NON-MONOTONICITY OF FERTILITY IN HUMAN CAPITAL ACCUMULATION AND ECONOMIC GROWTH

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OUTLINE OF THE TALK

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- Motivation
- (Preview of the) Main Results
- The Benchmark Model: *Exogenous Fertility* and *Linear Dilution in per-capita HC Investment*
- The Model with *Endogenous Fertility* and *Nonlinear Dilution in per-capita HC Investment*
- From Theory to Evidence (Empirical Results)
- Conclusions and Future Research

POPULATION CHANGE AND ECONOMIC GROWTH: SOME BASIC FACTS

- Most of the world population is today concentrated in poorer countries (UN, 2001; Bloom *et al.*, 2003; Bloom and Canning, 2004).

- This trend is expected to persist in the future.

  In the whole period 1950 - 2050 the share of world population living:

  - In **more-developed countries** is expected to decrease dramatically (from 32% to 13%)
  - In the **less-developed countries** is expected to increase slightly (from 60% to 67%)
  - In the **least-developed countries** is expected to rise sharply (from 8% to 20%)

POPULATION CHANGE AND ECONOMIC GROWTH: SOME (SELECTED) LITERATURE

PESSIMISTIC VIEW: *POPULATION GROWTH UNAMBIGUOUSLY DETERS ECONOMIC GROWTH*

- When *resources are available in fixed supply* and *technological progress is slow or totally absent*, the food production activity is overwhelmed by the pressures of a rapidly growing population. The available diet would then fall below the *subsistence level* and the productivity growth rate would ultimately decline **(Malthus, 1798)**

- When population growth is rapid, a large part of investment (typically in physical/human capital) is used to satisfy the needs of the growing population, rather than to increase the endowment of existing per-capita capital (*“investment-diversion effect”*, **Kelley, 1988**)

OPTIMISTIC VIEW: *POPULATION GROWTH PROMOTES ECONOMIC GROWTH*

- Larger economies can more easily build on, exploit and disseminate the flow of knowledge they produce (**Kuznets, 1960 and 1967**; **Simon, 1981**; **Boserup, 1981**; **Kremer, 1993**; **Jones, 2001 and 2003**; **Tamura, 2002 and 2006**)

“…MORE PEOPLE MEANS MORE ISAAC NEWTONS AND THEREFORE MORE IDEAS” **(Jones, 2003, p. 505)**

POPULATION AND ECONOMIC GROWTH WITH ENDOGENOUS TECHNOLOGICAL CHANGE: EXISTING LITERATURE (NO INVESTMENT IN HUMAN CAPITAL)

1. Romer (1990); Grossman and Helpman (1991); Aghion and Howitt (1992):

$$\gamma_y = f\left(\underset{+}{N}\right).$$

Empirical evidence does not support this **STRONG SCALE EFFECT**

2. Jones (1995); Kortum (1997); Segerstrom (1998):

$$\gamma_y = f\left(\underset{+}{n}\right), \qquad \gamma_y = f\left(0\right) = 0$$

The evidence does not support the prediction that income growth is unambiguously and positively correlated with population growth (S*emi-Endogenous* growth models - **WEAK SCALE EFFECT**)

3. Young (1998); Peretto (1998); Dinopoulos and Thompson (1998); Howitt (1999):
Explain why we can observe positive growth in per-capita incomes even in the absence of any population change:

$$\gamma_y = a + b \cdot n, \qquad a, b > 0$$

POPULATION AND ECONOMIC GROWTH WITH ENDOGENOUS TECHNOLOGICAL CHANGE: EXISTING LITERATURE (INVESTMENT IN HUMAN CAPITAL)

DALGAARD AND KREINER (D-K, 2001)
STRULIK (2005)
BUCCI (2008)

- ✓ Population growth has a non – positive effect on economic growth; positive economic growth is compatible with a stable population;

- ✓ Economic growth is ambiguously correlated with population growth (through different theoretical mechanisms).

EMPIRICAL RESEARCH CONFIRMS THIS AMBIGUITY:

"…Though countries with rapidly growing populations tend to have more slowly growing economies…, this negative correlation typically disappears (or even reverses direction) once other factors …are taken into account. …In other words, when controlling for other factors, there is little cross-country evidence that population growth impedes or promotes economic growth. This result seems to justify a third view: population neutralism" **(Bloom *et al.*, 2003, p.17)**.

POPULATION NEUTRALISM VIEW: *POPULATION GROWTH NEITHER SLOWS DOWN NOR FUELS ECONOMIC GROWTH*

Once other factors, such as:

- ✓ Country size;
- ✓ Openness to trade;
- ✓ …
- ✓ The quality of existing institutions;
- ✓ …

are taken into account, there exists *little evidence that population growth might either slow down or encourage economic growth*.

"…IN SOME COUNTRIES POPULATION GROWTH MAY ON BALANCE CONTRIBUTE TO ECONOMIC DEVELOPMENT; IN MANY OTHERS, IT WILL DETER DEVELOPMENT; AND IN STILL OTHERS, THE NET IMPACT WILL BE NEGLIGIBLE" **(Kelley, 1988, p. 1686)**.

MOTIVATION

- The less (and especially the least) developed regions of the globe are rapidly and increasingly gaining shares of the world population;
- These regions are those that actually exhibit the highest fertility and the lowest literacy and economic growth rates.

In such a framework, the following question becomes of paramount importance:

WHAT IS THE EFFECT THAT A FURTHER INCREASE IN THE FERTILITY RATE (THUS, IN THE POPULATION GROWTH RATE) MAY HAVE ON PER-CAPITA HUMAN CAPITAL ACCUMULATION AND, HENCE, ON LONG-RUN ECONOMIC GROWTH?

