that fertility, not population growth, is the relevant variable.

The paper proceeds as follows. Section 2 describes the contents of the data set and discusses its advantages and limits. The main findings of this descriptive examination are: (a) in most countries, population and income growth change enormously over the sample, suggesting that these countries are not in a steady state; (b) despite substantial convergence in physical capital and education levels, incomes have diverged, implying that additional factors affect the differences in productivity across countries; and (c) fertility rates differ by economic status, suggesting an interaction between fertility and economic development. Due to the problem of finding good instrumental variables in a cross-country data set, I was unable to correct for simultaneous equation bias using a model of multiple regression. Thus, the regression analysis is comprised of two parts: evaluating the effects of fertility on economic growth (Sect. 3), and estimating regressions with fertility as the dependent variable (Sect. 4).

Section 3 starts with an OLS examination of the negative correlation between fertility and GDP, and then examines the robustness of the findings by controlling for unobserved country components. The negative relationship between fertility and productivity is found to become more significant when these components are controlled for, implying that the cross-sectional estimates are biased downward due to the negative correlation between fertility and the unobservable variables. The second part of Sect. 3, presents estimates of a novel structural regression model, with per capita physical capital growth as the dependent variable. The findings support one of the main assumptions of the EFGM, namely, that the children-dependency effect is the main demographic factor that keeps countries with high fertility rates poor. Surprisingly, this crucial observation is ignored by the aforementioned studies.

Estimates of the fertility policy function are presented in Sect. 4. First, I find that physical capital and education levels explain 77% of the variation in fertility rates across countries and over time. Other important determinants of fertility are the education gap between men and women, and life expectancy. These findings complement the findings in Sect. 3, and extend the SGM assumptions by showing that fertility rates are endogenous to a country's economic performance. The robust panel data analysis indicates that fertility has a larger impact on income per capita than indicated by cross-sectional regression analysis. This is in large part due to the fact that OLS estimates do not account for the feedback effects of income and education on fertility. The last section summarizes key results of this empirical investigation and outlines several suggestions for improving economic growth policies.

2. The data

2.1. Main features

To construct the database for this study indicators from five data sources were merged. The resulting database covers approximately 50 indicators[2] for 114 countries. For each country, the data set contains annual time-series data from 1960 to 1989. Most of the analyses presented in this paper use only six data points (1965, 1970, 1975, 1980, 1985 and 1989), because the early years are used as lag variables, and five-year spans are less likely to be serially correlated (Islam 1995).

The variables in this database are divided into four categories: (1) national accounts variables related to expenditure and income; (2) social and demographic indicators, including school and fertility; (3) political indicators, indexing political instability, regime and market distortions; and (4) geographic regions in which the country is located. Most of the variables are in time-variant format, but some of them, mainly the political and geographic regions, are time-invariant.

Several features of this database make it especially attractive for growth analysis. First, because the data contain several observations per country, we can relax the strong assumption made by Mankiw et al. (1992) that the data are drawn from economies approaching steady state. Secondly, the panel data structure allows us to explore the time-series path of each country, and hence the empirical properties of the transition dynamics. Third, the database includes more countries and data points than any other study listed in the bibliography, and thus provides a better representation of the real world. Finally, the panel structure allows us to control for unobserved heterogeneity and measurement errors.[3]

2.2. Descriptive patterns of economic and demographic indicators

This section examines selected economic patterns over time and across income groups in order to determine whether there is *prima facie* evidence that population growth is correlated with economic growth. To simplify the presentation we aggregate the countries into three groups according to their real GDP per capita in 1965. A summary of this comparison is presented in Table 1. Part A reports average GDP levels and indicators of the levels of three *production inputs*, and Part B summarizes indicators for the flows of these four variables.

The descriptive examination reveals considerable diversity among the groups in GDP growth, investment, education and many other economic and demographic indicators. In 1965, GDP per capita in the high-income economies was nine times greater than in the low-income economies; by 1985, this ratio had grown to 11 : 1. Thus, the unconditional income gap between these

Table 1. Summary of selected economic and demographic indicators by country group (means)

		A) Low-income economies	B) Middle-income economies	C) High-income economies
Number of countries in each group		34	39	38
Part A:				
Real GDP per capita	1965–1985	633	1,538	5,761
		827	2,521	9,155
% change, 1965–85		30%	64%	59%
Average years of school	1965–1985	1.17	2.75	5.76
		2.04	4.24	7.67
% change, 1965–85		74%	54%	33%
Physical capital per capita	1965–1985	361	1,380	9,358
		1,120	5,568	25,574
% change, 1965–85		210%	303%	173%
Population density	1965–1985	44	136	190
		74	193	255
% change, 1965–85		68%	42%	34%
Part B:				
Annual GDP growth (percentage)	1965	1.0	2.7	4.3
	1975	2.1	2.8	2.5
	1985	−0.4	−0.8	0.3
Secondary school enrollment	1965	6.0	18.6	49.2
	1975	12.1	32.3	65.7
	1985	19.1	41.8	77.8
Investment share in GDP	1965	9.1	15.5	26.6
	1975	11.6	19.0	26.4
	1985	11.4	15.4	22.0
Fertility rate	1965	6.5	6.2	3.7
	1975	6.4	5.4	2.9
	1985	6.1	4.7	2.4
Annual population growth (percentage)	1965	2.4	2.6	1.6
	1975	2.6	2.5	1.3
	1985	2.8	2.4	1.1

