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NOTES

TECHNOLOGY, TRADE, AND GROWTH: THE ROLE OF EDUCATION

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We generalize a trade model with firm-specific heterogeneity and R&D-based growth to allow for endogenous education and fertility. The framework is able to explain cross-country differences in living standards and trade intensities by the differential pace of human capital accumulation among industrialized countries. Consistent with the empirical evidence, scale matters for relative economic prosperity as long as countries are closed, whereas scale does not matter in a fully globalized world. The average human capital of a country, by contrast, influences its relative economic prosperity irrespective of trade-openness.

Keywords: Technological Progress, Globalization, Demographic Change, Education

1. INTRODUCTION

Conventional R&D-based growth theory predicts a positive association between population growth and economic prosperity [cf. Jones (1995); Kortum (1997)]. Although there is ample evidence that human capital accumulation has indeed a positive impact on economic growth [cf. Cohen and Soto (2007); Hanushek and Woessmann (2012)], empirical analyses for the twentieth century contradict R&D-based growth models because they find a negative effect of fertility on economic growth [cf. Li and Zhang (2007); Herzer et al. (2012)]. However, there is some evidence that countries and regions that are rather closed to international trade and factor movements are able to benefit from scale to a certain extent: Kremer (1993) shows that in 1500 the five (until then almost entirely disconnected) regions "Old World,' "The Americas," "Australia," "Tasmania," and "Flinders Island" ranked in

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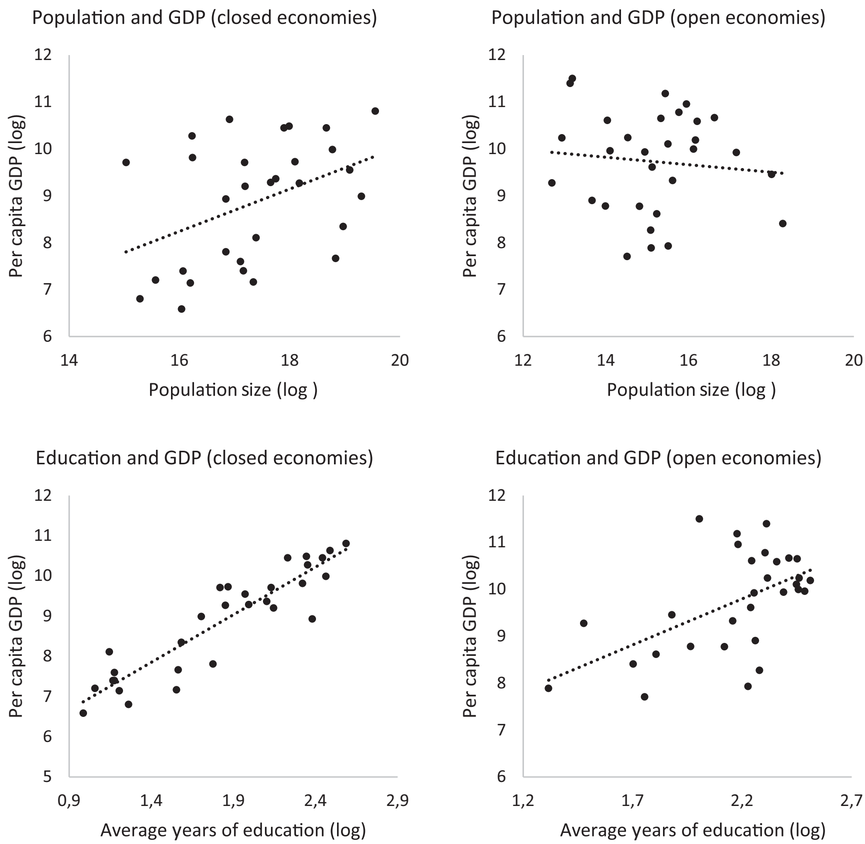

FIGURE 1. The relation between population size, education, and GDP in closed economies (left side) and open economies (right side).

the same order, irrespective of whether their level of technological sophistication or their population size was the variable of interest. He argues that there is only a 1 in 120 chance that these rankings would be the same if population size and technological sophistication were independent. In addition to this descriptive evidence, Alesina et al. (2005) show in panel data growth regressions that the interaction term between the population of a country and the country's openness has a statistically significant negative sign. This suggests that the importance of population size for economic growth declines with the openness of a country.