The main objective of this paper is to answer this question both theoretically and empirically. In the theoretical model(s) human capital investment will be the sole source of economic growth (NO technical progress, either exogenous or endogenous!)

(PREVIEW OF THE) MAIN RESULTS

- ✓ We start with a simple/stylized model in which **the birth rate is exogenous and affects negatively and linearly per-capita human capital investment**. This will be our benchmark model since assuming a linear and negative *dilution – effect* of population growth on per-capita human capital investment is the standard assumption in the literature (D-K, 2001, p. 190, Eq. 5; Strulik, 2005, p. 135, Eq. 24; Bucci, 2008, p. 1134, Eq. 12'). In the benchmark model we find that population growth has a <u>non – positive effect</u> on real per-capita income growth (as in D-K, 2001).

- ✓ We extend the benchmark model both by allowing for an **endogenous birth rate** and for a **nonlinear effect of this rate on per-capita human capital accumulation**. We see that, through these changes, the impact of population growth on economic growth can also be <u>positive</u>.

- ✓ We then proceed to test which one of the theoretical models captures in a better way the distribution of the data. In particular, we test the hypotheses of :

  - ➢ Exogeneity of the birth rate
  - ➢ Linearity of the relationship between per-capita human capital investment and the birth rate

In order to do so we use semi-parametric and fully non-parametric methods. **Our empirical investigation finds strong evidence against the exogeneity of the birth rate, as well as against the linearity of the relationship between per-capita human capital investment and the birth rate** (the main two assumptions of our benchmark model)

THE BENCHMARK MODEL: MAIN ASSUMPTIONS

- Households consume (an homogeneous good) and choose how much to invest in human capital.

- Each individual in the population offers inelastically one unit of labor-services per unit of time (population size, N, coincides with the available number of workers).

- Population growth (γ) depends on three fundamental factors: fertility (the birth rate, n), mortality (the death rate, d), and migrations.

  - To start with, **we abstract from fertility decisions**, **we neglect migrations** (the economy is closed to international trade in goods and services and to international migrations of people) and take **the mortality rate as an exogenous variable**.

  - Therefore, we take the growth rate of population as given.

  - Moreover, since in this paper we focus on the birth rate as the fundamental variable affecting agents’ decision of how much to invest in education, we simplify further the analysis by setting the death rate equal to zero ($d = 0$).

HENCE, THE POPULATION GROWTH RATE EQUALS THE BIRTH RATE $\dot{N}_t / N_t \equiv \gamma = n$

THE BENCHMARK MODEL: MAIN ASSUMPTIONS

- Following Barro and Sala-i-Martin (2004, Chap. 5, p. 240) the total stock of human capital ($H_t \equiv N_t h_t$) changes not only because population size can change, but also because the average quality of each worker in the population (or per capita human capital, h_t) may increase over time.

- Consumption goods (or final output) are produced competitively by using solely human capital (H_Y) as an input. The aggregate technology for the production of these goods is:

$$Y_t = AH_{Yt}, \qquad A > 0 \qquad H_{Yt} = u_t H_t. \tag{1}$$

- Final output (the *numeraire* in this economy) can be only consumed.

THE AGGREGATE PRODUCTION FUNCTION (1) IS LINEAR IN THE AMOUNT OF HUMAN CAPITAL DEVOTED TO FINAL OUTPUT MANUFACTURING. HOWEVER, UNLIKE *"AK"-TYPE* GROWTH MODELS, INDIVIDUALS CHOOSE ENDOGENOUSLY HOW TO ALLOCATE THE EXISTING STOCK OF (HUMAN) CAPITAL BETWEEN PRODUCTION OF CONSUMPTION GOODS (u_t) AND PRODUCTION OF NEW HUMAN CAPITAL ($1 - u_t$)

THE BENCHMARK MODEL: MAIN ASSUMPTIONS

Under our assumptions, the economy-wide budget constraint is:

$$Y_t = AH_{Yt} = Au_t H_t = Au_t h_t N_t = C_t. \qquad (2)$$

Concerning human capital accumulation, we follow Uzawa (1965) and Lucas (1988) and assume that the law of motion of human capital at the economy-wide level is:

$$\dot{H}_t = \sigma(1-u_t)H_t, \qquad \sigma > 0. \qquad (3)$$

Given $\dot{H}_t$, the law of motion of per-capita human capital is (see, for example, Strulik, 2005, p. 135):

$$\dot{h}_t = \frac{\dot{H}_t}{N_t} - nh_t = \left[\sigma(1-u_t) - n\right]h_t.$$

In the last equation THE TERM $-nh_t$ REPRESENTS THE COST (IN TERMS OF PER-CAPITA HUMAN CAPITAL INVESTMENT) OF UPGRADING THE LEVEL OF EDUCATION OF THE NEWBORNS (WHO ARE UNEDUCATED) TO THE AVERAGE LEVEL OF EDUCATION OF THE EXISTING POPULATION (**linear, direct and negative *dilution* in human capital investment** at the individual level).