Notes: a) The three groups are based on GDP in the initial period, 1965. b) The income groups are (1) 0–1000; (2) 1001–2500; (3) 2501–12000 (all values in $ per annum). c) Annual GDP growth and population growth are calculated as five-year averages. d) The comparison is restricted to 111 observations because of missing observations in 1965.

two groups diverges rather than converges, as suggested by the neoclassical models of Solow (1956) and Cass (1965). This result supports Increasing-Return-to-Scale production functions, which is the engine of growth in the Romer (1986) and Lucas (1988) endogenous growth models. However, the fact that the physical capital gap between the richest and poorest economies decreased from 25 : 1 to 22 : 1, contradicting Lucas' results that the GDP and capital gaps have to increase in the same proportion, suggests that other factors contribute to the observed GDP divergence. On the other hand, population in the low-income countries grew by 68%, i.e., at almost double the rate in the high-income group of countries. This may be considered as *prima facie* evidence that population growth is correlated with economic growth.

The figures point out two problems with variables central to our analysis. The first of these is that GDP growth rates fluctuate considerably over the sample period. Some countries with rapid growth rates in the early period did poorly later, and *vice versa*. This high degree of fluctuation compels us to exercise caution when drawing inferences about long-term economic paths based solely on the average annual GDP growth rate from 1965 to 1985. The second problem is that school attainment, which is used in this type of analysis (Barro and Lee 1993) as a proxy for human capital, grows faster in low-income countries, suggesting that we fail to fully account for the quality of human capital.

With striking consistency, population growth differs by economic cluster: the rate in high-income economies is less than half the rate in low-income economies (1.1% compared with 2.8%, respectively, in 1985). Moreover, on average the rate of population growth is on the increase in low-income economies, whereas it is decreasing in high-income economies. In low-income economies, most changes are related to rapidly declining death rates[4] (30% in group A compared with only 12% in group C). In developed countries, the changes are associated with a rapid drop in fertility (35% in group C compared with only 6% in group A). Again, this finding suggests that growth models should include, in addition to the commonly used population growth, both fertility and death rates.

Formal tests reject the hypothesis that changes in annual GDP growth, secondary school enrollment, investment share, fertility and population growth from 1965 to 1985 are *zero* at a significance level of 1%. This evidence is inconsistent with the common assumption of steady-state growth,[5] and challenges conclusions based on this assumption. For this reason, the following empirical analysis does not assume steady state.

3. The effect of fertility on productivity

According to the foregoing descriptive analysis, fertility, income per capita and economic growth are correlated. Pursuing this line, we apply regression analysis to examine whether the negative correlation between GDP and fertility holds when we control for the observed and unobserved characteristics of each country. Then, in the second part of this section, we estimate the magnitude of the effect of fertility on economic growth by employing a structural, non-linear analysis.

3.1. Linear estimation with "country effects"

By taking advantage of the panel data and utilizing a panel estimation framework that allows us to control for country-specific, unobserved components (Mundlak 1978), this section examines whether the negative correlation between fertility and GDP is robust.[6] I control for omitted variable bias using two methods: Random Effect (RE) and Fixed Effect (FE) specifications.

I consider the following linear form,

$$\ln y_{it} = \ln A_{it} + \alpha_1 \ln g_{it} + \alpha_2 \ln k_{it} + \alpha_3 \ln h_{it} + e_{it}^{y}, \tag{1}$$

where y_{it} denotes output per capita, A_{it} is a vector of technology level, resource endowments and institution characteristics that affect the productivity level in country i at period t, g_{it} is the fertility rate, k_{it} is physical capital per capita, and h_{it} is a vector of variables that represent a country's level of human capital.

Regression 1 in Table 2 employs pooled panel data for 1965–1989 with the basic covariates; regression 2 adds population growth to this set of basic covariates; regression 3 presents results in which the unobserved effects are assumed to be random; regressions 4 and 5 use the same covariates as regressions 1 and 2, respectively, with country fixed effects; and regression 6 uses both time and country fixed effects. The aims of the analyses in regressions 3–6 are: (a) to learn about the nature of the omitted variables;[7] and (b) to compare the impact of different specifications of the unobserved terms in each model, with particular attention to the sign and magnitude of the main coefficients of interest (LNFERT, LNCAP and SECENRR).

In order to determine which specifications of the error terms are most appropriate, three statistical tests are employed:[8] (1) the F-statistic for testing restrictions on the structural parameters; (2) the Breusch-Pagan Lagrangian Multiplier (LM) statistic for testing the RE model against the OLS model; and (3) Hausman's chi-square statistic (H) for testing whether the RE model is an appropriate alternative to the FE model. The results of these tests (reported in Table 2) indicate that regression 6 is the appropriate model. Hence, the cross-country OLS estimates (columns 1 and 2) are biased and, having found that the FE (column 4) dominates the RE (column 3), we infer that the unobservables are correlated with the time-variant covariates. Finally, regression 6, which includes dummy variables for each year, is statistically superior to regression 4, confirming the hypothesis that the missing components include time-shifts.