THE BENCHMARK MODEL: MAIN ASSUMPTIONS

With CIES instantaneous utility function, the objective of the family – head is to:

$$\underset{\{c_t, u_t, h_t\}_{t=0}^{+\infty}}{Max} U \equiv \int_0^{+\infty} \left(\frac{c_t^{1-\theta}}{1-\theta} \right) N_t^{\nu} e^{-\rho t} dt, \qquad \rho > 0; \qquad \nu \in [0;1]; \qquad \theta > 0 \qquad (4)$$

$$s.t.: \ \dot{h}_t = \left[\sigma (1-u_t) - n \right] h_t, \qquad \sigma > 0; \qquad n \geq 0; \qquad u_t \in [0;1], \quad \forall t \geq 0 \qquad (5)$$

along with the transversality condition: $\lim_{t \to \infty} \lambda_{ht} h_t = 0$ (6)

and the initial condition: $h(0) > 0$. (7)

- We make a formal distinction between two types of altruism: ***inter-temporal*** (the pure rate of time preference, ρ) and ***intra-temporal altruism***, ν (see Razin and Sadka, 1995, among others).

- With $\nu = 1$ we have *perfect altruism* (the family-head maximizes the discounted value of total utility, *i.e.* per-capita utility multiplied by the aggregate family size).

- With $\nu = 0$ we have the minimal degree of altruism (the family-head maximizes solely the discounted value of per capita utility).

- $\nu \in (0;1)$ describes intermediate degrees of intra-temporal altruism.

THE BENCHMARK MODEL: RESULTS

$$(1-u)=\frac{(\sigma-\rho)+(\theta+v-1)n}{\sigma\theta} \qquad g=\frac{(\sigma-\rho)-(1-v)n}{\theta}$$

Population growth, *n*, has a non – positive effect on real per-capita income growth, *g*.

Economic growth is driven by human capital accumulation: $\dot{h}_t / h_t \equiv g = \sigma(1-u)-n$

AN INCREASE IN n HAS TWO OPPOSING EFFECTS:

- It deters HC investment and economic growth through the direct, linear and negative *'dilution'* effect (the term $-n$ in the equation above).
- If $\theta+v>1$, it fosters HC investment and economic growth through the indirect and positive '*accumulation*' effect – the term $(1-u)$ in the equation above. If $\theta+v=1$, then there is no positive effect of population growth on human capital accumulation.

THE ABOVE ARGUMENT SUGGESTS THAT IN THE BENCHMARK MODEL THE DIRECT, LINEAR AND NEGATIVE DILUTION EFFECT ALWAYS PREVAILS OVER (OR, AT MOST, IS EQUAL TO) THE POSITIVE ACCUMULATION EFFECT

$(e.g.\ \partial g / \partial n \le 0,\ \forall n \ge 0)$

THE MODEL WITH ENDOGENOUS FERTILITY AND NONLINEAR DILUTION IN PER-CAPITA HUMAN CAPITAL INVESTMENT

We now postulate:

$$u(c_t;n_t) \equiv \frac{\left(c_t^{\beta} n_t^{1-\beta}\right)^{1-\theta}}{1-\theta}, \qquad \beta \in (0;1], \qquad \theta > 0 \qquad \text{and} \qquad \theta \neq 1 \qquad (9)$$

where $c_t \equiv C_t / N_t$ is per-capita consumption

- ✓ The hypothesis $\beta \in (0;1]$ suggests that per-capita consumption is a fundamental argument of individual instantaneous felicity
- ✓ As in Palivos and Yip (1993), θ must be different from one for an equilibrium (finite) value of n to exist (see next Eq. 14)
- ✓ For any positive value of c_t and n_t and $\beta \in (0,1)$, the assumption $0 < \theta < 1$ guarantees that $u(\cdot)$ remains always strictly positive

The inter-temporal problem faced by the representative family-head is:

ENDOGENOUS FERTILITY AND NONLINEAR DILUTION IN PER-CAPITA HC INVESTMENT

$$\underset{\{c_t, u_t, n_t, h_t, N_t\}_{t=0}^{+\infty}}{Max} U \equiv \int_0^{+\infty} \frac{\left(c_t^{\beta} n_t^{1-\beta}\right)^{1-\theta}}{1-\theta} e^{-\rho t} N_t^{\nu} dt, \qquad \rho > \nu n \geq 0; \qquad \nu \in [0;1]; \qquad \beta \in (0;1]; \qquad \theta \in (0;1) \qquad (11)$$

$$s.t.: \quad \dot{N}_t = n_t N_t, \qquad n_t \geq 0, \quad \forall t \geq 0 \qquad (10)$$

$$\dot{h}_t = \left[\sigma(1-u_t) + f(n_t)\right] h_t, \qquad \sigma > 0; \qquad u_t \in [0;1], \quad \forall t \geq 0 \qquad (8')$$

along with the two transversality conditions: $\lim_{t\to\infty} \lambda_{ht} h_t = 0$; $\lim_{t\to\infty} \lambda_{Nt} N_t = 0$

and the initial conditions: $h(0) > 0$, $N(0) > 0$

DEFINITION: BGP EQUILIBRIUM

A BGP equilibrium is an equilibrium path along which:

(i) All variables depending on time grow at constant (possibly positive) exponential rates

(ii) The allocation of human capital between production of consumption goods and production of new human capital is constant ($u_t = u$, $\forall t \geq 0$)

ENDOGENOUS FERTILITY AND NONLINEAR DILUTION IN PER-CAPITA HC INVESTMENT: RESULTS

PROPOSITION 1: Along the BGP equilibrium:

$$u = \frac{\beta(\theta-1)\left[\sigma + f(n)\right] + \rho - vn}{\sigma\left[\beta(\theta-1)+1\right]} \tag{12}$$

$$g_c = g_y = g_h \equiv g = \frac{(\sigma-\rho) + vn + f(n)}{\left[\beta(\theta-1)+1\right]} \tag{13}$$

$$f^{'}(n) = \frac{v}{\beta(\theta-1)} - \left(\frac{1-\beta}{\beta n}\right)\left[\frac{\sigma\beta(\theta-1) + \beta(\theta-1)\,f(n) + \rho - vn}{\beta(\theta-1)+1}\right] \tag{14}$$

- Economic growth is a nonlinear function of n (Eq. 13)
- Because $f^{'}(n)$ is a quadratic function of n in the data, in general Eq. (14) is satisfied (for given β, v, θ, σ and ρ) for three different values of n

IN TABLE A.1 WE PROVIDE THE **<u>REAL AND POSITIVE ROOTS</u>** OF EQ. 14
FOR SPECIFIC COMBINATIONS OF THE PARAMETER – VALUES

ENDOGENOUS FERTILITY AND NONLINEAR DILUTION IN PER-CAPITA HC INVESTMENT: RESULTS

PROPOSITION 2

Assume $\sigma > \rho - \nu n > 0$. *The following inequality:*

$$-(\sigma - \rho + \nu n) < f(n) < \frac{\rho - \nu n - \sigma\beta(1-\theta)}{\beta(1-\theta)} \tag{15}$$

ensures that along the BGP equilibrium $g > 0$ *and* $u \in (0;1)$ *hold simultaneously*

PROPOSITION 3: COMPARATIVE STATICS ON THE MODEL'S PARAMETERS

DIRECT EFFECT	INDIRECT EFFECT	TOTAL EFFECT
$\frac{\partial g}{\partial \sigma} > 0$	$\frac{\left[v+f'(n)\right]\frac{\partial n}{\partial \sigma}}{\left[\beta(\theta-1)+1\right]}>0;\ \frac{dn}{d\sigma}<0$	$\frac{dg}{d\sigma}>0$
$\frac{\partial g}{\partial v} > 0$	$\frac{\left[v+f'(n)\right]\frac{\partial n}{\partial v}}{\left[\beta(\theta-1)+1\right]}<0;\ \frac{dn}{dv}>0$	$\frac{dg}{dv}>0$
$\frac{\partial g}{\partial \rho} < 0$	$\frac{\left[v+f'(n)\right]\frac{\partial n}{\partial \rho}}{\left[\beta(\theta-1)+1\right]}<0;\ \frac{dn}{d\rho}>0$	$\frac{dg}{d\rho}<0$
$\frac{\partial g}{\partial \beta} > 0$	$\frac{\left[v+f'(n)\right]\frac{\partial n}{\partial \beta}}{\left[\beta(\theta-1)+1\right]}>0;\ \frac{dn}{d\beta}<0$	$\frac{dg}{d\beta}>0$
$\frac{\partial g}{\partial \theta} < 0$	$\frac{\left[v+f'(n)\right]\frac{dn}{d\theta}}{\left[\beta(\theta-1)+1\right]}>0;\ \frac{dn}{d\theta}<0$	$\frac{dg}{d\theta}<0$, for small altruism $\frac{dg}{d\theta}>0$, for high altruism

The motivation of having children goes beyond the depletion of available resources ($\partial n / \partial \rho > 0$)

FROM THEORY TO EVIDENCE: EMPIRICAL STRATEGY, VARIABLES AND DATA DESCRIPTION

Through equations (12) and (13) we observe that fertility plays a non-monotonic role in this economy, something that we have to check empirically.

Our main interest is to estimate Eq. (8’):

$$\frac{\dot{h}_t}{h_t} = \left[\sigma(1-u_t) + f(n_t)\right]$$

By replacing equation (12) into equation (8’) we end up with:

$$\frac{\dot{h}_t}{h_t} = \underbrace{\sigma(1-u_t)}_{\text{accumulation}} + \underbrace{f(n_t)}_{\text{dilution}} = \underbrace{\sigma - \frac{\beta(\theta-1)\left[\sigma + f(n)\right] + \rho - vn}{\left[\beta(\theta-1)+1\right]}}_{\text{accumulation}} + \underbrace{f(n_t)}_{\text{dilution}} \equiv \phi(n_t)$$

Hence, the equation we ultimately wish to estimate is of the form: $\frac{\dot{h}_t}{h_t} = \phi(n_t)$

FROM THEORY TO EVIDENCE:
EMPIRICAL STRATEGY, VARIABLES AND DATA DESCRIPTION

- We use non-parametric techniques because they provide more consistent results in case of mis-specified OLS models

- Furthermore, we can check the existence of non-monotonicity of the birth rate in per-capita human capital accumulation, which implies that fertility plays different roles in countries displaying different fertility rates.

SAMPLE: Consists of a panel of 99 countries (OECD and non-OECD) for the period 1960 – 2000. The observations are averages over a 5 years-interval

HUMAN CAPITAL ACCUMULATION (our dependent variable):

- We use enrollment rates for population aged between 15 and 65 years (Barro – Lee, 2000)

- We use total human capital, which is the sum of primary, secondary and higher education

FROM THEORY TO EVIDENCE: EMPIRICAL STRATEGY, VARIABLES AND DATA DESCRIPTION

- ✓ The data for the (crude) ***birth rate*** (*cbr*) come from the UN dataset (2008).
- ✓ We use **time – dummies** (d_t) in order to capture any time-specific effects and **group – dummies** ($dOECD_i$) in order to capture any potential difference (in schooling-quality) across OECD and non-OECD countries.
- ✓ Following Kalaitzidakis *et al*. (2001), we also employ **regional – dummies** ($d\mathrm{Re}gion_i$) such as dummies for Latin America (*la*) and Sub-Saharan Africa (*af*) countries to control for possible heterogeneity in our sample.
- ✓ We use a vector $X_{i,t}$ = (lifexp, hum60, infmort) of **control variables** that are used in order to check for the robustness of the results. These variables are life expectancy (*lifexp*), human capital at 1960 (*hum60*), and infant mortality (*infmort*).
- ✓ The data concerning the two demographic variables (life expectancy and infant mortality), like those on the birth rate, come from the UN (2008) dataset.
- ✓ Human capital accumulation for country *i* at time *t* is denoted by $HUM_{i,t}$.