Evaluating the value of the coefficients themselves shows that the coefficient on fertility becomes more significant as we improve the control for the unobservables. On the other hand, the coefficients on physical capital and schooling are less significant in the RE and FE regressions (compared to OLS), and shift back toward the OLS level in column 6. The implication of this result is that when a researcher runs similar regressions, but does not include a rich set of covariates, or uses cross-section data, the significance level of the coefficient on LNFERT will typically decrease. This is the main reason why Barro and Lee (1993, Table 5, columns 9–11) find the coefficient on LNFERT to be insignificant. The second implication from the above results is that the unobserved factors are negatively correlated with fertility and positively correlated with physical capital levels. There are several variables that we can not observe, but we know from other studies that they are good candidates that exhibit these patterns, e.g., technological level, quality of school and quality of the health system. In theoretical models, these unobservable components are part of the human capital variable.

We also test the hypothesis that LNFERT is an exogenous variable in this set of GDP regressions, using the Wald criterion. The hypothesis is rejected with a p-value of 0.006, meaning that the *true* effect of fertility on GDP is even larger than the effect obtained here (because high income decreases fertility). The determination of fertility as an endogenous variable within the economic system is analyzed further in Sect. 4.

The regressions presented in columns 2 and 5 include a variable for popu-

Table 2. Regressions for GDP (controlling for unobserved effects)

Specification and Model Type	Pooled regression with Regional Effects OLS (1)	(1) *plus* GPOP5 OLS (2)	Control for regional and Random Effects GLS (3)	Control for country Fixed Effects (4)	(4) *plus* GPOP5 (5)	Control for time and country Fixed Effects (6)
# of Observations	675	675	675	675	675	675
LNFERT	−.2118***	−.2168***	−.2846***	−.3250***	−.2967***	−.3665***
	(.057)	(.070)	(.053)	(.054)	(.058)	(.053)
GPOP5		.2543			−1.8198	
		(2.053)			(1.343)	
LNCAP	.4374***	.4369***	.3721***	.3621***	.3650***	.4028***
	(.017)	(.017)	(.020)	(.022)	(.022)	(.024)
SECENRR	.3582***	.3594***	.2192**	.2405**	.2394**	.3566***
	(.109)	(.110)	(.093)	(.094)	(.094)	(.092)
GRADE	.0109	.0110	.0120	.0058	.0043	.0209
	(.009)	(.009)	(.011)	(.013)	(.013)	(.013)
M_GRADE	.1179***	.1183***	−.0062	−.0728	−.0835*	−.1249***
	(.040)	(.041)	(.043)	(.046)	(.047)	(.045)
LIFEX	.0009	.0008	−.0132***	−.0177***	−.0169***	−.0020
	(.002)	(.002)	(.003)	(.003)	(.003)	(.004)
AGRIL	.0010*	.0010*	−.0006	−.0078***	−.0081***	−.0069***
	(.001)	(.001)	(.001)	(.003)	(.003)	(.003)
CIVLIB	−.0506***	−.0506***	−.1162***			
	(.011)	(.011)	(.020)			
EUROPE	.0127	.0145	.1641*			
	(.045)	(.047)	(.089)			
AFRICA	−.1091***	−.1097***	−.2568***			
	(.039)	(.039)	(.076)			
LAAMER	.0197	.0204	.0344			
	(.035)	(.036)	(.074)			
OIL	.2316***	.2310***	.3260***			
	(.052)	(.052)	(.108)			
Constant	4.4355***	4.4456***	6.3023***	6.5324***	6.4809***	5.3834***
	(.215)	(.230)	(.231)	(.226)	(.229)	(.286)

Notes: a) Asymptotic standard errors are in parentheses. b) *, ** and *** denote significant at 10%, 5% and 1% levels, respectively. c) For definitions of variables, see Appendix 1.

Hypotheses Test for Table 2 (all hypotheses tested at 5% critical value): a) (3) vs. (1) – LM = 583 Favor (3); b) (4) vs. (1) – F = 18.4 Favor (4); c) (4) vs. (3) – H = 113 Favor (4); d) (6) vs. (4) – F = 10.1 Favor (6).

lation growth (GPOP5). The coefficient on this variable is not significant in both regressions. Thus, there is no indication that population growth reduces GDP once we control for fertility rates. In fact, the coefficient on GPOP5 is much smaller than the ones reported in the empirical neoclassical growth studies of Mankiw et al. (1992), Brander and Dowrick (1994) and Islam (1995). Our result suggests that the cost of raising children (children dependency) has a stronger effect on an economy's productivity than does capital dilution (the main channel through which population growth affects production in neoclassical models). A more refined analysis of this issue is presented in Table 3, which deals with a structural estimation of the growth equation.

The value of the coefficients on LNCAP range around 0.44 in regressions 1 and 2. When country-specific unobserved components are controlled for (columns 3–6), the values of physical capital share fall to 0.36–0.38. Note that this is in the opposite direction to the bias on LNFERT, suggesting that in the OLS regression α_2 captures some of the unobserved technological diversity across countries.

Despite the inherent difficulty involved in observing human capital, the present analysis includes several proxies for productivity level (A_{it}) and human capital (h_{it}). The two main proxies for human capital are SECENRR and GRADE. In theory, SECENRR represents flows and GRADE represents stocks. While both coefficients are positive, the former tends to be more significant than the latter. This is probably the result of a measurement error in the latter indicator, and has nothing to do with the variables' theoretical basis. The regressions employ AGRIL and OIL as observed proxies for productivity level, and three continent dummy variables as proxies for climate and resource endowment differences. Although the coefficient on AGRIL is positive in regressions 1 and 2, it becomes negative when FE estimation is employed (column 4), illustrating the power with which FE estimation eliminates bias. Note that a country with a larger agricultural sector is relatively more productive only when we do not control for the unobservables.

To conclude, our results support the hypothesis that off-steady-state levels of GDP are inversely correlated with fertility rates. The main objective of this analysis is to judge the robustness of the negative sign on the LNFERT coefficient in the LNGDP equation. In addition, special attention is devoted to the sign and magnitude of the coefficients of the parameters of the production function (for example, physical capital share). Building on these findings, the next section addresses the structural estimation of the effects of fertility on economic growth.

3.2. The structural econometric model

This section reviews the resource growth constraint utilized in the theoretical EFGM developed in Ahituv (1995). The present model is slightly modified for the purpose of this empirical work in order to focus on cross-country implications. Building on this model, I formulate and interpret an empirical model that allows me to estimate the direct and indirect effects of fertility rates on per capita income growth.

Consider a closed economy, in which output Y is produced by three inputs according to

$$Y(t) = A(t)K(t)^{\alpha}h(t)^{\beta}L(t)^{1-\alpha},$$

where A is a measure of productivity, K is physical capital, h is human capital, and L is efficiency units of labor. The number of efficiency units of labor per capita in the production sector is $L = Z - \pi Z_c$, where Z is the total population (including children), Z_c is the number of dependent children in the economy, and the parameter π represents the number of units of labor per child that are withheld from the production sector. The model predicts that $\pi > 1$ because children do not work, and each child needs extra time input from its parents. Accordingly, this dependency effect represents the mixture of resources allocated to child rearing and the accumulation of human capital by the younger generation. Hence, I anticipate larger π in countries with high levels of human capital. To investigate this hypothesis I consider two cases: one in which π is restricted to be constant across all countries, and another in which π varies by economic cluster.

The term $A(t)$ reflects technology level, resource endowment, climate and institutional characteristics in each country. Although $A(t)$ is presumed to vary across countries and over time, I begin by imposing the assumption that

$$A_{it} = A_0 e^{\varepsilon it},$$

where A_0 is a constant and ε_{it} is a random shock to the productivity of country i in period t. We will relax this constraint later, and estimate specific productivity factors by period or income group.

As in the neoclassical growth model, production of the one good is divided into consumption $c(t)$ and capital accumulation $K(t)$. Thus, the physical capital growth equation is

$$\dot{K}(t) = Y(t) - Z(t)c(t) - \delta K(t).$$

The rate of depreciation, δ, is taken to be 0.07, for all countries and all years. Various changes in this assumption (Mankiw et al. 1992, use 0.05) have little effect on the estimates.

In order to formulate the dynamic growth equation in per capita terms, we divide both sides by $Z(t)$ and then substitute for population growth. Thus, the evolution of the stock of physical capital per capita is given by

$$\dot{k} = A(1 - \pi G)^{1-\alpha}k^{\alpha}h^{\beta}e^{\varepsilon} - c - (g - d + \delta)k, \tag{2}$$

where $G = Z_c/Z$ is the share of dependent children in the economy, c is consumption per capita, g is the birth rate and d is the death rate. Note that G is positive function of g and negative function of d.

The major difference between equation (2) and the neoclassical framework is that, in the present case, fertility affects the per capita capital growth equation twice: in addition to the traditional capital dilution effect, a dependency effect is also included. Estimating the above equation requires two more steps: first, dividing both sides of equation (2) by k, yielding the physical capital per capita growth rate on the left-hand side; and second, shifting the two arguments on the right-hand side of the equation (because there are no parameters to be estimated in these terms) to the left. Doing so yields the following equation,

$$\phi_{it}^{k} \equiv \left(\frac{\dot{k}}{k} + \frac{c}{k} + g - d + \delta\right)_{it} = A_0(1 - \pi G_{it})^{1-\alpha} k_{it}^{\alpha-1} h_{it}^{\beta} e^{\varepsilon_{it}}. \tag{3}$$

By identity, the dependent variable in this regression, ϕ^k, can be computed in two ways: (1) output per capita *divided by* physical capital per capita; or (2) the sum of the following four variables: growth rate of physical capital per capita; the ratio of consumption per capita *divided by* physical capital per capita; the population growth rate; and the depreciation rate. Comparison of the results from the two computation methods shows no significant differences and thus most of the analysis in Table 3 uses the second definition. The mean of ϕ^k is 0.81. The average is higher in low-income countries (1.16) than in high-income countries (0.46), a result driven mainly by the higher population growth (GPOP5) and consumption to physical capital ratios (c/k) in low-income countries. Conversely, physical capital per capita growth rates are higher in high-income countries.

On the right-hand side of equation (3) we have a production function that includes the share of children in the population. This share is obviously a function of the fertility rate. The nonlinear specification of the production function allows us to estimate one additional parameter, π, which we cannot estimate using a linear equation. In addition, as in Benhabib and Spiegel (1994), A_0, α and β are also objects of estimation.

To conclude, the above formulation differs from the presentation in the existing literature in three ways: (a) it includes the direct effect of raising children on productivity; (b) it is obtained without relying on the assumption that the sampled countries are in steady state; and (c) it allows us to directly estimate the parameters of the growth resource constraint without relying on linear approximation around a steady state.

3.3. Nonlinear estimation of the growth equation

Equation (3) is estimated using a nonlinear least-squares procedure. Several specifications were tried for each of the variables. The point estimates and the significance levels of the parameters are stable across empirical specifications, leading to the conclusion that the results support the functional form of equation (3). Specifically, the results support the addition of dependency cost to the equation as an important factor that explains cross-country differences in economic growth.