FROM THEORY TO EVIDENCE: EMPIRICAL STRATEGY, VARIABLES AND DATA DESCRIPTION

BY PERFORMING THE DURBIN-WU-HAUSMAN TEST FOR ENDOGENEITY, WE OBSERVE THE EXISTENCE OF ENDOGENEITY AND THEREFORE WE USE LAGGED VALUES OF THE BIRTH RATE

The equation we estimate by OLS is the following:

$$HUM_{i,t} = b_0 + b_1\left(dOECD_i\right) + b_2\left(dRegion_i\right) + b_3 d_t + b_4 n_{i,t} + \varepsilon_{i,t},$$

where $\varepsilon_{i,t}$ is an *iid* error term.

The equation we estimate in the semi-parametric framework is:

$$HUM_{i,t} = b_0 + b_1\left(dOECD_i\right) + b_2\left(dRegion_i\right) + b_3 d_t + \phi\left(n_{i,t}\right) + \varepsilon_{i,t}.$$

$\phi(n_{i,t})$ is used to capture possible nonlinearities in the relationship between birth rate and human capital accumulation (all the other variables enter linearly in our specification).

- Having established the presence of a nonlinear relationship, we try to best-approximate this relation by different polynomials (both in the model with and without control variables), selecting in the end the one with the highest explanatory – power.

- Subsequently, we use the specification with the extra control variables for conducting sensitivity analysis.

FROM THEORY TO EVIDENCE: EMPIRICAL STRATEGY, VARIABLES AND DATA DESCRIPTION

In order to check for the **robustness of the linear specification estimates**, we use the following equation (a similar equation is used when we include the optimal polynomial of the birth rate):

$$HUM_{i,t} = b_0 + b_1\left(dOECD_i\right) + b_2\left(dRegion_i\right) + b_3 d_t + b_4 n_{i,t} + b_5 X_{i,t} + \varepsilon_{i,t}$$

where $X_{i,t}$ = (lifexp, hum60, infmort) is the vector of control variables.

Finally, the equation we estimate by considering all the variables **non-parametrically** is:

$$HUM_{i,t} = f\,(b_0,\ dOECD_i,\ dRegion_i,\ d_t,\ n_{i,t}) + \varepsilon_{i,t}.$$

- The fully non – parametric method that is used in this paper is the one proposed first by Racine and Li (2004), and in which a Gaussian kernel is used.

- We also use the Hsiao *et al.* (2007) test to check whether the linear model is well specified against the semi/non parametric alternatives. This test is Kernel-based and is appropriate both for discrete and continuous variables.

- We use a significance test for the nonparametric regression model in order to ensure that the birth rate is significant in the nonparametric framework.

EMPIRICAL RESULTS

- ✓ At first glance, **by using a linear specification**, there seems to be **a negative relationship between the birth rate and human capital investment** (which is a result covered by the benchmark model).

- ✓ **The** (linear) **benchmark specification suffers from an endogeneity bias, since the birth rate cannot be taken as an exogenous variable.**

- ✓ **Re-estimation of the human capital – birth rate nexus using semi-parametric and nonparametric methods reveals the presence of a strong nonlinear relationship**.

- ✓ **For small values of the birth rate, the accumulation effect dominates the dilution effect and for high values of the birth rate we have the opposite results**. This suggests that more developed countries should increase their birth rates, whereas less developed countries should reduce the birth rates substantially (FIG. 1 and FIG. 2).

- ✓ Adding extra control variables does not change the overall nonlinear pattern of the relationship.

GENERAL CONCLUSIONS

- We have re-assessed the long-run correlation between population growth (fertility) and economic growth (human capital investment) from an empirical, as well as a theoretical point of view.

- Empirically, our primary motivation was to search for possible nonlinearities in the correlation between the birth rate and human capital investment at the individual level.

- Theoretically, instead, our core objective was to compare the results of two different categories of models: (*i*) A (benchmark) model in which the birth rate is exogenous and affects linearly and negatively per – capita human capital accumulation, and (*ii*) A richer model in which the birth rate is endogenous and the *dilution – effect* is nonlinear.

- In the second, more realistic model the mutual presence of an endogenous birth rate and a nonlinear dilution of such rate in per-capita human capital investment represents another way (alternative to those already existing in the literature, mainly based upon the joint accumulation of human and technological capital) to restoring the result of an ambiguous correlation between population and economic growth rates (depending on a country’s fertility rate).

FUTURE RESEARCH

THIS PAPER CAN BE EXTENDED ALONG DIFFERENT PATHS:

- By employing a *'human capital production technology'* different from Lucas (1988), and more consistent with Mincer (1974) – and in the spirit of Bils and Klenow (2000), and Jones (2002).

- By building and testing a theory of endogenous fertility in which there is more than one reproducible factor-input (apart from human capital), and where there do exist nonlinear *dilution – effects* of the birth rate in the law of motion of one or all of these factor-inputs.

- By developing a micro-founded model in which nonlinearities are derived from an individual (rather than aggregate) behavior.

APPENDIX

Table A.1 provides the solutions (the real and positive roots) of Eq. (14), for specific combinations of the values of the parameters. We use:

- $\theta = 0.8$;

This value is used by Growiec (2006, p. 16, Table 1).