Results of sensitivity analyses of the dependent variable are presented in columns 2 and 3 of Table 3. The model presented in column 2 uses ϕ^k as the dependent variable, while the model in column 3 uses GDP *divided by* CAP. These two have the same theoretical content only if the assumptions concerning the production function of the EFGM, described above, are valid. Hence, the similarity of the results in regressions 2 and 3 contributes to our confidence that the dependency effect is an integral part of the physical capital growth constraint (equation 2). In addition, by comparing the results of these two models, we can evaluate the sensitivity of the results to measurement errors in the calculation of the physical capital growth rate, and verify that imposing a constant depreciation rate has little effect on the model's estimates.

Table 3. Nonlinear estimation of the endogenous fertility growth model

Specification or sample	Neoclassical regression (1)	Baseline regression (2)	Dependent variable is y/k (3)	1970 only (4)	1985 only (5)	Low-income countries (6)	Middle and high-income countries (7)
A_0	11.6***	33.0***	49.5***	31.3***	18.7***	77.5***	42.9***
	(.81)	(3.67)	(5.69)	(7.22)	(4.69)	(15.4)	(6.97)
π		1.57***	1.56***	1.33***	1.56***	.79**	1.47***
		(.054)	(.053)	(.184)	(.119)	(.395)	(.077)
α	.596***	.529***	.492***	.522***	.535***	.342***	.514***
	(.014)	(.014)	(.015)	(.029)	(.029)	(.025)	(.019)
β	.109***	.094***	.106***	.137***	.192***	.069***	.066**
	(.020)	(.019)	(.019)	(.037)	(.044)	(.023)	(.027)
R^2	.74	.77	.79	.82	.79	.81	.77
N	675	675	675	113	114	209	466

Notes: a) Asymptotic standard errors are in parentheses. b) *, ** and *** denote significance at the 10%, 5% and 1% levels, respectively.

In the last four columns of Table 3 (4–7), I relax the assumption that the coefficients are uniform across countries and over time. This is accomplished by running separate regressions for each year and for each group of countries (poor versus rich).

The coefficients on π are significant and have the expected sign, and thus dependency cost explains an important portion of the growth differences between rich and poor countries. It is important to note that according to the SGM approach π has to be zero, because population growth has already been entered into the left hand-side of the equation. In contrast to the SGM approach, the magnitude of π is significantly greater than one (p-value smaller than 5%) in five of the regressions presented in Table 3; it is less than one only in the regression for the group of low-income countries. These findings support the hypothesis the cost imposed by children on the economy stems from two factors: (a) children consume, but do not produce (the *wedge effect*); and (b) children need time-input from their parents (*parents' time-constraint*). We are unable to distinguish between these two factors, mainly because we do not have a reliable variable for labor-force participation. The two factors affect the value of π in the same direction: in low-income countries children enter the labor force at earlier ages, and the per capita investment in their education (both formal and within the family) is lower. As a result, the point estimate of π in regressions 5 and 7 is about twice of the value in regression 6.

To compare these results with those of other empirical studies (e.g., Mankiw et al. 1992; Islam, 1995), I run regression without CHILD (regression 1). In this model, α grows larger (0.60 compared to 0.53 in regression 2), and R^2 decreases by 3 percentage points. Thus, the omitting the dependency effect results in an upward bias in the capital share parameter, changing the speed of convergence. As noted above, education is only a proxy for human capital, and thus the value of β says nothing about whether the production function exhibits increasing or decreasing returns to scale. Nevertheless, this coefficient is positive and significant, supporting the prediction that level of schooling has a positive effect on production, contradicting the findings of Benhabib and Spiegel (1994) and Islam (1995), who report that the coefficient on education in a GDP regression is zero. It is important to note that, as opposed to π, the point estimate of β is statistically similar in regressions 6 and 7.

A comparison between the 1970 and the 1985 regression reveals that the child dependency cost (π) increases, as expected. In addition, β increases as well. These two results reflect the positive correlation between the value of time and the return to human capital. The only result that is somewhat difficult to interpret is that A_0 is higher in the regression that includes only low-income countries. This result is, however, offset by a higher value of α in the regression that includes only middle- and high-income countries.

To conclude this analysis, I run simulations to determine the direct effect (not including the indirect effect of changes in education and saving rates) of fertility on physical capital per capita growth. This simulation plugs the coefficient of column 2 into equation 2, keeping physical capital, school enrollment, and consumption rate constant. As the main purpose of the simulation is to obtain some measure of each of the three effects of fertility on growth, I conduct three exercises: (a) changing only the annual population growth to measure the dilution effect; (b) changing the dependency rate to measure the wedge effect; and (c) reducing the value of the child dependency cost (π) to estimate the importance of the baby-sitting effect.

Table 4. Effect of changes in fertility on physical capital growth

	Annual population growth (percent)	Dependency rate (percent of children under 15)	Annual physical capital growth
Means in full sample	2.11	38.1	5.25
Means in high-income countries	1.26	28.5	5.95
Means in 1989	2.02	35.8	0.74
Baseline simulation	2.00	38.0	5.23
Effects of decrease in	1.50	38.0	5.73
population growth	1.00	38.0	6.23
Effects of decrease in	2.00	36.0	7.27
dependency rate	2.00	34.0	9.42
Effects of increase in	2.00	40.0	3.11
dependency rate	2.00	42.0	0.88
Effect of reduced π per unit $\pi = 1$	2.00	38.0	18.05

Notes: The simulations are evaluated at the following levels: CAP $= 5,870$; SECENRR $= 49$; and $c/k = 0.43$.

The first effect is linear: a decrease in annual population growth from 2% to 1% increases annual per capita physical capital growth commensurately, from 5.2% to 6.2%. The data show that annual population growth of 2% is associated with a dependency rate of 0.38, a growth rate of 1.5% is associated with a dependency rate of 0.34, and a 1% growth rate – with 0.29. Accordingly, I evaluate changes of dependency rates within these boundaries. When the dependency rate is increased to 0.42, the annual per capita physical capital growth sinks to almost zero, and the dependency rate is reduced to 0.34, the annual per capita physical capital growth rate jumps to 9.2%.[9] Thus, at these values, the dependency effect is about eight times larger than the capital dilution effect.

The result in the last row of Table 4 shows that capital growth rates are very sensitive to changes in the values of π. As mentioned above, π is a function of several arguments (not just baby-sitting), but a change in the number of hours adults spend on raising children is a change in the dependency cost.

4. The effects of the economy on fertility

The endogenous fertility growth model (EFGM) deviates from the SGM approach in yet another way. While the SGMs ignore the effects of economic circumstances on population growth, the number of children per family becomes a choice variable in the EFGMs, and thus the set of equations that describes the solution in EFGMs treats fertility as an endogenous variable. In addition, the results of Sect. 3.1 support the hypothesis that fertility is not exogenous to GDP, meaning that the effects we observed earlier are the lower bound. In this section, we run regressions that employ LNFERT as a dependent variable, examining the effect of the economic situation on fertility.

In general, the fertility policy function in EFGMs can have a non-linear shape. However, if the preferences are of the Barro and Becker (1989) constant-elasticity type, and if the production function is Cobb-Douglas (as in equation 2 above), then the fertility policy function is approximately log-linear,[10]

$$\ln g_{it} = \beta_0 + \beta_1 \ln k_{it} + \beta_2 \ln h_{it} + \beta_x X_{it} + e_{it}^g, \tag{4}$$

where g_{it} denotes the fertility rate, k_{it} denotes the stock of physical capital per capita, h_{it} denotes the level of human capital, X_{it} is a vector of several control variables, and e_{it}^g is the residual term. The theory developed in Ahituv (1995) predicts that the coefficients β_1 and β_2 will be negative. Thus, as the economy becomes richer, parents have fewer children because of the trade-off between the quality and quantity of children described in Becker (1992). The signs and magnitudes of the coefficient in the vector β_x represent additional factors that affect fertility.

Table 5 presents estimates for six specifications of the fertility equation. The results are consistent with the main hypothesis suggested above. The coefficients on LNCAP and SECENRR are significantly negative across all six specifications. This partial correlation is robust[11] even when the set of behavioral and control variables on the right-hand side of the regression are shuffled, and even when we control for unobservable country differences (columns 4–6). Furthermore, the sign and significance levels of the coefficients remain stable for different sub-periods of the sample (for example, a cross-sectional regression with observations from 1965, 1970, or 1985), and even for different income sub-groups. The hypothesis of non-constant coefficients can be rejected at all reasonable levels of significance using the Swamy test.

The table starts with the basic regression (column 1) that includes only LNCAP and SECENRR as the independent variables. These two variables explain 77% of the variation in fertility rates across countries and over time. Column 2 includes additional factors of productivity levels (human capital, gender gaps and death rates). An interesting finding from this model is that the coefficients for both GRADE and SECENRR are negative, suggesting a nonlinear convex effect of schooling on fertility. Note again, that GRADE represents the stock of education in the total population, while SECENRR represents the flow rate of investment in education.

Recent analyses have used separate indicators for female and male education as independent variables in a single regression. For example, Barro and Lee (1993) found that the two coefficients have opposite signs, leading to misinterpretation of the partial effects of the indicators. My suspicion is that the estimates in such specifications suffer from the high degree of correlation between these two independent variables. To break this correlation, I calculate a new variable that represents the difference between male and female rates of secondary school enrollment (MFSEC). This variable is included in regression 2, and has a positive coefficient, indicating that the education effect for women is higher than for men. However, the effect for men is negative and not as reported by Barro and Lee. The stronger effect on women suggests that an efficient way to reduce fertility is to increase the investment in educating girls. A somewhat different interpretation of this positive effect is that a gender gap in education uncovers discrimination against women on the family level. This type of discrimination is not captured by CIVLIB, since the construction of CIVLIB is at the political-macro level.

The coefficient on life expectancy (LIFEX) is negative. The life expectancy variable has several interpretations: first, it is a good proxy variable for health;

secondly, high life expectancy means that fewer births are required for replacement, and thus the number of children desired by each family is reduced. Meltzer (1992) argues that the sign on this coefficient is altered by the value of the intertemporal elasticity. The results presented here show that the point estimate is reduced by half when we run the GLS model. Thus, calculating an intertemporal elasticity based on cross section regression is not robust.