- $\rho = 0.08$;

This value comes also from the numerical example discussed in Growiec (2006, p. 16, Table 1).

- $\sigma = 0.12$.

This parameter-value comes from Mulligan and Sala-i-Martin (1993, p. 761).

- $\nu \in [0;1]$

We use four different values of ν, namely: $\nu = 0$; $\nu = 0.13$; $\nu = 0.5$; $\nu = 1$.

- $\beta(0;1]$

Like ν, we use four different values for β, as well: $\beta = 0.25$; $\beta = 0.5$; $\beta = 0.75$; $\beta = 1$.

	$\theta = 0.8;\ \rho = 0.08;\ \sigma = 0.12$
$v = 0;\ \beta = 0.25$	$n_1 = 0.0214;\ n_2 = 0.0653$
$v = 0;\ \beta = 0.5$	$n_1 = 0.0163;\ n_2 = 0.0673$
$v = 0;\ \beta = 0.75$	$n_1 = 0.0145;\ n_2 = 0.0682$
$v = 0;\ \beta = 1$	$n_1 = 0.0138;\ n_2 = 0.0688$
$v = 0.13;\ \beta = 0.25$	$n_1 = 0.0230;\ n_2 = 0.0634$
$v = 0.13;\ \beta = 0.5$	$n_1 = 0.0170;\ n_2 = 0.0665$
$v = 0.13;\ \beta = 0.75$	$n_1 = 0.0150;\ n_2 = 0.0676$
$v = 0.13;\ \beta = 1$	$n_1 = 0.0143;\ n_2 = 0.0683$
$v = 0.5;\ \beta = 0.25$	$n_1 = 0.0286;\ n_2 = 0.0572$
$v = 0.5;\ \beta = 0.5$	$n_1 = 0.0193;\ n_2 = 0.0640$
$v = 0.5;\ \beta = 0.75$	$n_1 = 0.0166;\ n_2 = 0.0660$
$v = 0.5;\ \beta = 1$	$n_1 = 0.0155;\ n_2 = 0.0671$
$v = 1;\ \beta = 0.25$	$n_1 = 0.0408;\ n_2 = 0.0439$
$v = 1;\ \beta = 0.5$	$n_1 = 0.0230;\ n_2 = 0.0600$
$v = 1;\ \beta = 0.75$	$n_1 = 0.0190;\ n_2 = 0.0635$
$v = 1;\ \beta = 1$	$n_1 = 0.0174;\ n_2 = 0.0652$

Table A1: *The roots of the equation* $f'(n) = \frac{v}{\beta(\theta-1)} - \left(\frac{1-\beta}{\beta n}\right)\left[\frac{\sigma\beta(\theta-1) + \beta(\theta-1)f(n) + \rho - vn}{\beta(\theta-1)+1}\right]$ *for possible combinations of* v *and* β *and for given:* $\theta = 0.8,\ \rho = 0.08,\ \sigma = 0.12$; $f(n) = 26.35n - 1143n^2 + 9224n^3$

For each single combination of the parameters, restrictions $\rho - vn > 0$ and $\sigma > \rho - vn$ (Proposition 2) hold

LIST OF COUNTRIES USED IN THE EMPIRICAL ANALYSIS

OECD COUNTRIES: Australia, Austria, Belgium, Canada, Chile, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Republic of Korea, Spain, Sweden, Switzerland, Turkey, U.K., U.S.

NON-OECD COUNTRIES: Afghanistan, Algeria, Argentina, Bahrain, Bangladesh, Barbados, Bolivia, Botswana, Brazil, Bulgaria, Cameroon, Central African Republic, Colombia, Costa Rica, Cuba, Cyprus, Dominican Republic, Ecuador, El Salvador, Fiji, Ghana, Guatemala, Guyana, Haiti, Honduras, Hong Kong, India, Indonesia, Iran (Islamic Republic of), Iraq, Israel, Jamaica, Jordan, Kenya, Kuwait, Lesotho, Liberia, Malawi, Malaysia, Mali, Mauritius, Mozambique, Myanmar, Nepal, Nicaragua, Niger, Pakistan, Panama, Papua New Guinea, Paraguay, Peru, Philippines, Romania, Senegal, Sierra Leone, Singapore, South Africa, Sri Lanka, Sudan, Swaziland, Syrian Arab Republic, Thailand, Togo, Trinidad and Tobago, Tunisia, Uganda, Uruguay, Venezuela, Zambia, Zimbabwe.

OPEC COUNTRIES: Algeria, Ecuador, Indonesia, Iran (Islamic Republic of), Iraq, Kuwait, Venezuela

EASTERN EUROPEAN/EX-SOCIALIST COUNTRIES: Bulgaria, Czech Republic, Cuba, Hungary, Poland, Romania

LATIN AMERICA COUNTRIES: Argentina, Barbados, Bolivia, Brazil, Central African Republic, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, Guatemala, Guyana, Haiti, Honduras, Jamaica, Mexico, Nicaragua, Panama, Paraguay, Peru, Trinidad and Tobago, Uruguay, Venezuela

SUB-SAHARAN AFRICA COUNTRIES: Botswana, Cameroon, Ghana, Kenya, Lesotho, Liberia, Malawi, Mali, Mauritius, Mozambique, Niger, Senegal, Sierra Leone, South Africa, Sudan, Swaziland, Togo, Uganda, Zambia, Zimbabwe

TABLE B.1: *SEMI /NON – PARAMETRIC REGRESSION RESULTS*

	OLS	SP	NP
Variables	(A)	(B)	(C)
constant	1.1521*** (0.0176)	0.6132*** (0.0164)	-
doecd	0.0528*** (0.0115)	0.0883*** (0.0168)	-
la	0.1709*** (0.0136)	0.1547*** (0.0135)	-
af	0.0153 (0.0197)	0.0355*** (0.0162)	-
d1965	0.0044 (0.0221)	0.0078 (0.0216)	-
d1970	0.0250 (0.0211)	0.0281 (0.0214)	-
d1975	0.0226 (0.0194)	0.0219 (0.0209)	-
d1980	0.0280 (0.0185)	0.0252 (0.0204)	-
d1985	0.0274 (0.0176)	0.0268 (0.0268)	-
d1990	0.0317 (0.0175)	0.0318 (0.0318)	-
d1995	0.0181 (0.0172)	0.0168 (0.0168)	-
cbr	-16.3436*** (0.5328)	-	-
N	792	792	792
R2/R2adj.	72.37/71.98	74.2/73.7	77.66/-
F-test	185.8***		
Heterosked.$^{(1)}$	158.96***		
$\mathrm{P}(\mathrm{Specific.})^{(2)}$	2.22e-16***	2.22e-16***	
$\mathrm{NP}(Test)^{(3)}$	0.012531*		

Notes: ***, **, and * denote the 1%, 5% and 10% significance levels. (1): Heterosked. is the heteroskedasticity LM-test by Breusch and Pagan (1979). Robust standard errors are in parentheses. (2): The P(specific.) shows the p-values if the null of the parametric linear (linear-OLS) is correctly specified in comparison to a fully *non-parametric* (NP) model, using the Hsiao *et al.* (2007) test for continuous and discrete data models after 399 Bootstrap replications. The P(specific.) at column B, checks if the parametric model (linear-OLS) is well specified when compared to the *semi-parametric* (SP) model. (3): The NP(Test) is a significance test for the explanatory variable (*cbr*) in the locally linear nonparametric specification. It is based on Racine (1997). We drop the time dummy for 2000.

TABLE B.2: *REGRESSION RESULTS BY USING POLYNOMIAL TERMS FOR THE BIRTH RATE (cbr)*

	OLS	OLS	OLS	OLS
Variables	(A)	(B)	(C)	(D)
constant	1.1521*** (0.0176)	0.6958*** (0.0699)	1.1926*** (0.0205)	0.6108*** (0.1305)
doecd	0.0528*** (0.0115)	0.0883*** (0.0115)	-0.0630 (0.02428)	0.1007 (0.1563)
la	0.1709*** (0.0136)	0.1551*** (0.0140)	0.1626*** (0.0140)	0.1546*** (0.0143)
af	0.0153 (0.0197)	0.0301 (0.0195)	0.0227*** (0.0198)	0.0312 (0.0195)
d1965	0.0044 (0.0221)	-0.0023 (0.0219)	0.0022 (0.0219)	-0.0018 (0.0222)
d1970	0.0250 (0.0211)	0.0180 (0.0209)	0.0236 (0.0210)	0.0194 (0.0211)
d1975	0.0226 (0.0194)	0.0139 (0.0193)	0.0222 (0.0193)	0.0147 (0.0195)
d1980	0.0280 (0.0185)	0.0199 (0.0182)	0.0280 (0.1844)	0.0237 (0.0172)
d1985	0.0274 (0.0176)	0.0234 (0.0171)	0.0290 (0.0175)	0.0237 (0.0172)
d1990	0.0317 (0.0175)	0.0300 (0.0170)	0.0335 (0.0173)	0.0307 (0.0171)
d1995	0.0181 (0.0172)	0.0165 (0.0166)	0.0195 (0.0169)	0.0163 (0.0166)
cbr	- 16.3436*** (0.5328)	26.35** (7.670)	-17.4017*** (0.6085)	34.04* (13.3694)
$(cbr)^2$		-1143*** (265.99)		-1355** (419.65)
$(cbr)^3$		9224** (2868.025)		11050** (4147.205)
$oecd(cbr)$			5.1988*** (1.040)	4.665 (18.14)
$oecd(cbr)^2$				-403.77 (674.02)
$oecd(cbr)^3$				-6856 (7950)
N	792	792	792	792
R2/R2adj.	72.37/71.98	73.87/73.43	72.84/72.42	73.91/73.37
F-test	185.8***	169.2***	174.1***	137.2***
F-Joint	158.96***	22.269***	13.371***	0.4312
Heterosked.(1)	133.24***	183.37***	167.11***	185.55***

Notes: ***, **, and * denote the 1%, 5% and 10% significance levels. (1): Heterosked. is the heteroskedasticity LM-test by Breusch and Pagan (1979). Robust standard errors are in parentheses. We drop the time dummy for 2000.