Regression 3 adds three dummy variables for region (EUROPE, AFRICA and LAAMER), one indicator for political regime (CIVLIB), and two dummy variables for the religious affiliation of the majority of the population in the country (MUSLIM and ROMAN). These six variables are time-invariant. As expected, the coefficient on EUROPE is negative, while the other two dummy variables for region are positive. Surprisingly, the coefficient on AFRICA is insignificant. Hence, the high fertility rates in Africa are well explained by the regressors. The coefficient on MUSLIM is significantly positive, while the dummy variable for Catholic countries (ROMAN) does not differ from the reference category. This is regardless of similar attitudes to childbirth and abortion taking by the leaders of these two religions. An interesting observation is that the coefficients on these two dummy variables remain unchanged when we run separate regressions for 1965 and 1985 sub-samples.

The entire evaluation includes many other explanatory variables and experiments with some additional hypotheses. Due to lack of space, these are not reported in Table 5. The main results of these inquiries are as follows: weighted regressions by per capita GDP and population were run to control for heteroskedasticity across countries and to check the assumption that each family chooses its own rate of reproduction. By running a weighted regression by population, each individual is assigned the same value, while in the non-weighted OLS, individuals from small countries get higher values. A comparison to the unweighted regressions shows only minor differences.

Columns 4–6 report random effect (RE), fixed effect (FE) and time-effect (TE) results. This analysis has two objectives: to evaluate the direction of the bias in the estimators, and to try to identify and interpret the underlying components of the unobservable country effects. In order to achieve the first objective, the estimates are evaluated relative to the coefficients in columns 1–3. To empirically assess the second objective, the present results are compared with the results of Table 2. Based on the OLS estimates (column 3) and the RE estimates (column 4), we obtain a Lagrangian Multiplier (LM) test statistic of 699. This supports the random component model. Based on the FE estimates (columns 5) and the RE estimates, we obtain a Housman's test statistic of 15.57. This finding again favors the random component model. Based on regression 6, we reject the null hypothesis that the unobservable effects are time-variant. Therefore, RE (column 4) is the appropriate model with which to estimate the fertility policy function. This result differs from the finding in Sect. 3.1, where LNGDP was the independent variable. Hence, this last comparison reveals that the unobservable effects in equations 3 and 4 have different characteristics.

The different nature of the unobservables in equations 3 and 4 makes sense when we recall the original factors included under this umbrella category. In the LNGDP equation, it is difficult to observe human capital and productivity factors, which are part of the production function, and hence should be correlated with physical capital levels and the indicators for educational status in

Table 5. Regressions for fertility (controlling for unobserved effects)

Specification and model type	Baseline pooled data OLS (1)	(1) *plus* X_{it} OLS (2)	(2) plus Regional Effects OLS (3)	Control for Regional and Random Effects GLS (4)	Control for Country Fixed-Effects (5)	Control for Time and Country Fixed-Effects (6)
# of Obs.	675	675	675	675	675	675
LNCAP	−.0717***	−.0322***	−.0212**	−.0488***	−.0636***	−.0528***
	(.012)	(.011)	(.010)	(.013)	(.016)	(.018)
SECENRR	−1.1499***	−.7171***	−.5441***	−.5370***	−.4965***	−.4452***
	(.060)	(.077)	(.070)	(.063)	(.068)	(.069)
GRADE		−.0277***	−.0202***	−.0352***	−.0508***	−.0433***
		(.006)	(.006)	(.007)	(.009)	(.010)
M_GRADE		−.1810***	−.1556***	−.1550***	−.1440***	−.1628***
		(.029)	(.026)	(.030)	(.034)	(.035)
LIFEX		−.0112***	−.0100***	−.0079***	−.0054**	.0016
		(.002)	(.002)	(.002)	(.002)	(.003)
MFSEC		.0045***	.0046***	.0051***	.0051***	.0050***
		(.001)	(.001)	(.001)	(.001)	(.001)
EUROPE			−.2339***	−.2220***		
			(.029)	(.060)		
AFRICA			.0161	−.0185		
			(.026)	(.050)		
LAAMER			.1025***	.0926		
			(.038)	(.080)		
CIVLIB			.0184***	.0014		
			(.007)	(.014)		
ROMAN			.0106	.0022		
			(.032)	(.069)		
MUSLIM			.1122***	.0912*		
			(.023)	(.047)		
Constant	2.4805***	2.7566***	2.4211***	2.6509***	2.6558***	2.1724***
	(.074)	(.086)	(.101)	(.121)	(.112)	(.190)

Notes: a) asymptotic standard errors are in parentheses; b) *, ** and *** denote significant at 10%, 5% and 1% levels, respectively; and c) for definitions of variables, see Appendix 1.

Hypothesis Test for Table 4 (all hypotheses tested at 5% critical value): a) (4) vs. (3) – LM = 699 Favor (4); b) (5) vs. (4) – H = 15.6 Favor (4); c) (6) vs. (5) – F = 2.72 Favor (5).

each country. Since these factors are time-variant, the time period coefficients should be significant. On the other hand, in the LNFERT equation we have limited information on preferences and cultural differences. Intuitively, this set of omitted variables is orthogonal to the regressors. Therefore, it is practical and consistent to estimate the fertility equation using the RE model, thereby avoiding the cost, in terms of degrees of freedom lost, of including dummy variables for each country and year. Indeed, the empirical evidence supports the hypothesis that the fertility policy function is stable over time, and that the log-linear function is a suitable approximation.

5. Concluding remarks

This paper investigates the empirical consistency of the endogenous fertility growth model (EFGM). Using three different approaches, I find strong evidence that the negative relations between fertility and GDP growth are a result of a bi-directional causality. Therefore, I argue that by ignoring fertility as a choice variable, the standard growth model (SGM) misses an important element. Hence, calibrating the estimates of the present study would be a useful input into theoretical growth models that aim to explain international differences in income per capita.

Methodologically, the empirical analysis contributes to the existing growth literature in the flowing directions. First, this study uses more countries and more data points per country than do previous studies. Secondly, the regression analysis employs robust estimation methods that control for unobserved country-specific components. Third, the structural model in Sect. 3 allows us to identify the magnitudes of the two effects (children dependency and capital dilution) through which fertility reduces productivity.

Due to the problem of finding good instrumental variables in cross-country data, I was unable to correct for simultaneous equation bias using a model of multiple regressions, so that the parameters in the present study (including fertility) are subject to endogeneity bias. Although it does not solve the above problem, I estimate a set of regressions with fertility as the dependent variable (Sect. 4), and find that the levels of physical capital, school attainment, and life expectancy account for most of the variations in fertility rates across countries and time. Hence, as suggested by modern theoretical EFGMs, this empirical analysis reveals a powerful simultaneous relationship between income and fertility: fertility reduction leads to an increase in national income, and income growth leads to decisive fertility decline.

Accepting the hypothesis that the predictions of EFGMs are consistent with international variations has several implications. First, the EFGM emphasizes that choices concerning saving and reproduction are made simultaneously. In other words, variations in investment and fertility rates are generated by human decisions, not by exogenous shocks, and therefore policies designed to push an economy out of underdeveloped equilibrium should not neglect family planning. Secondly, in many countries technological progress reduces death rates faster than birth rates, implying that action has to be taken in order to reduce population growth and environmental degradation. This empirical regularity also indicates that income inequality worldwide may continue to increase despite technology diffusion across countries. The results described above indicate that narrowing the gender gap in education and improving civil rights are crucial strategies to accomplishing the twin goals of fertility reduction and income growth.

Finally, for several reasons the results in favor of EFGMs complicate the recent debate on convergence in the economics growth literature. Several EFGMs studies (Becker et al. 1990; Galor and Weil, 1996; Ahituv, 1995) raised the possibility of multi-social-efficient stable equilibria. According to this type of solution, different countries may reach different steady states. Consequently, resolving the debate about the empirical consistency of conditional convergence is different from asking why cross-country variation in living standards continues to diverge.

Appendix 1: Definitions of variables

Variable	Definition and explanation
AFRICA	Dummy variable for Africa.
AGRIL	Agricultural land (% of land used for agriculture).
BIRTH	Crude birth rate per thousand.
CAP	Gross physical capital per capita.
CHILD	The share of children under the age of 15, in the total population.
CIVLIB	Index of civil liberties (1 = highest, 7 = lowest).
DEATH	Crude death rate per thousand.
EUROPE	Dummy variable for Europe.
FERT	Total fertility rate (average number of children per woman).
GDP	Gross Domestic Product per capita, in real terms.
GGDP5	Average annual growth rate of GDP in the past five years.
GPOP5	Average annual growth rate of population in the past five years.
GRADE	Average years of school attainment in the total population.
INVSH	Investment share in real GDP.
LAAMER	Dummy variable for Latin America.
LIFEX	Life expectancy at birth (years).
LNCAP	Log of physical capital.
LNFERT	Log of FERT.
LNGDP	Log of GDP.
M_GRADE	A dummy variable that flags missing observations.
MFSEC	Male *minus* Female SECENRR.
MUSLIM	Dummy for presence of Muslim majority.
OIL	Dummy for OPEC member.
POPDENS	Population density (thousands per square km).
ROMAN	Dummy for presence of Roman-Catholic majority.
SECENRR	Gross enrollment ratio, secondary education. Constructed as the ratio of total students enrolled in secondary education to the estimated number of individuals aged 12–17 years.

Endnotes

[1] Recent surveys by Becker (1992), Olsen (1994) and Ehrlich and Lui (1997) provide a comprehensive review of related empirical and theoretical work.
[2] Only the variables that appear in the paper are listed in Appendix 1.
[3] For a formal discussion, see Ahituv (1995), Appendix 5.
[4] The figures on death rates are from the World Bank (1992).
[5] For example, according to Barro and Sala-i-Martin (1994), steady state equilibrium is associated with constant levels of the control variables and constant growth rates of the state variables.
[6] Mundlak (1978), Ahituv (1995), and Hall and Jones (1999) give several reasons why it may be better to run regressions in levels rather than in growth rates.
[7] In Ahituv (1995), I formally discuss the anticipated direction of the bias for each coefficient. I consider three cases: A_{it} is unobserved; h_{it} is unobserved; and the observation of k_{it} includes country-specific measurement errors. This study is available upon request.
[8] See Hsiao (1986) for more details on these tests.
[9] Because the equation is not linear, I evaluate the dependency effect at several points. Surprisingly, the effect is almost symmetric.
[10] Simulations for such an off-steady-state fertility dynamic are presented in Ahituv (1995), Figure 3. In this empirical study, I explore additional functional forms (higher order terms, interaction variables, and other non-linear specifications) to improve the statistical fit. To save space, I present only the log-linear specification here.
[11] I use the Extreme Bound Analysis (EBA) test to evaluate the robustness of OLS results. This test was developed and used by Levine and Renelt (1992) for other policy indicators.

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