TABLE B.3: *REGRESSION RESULTS USING POLYNOMIAL TERMS FOR THE BIRTH RATE (cbr) AND CONTROL VARIABLES*

	OLS	OLS	OLS	OLS
Variables	(A)	(B)	(C)	(D)
constant	0.33319** (0.1454)	0.0449 (0.1504)	0.3824*** (0.1413)	0.0161 (0.1754)
doecd	0.0038 (0.0097)	0.0205 (0.0094)	-0.0816*** (0.0205)	0.1449 (0.1339)
la	0.1260*** (0.0093)	0.1158*** (0.0094)	0.1204*** (0.0094)	0.0113*** (0.1138)
af	0.0610*** (0.0119)	0.0704*** (0.0114)	0.0643*** (0.0118)	0.0709*** (0.0115)
d1965	-0.0180 (0.0164)	-0.0298* (0.0165)	-0.0233 (0.0163)	-0.0274 (0.0162)
d1970	-0.0132 (0.0162)	-0.0231* (0.0161)	-0.0172 (0.0160)	-0.0204 (0.0162)
d1975	-0.0154 (0.0155)	-0.0246 (0.0154)	-0.0179 (0.0153)	-0.0218 (0.0155)
d1980	-0.0098 (0.0146)	-0.0170 (0.0141)	-0.0113 (0.0144)	-0.0149 (0.0144)
d1985	-0.0110 (0.0139)	-0.0147 (0.0136)	-0.0108 (0.0137)	-0.0131 (0.0136)
d1990	-0.0029 (0.0133)	-0.0048 (0.0132)	-0.0020 (0.0131)	-0.0035 (0.0131)
d1995	-0.0021 (0.0135)	-0.0492*** (0.0133)	-0.0012 (0.0133)	-0.0030 (0.0132)
hum60	0.0466*** (0.0030)	19.17*** (0.0033)	0.0478*** (0.0030)	0.0496*** (0.0032)
infmort	-0.002*** (0.003)	-0.0016*** (0.003)	-0.002*** (0.0003)	-0.0017*** (0.0003)
lifexp	0.0048*** (0.0018)	0.0054** (0.0017)	0.0045*** (0.0017)	0.0051*** (0.0017)
cbr	-0.5468 (0.6897)	19.17*** (5.2137)	-1.4363*** (0.7230)	24.78* (9.9806)
$(cbr)^2$		-487.7*** (189.44)		-665* (306.6897)
$(cbr)^3$		3384 (1895)		5067 (2985.376)
$oecd(cbr)$			3.7724*** (0.8013)	-14.82 (15.7202)
$oecd(cbr)^2$				488.5 (585.4747)
$oecd(cbr)^3$				-4455 (6899.486)
N	792	792	792	792
R2/R2adj.	88.34/88.13	88.8/88.57	88.58/88.36	88.84/88.57
F-test	420.5***	384.2***	401.2***	322.6***
F-Joint			16.153***	0.9286
F-Joint 3rd Polyn.	-	16.049***	-	7.8147***
Heterosked.(1)	33.30***	27.01***	29.20***	22.99***

Notes: ***, **, and * denote the 1%, 5% and 10% significance levels. (1): Heterosked. is the heteroskedasticity LM-test by Breusch and Pagan (1979). The standard errors are in parentheses and t-statistics are available upon request. We drop the time dummy for 2000,. Instead of life expectancy we have used also crude death rate. This variable has negative sign contrast to the sign of life expectancy, is statistically significant and the results for the variable of birth rate (*cbr*) remain the same.

FIGURE 1: *SEMI – PARAMETRIC PLOT FOR THE CONTEMPORANEOUS BIRTH RATE IN THE WHOLE SAMPLE*

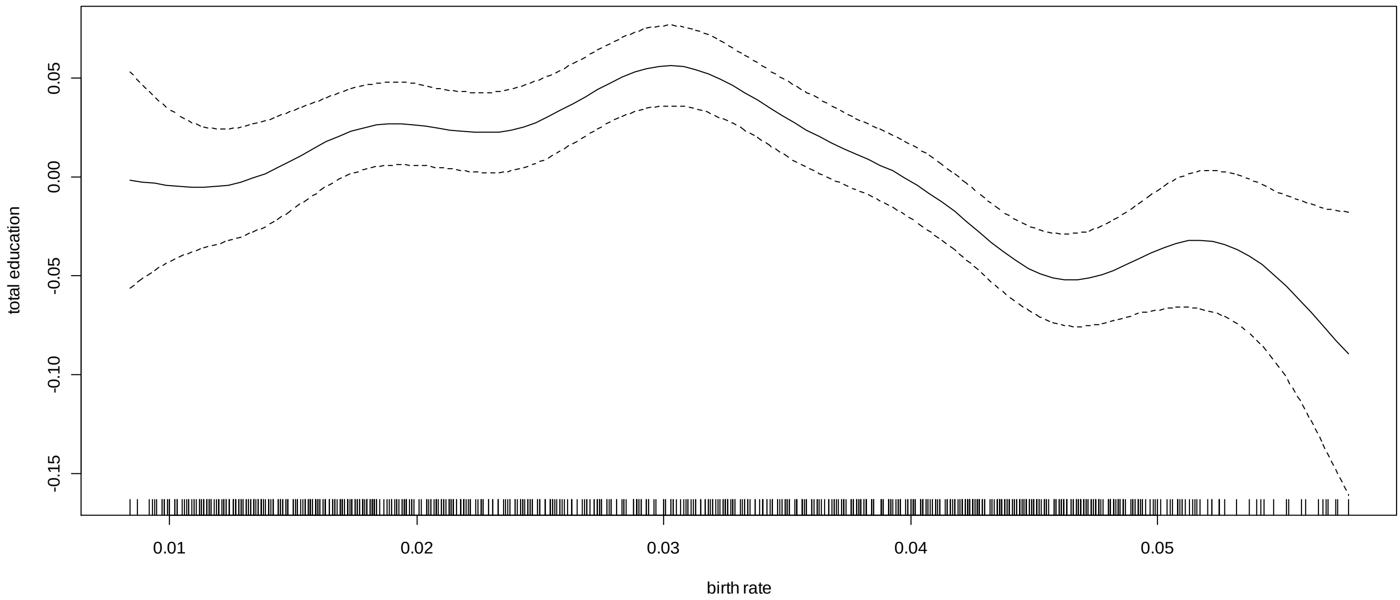

FIGURE 2: *SEMI – PARAMETRIC PLOT FOR THE LAGGED BIRTH RATE IN THE WHOLE SAMPLE*