This general pattern is also visible in cross-country data for the year 2010. Figure 1 shows the relationship between per capita GDP and population size and between per capital GDP and average years of schooling for countries that we classify as either "closed" or "open" according to their trade shares. The data were obtained from Barro and Lee (2013) and the World Bank (2014), and they were available for 133 countries in 2010. We sorted the countries according to their trade shares and classified the thirty countries with the lowest trade shares as

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closed and the thirty countries with the highest trade shares as open (for a detailed list of the countries included in both classifications see Appendix A.1). The two diagrams on the left side show the relationships for the closed economies, whereas the two diagrams on the right side show the relationships for the open economies. The figure suggests that per capita GDP and education are positively correlated irrespective of the degree of trade openness (the slopes of both regression lines are significant at the 5% level), whereas population size is only positively correlated with per capita GDP in closed economies (the slope of the regression line is significant at the 5% level in closed economies and it is insignificant at every conventional significance level in open economies).[1]

To reconcile the theoretical predictions of the R&D-based growth literature with the observable patterns described in Figure 1 and with the empirical findings of Kremer (1993) and Alesina et al. (2005), we generalize the trade model of Eaton and Kortum (2001) with firm-specific heterogeneity and R&D-based growth to allow for endogenous human capital investments and endogenous population development. We show that the quality–quantity trade-off between the number of children and their education levels [cf. Becker and Lewis (1973)] represents a mechanism that could be responsible for the negative effect of population growth and the positive effect of education on technological progress and economic prosperity. The intuitive explanation is that lower fertility sets free parental resources that are invested instead in education of each child. As far as the evolution of the aggregate human capital stock is concerned, the positive effect of higher education overcompensates for the negative effect of lower fertility. Furthermore, we show that the scale of a country only has a positive impact on economic prosperity as long as the country in question is closed. The intuitive explanation for this finding is that citizens of open economies benefit from technological progress all over the world, because they are able to import goods from the cheapest source countries. This raises their purchasing power as compared to that of citizens in closed economies who are only able to purchase domestically produced goods. While consistent with the cited empirical evidence and with the data shown in Figure 1, our framework has the additional advantage that positive long-run growth at the steady state does not hinge on the unrealistic assumption of an ever-expanding population.

Some studies have investigated the relationship between education and trade. Yeaple (2005) proposes a model in which firms have access to two types of technologies: "high-tech" and "low-tech." The labor force is heterogeneous, with high-skilled workers having a comparative advantage in high-tech production. At equilibrium, exporting firms are shown to be larger, to employ more high-skilled workers, and to pay higher wages. A similar result has been derived by Manasse and Turrini (2001) for an economy in which firms are led by entrepreneurs of different ability. However, the roles of population size and its growth rate have not been investigated in either of these studies. In contrast, Galor and Mountford (2006, 2008) focus on the relations between trade, fertility, and education.[2] Based on a two-region Ricardian trade model in which the North specializes in skill-intensive industrial goods, whereas the South specializes in labor-intensive agriculture, they identify a theoretical channel by which one would expect a positive causal impact of trade on fertility in the South and a positive causal impact of trade on education in the North. The reason is that trade increases demand for industrial goods from the North and for agricultural goods from the South. Because this in turn raises the demand for the production factor that is used intensively, education increases in the North and fertility increases in the South. Galor and Mountford (2006, 2008) substantiate their claim empirically by showing that the volume of trade is associated positively with education and negatively with fertility in OECD countries, whereas the converse holds true in non-OECD countries. None of these studies, however, is concerned with the differential impact of population size on economic prosperity in closed and in open economies, which is the central focus of our study.

Our paper is structured as follows: Section 2 outlines the framework that we use for the analysis, Section 3 contains the central results, and Section 4 concludes.

2. THE MODEL

2.1. Basic Assumptions

Consider a discrete-time version of the multicountry trade model of Eaton and Kortum (2001) with firm-specific heterogeneity and endogenous technological progress. There is a continuum of consumption goods $j \in [0, 1]$, which are produced in the countries indexed by i and consumed in the countries indexed by n with $n, i = 1, \ldots, N$. Iceberg transport costs $d_{n,i} \geq 1$ prevail for shipping goods between the corresponding countries. Aggregate human capital $H_{i,t}$ is the only input in production and it is mobile within countries but immobile between them. The aggregate stock of human capital in a country is the compound of average human capital $h_{i,t}$ and population size $L_{i,t}$ such that $H_{i,t} = h_{i,t} L_{i,t}$. Average human capital is determined by the education investments of parents, whereas the aggregate stock of raw labor is determined by their fertility choices. Let the wage rate per unit of effective labor in country i at time t be denoted by $w_{i,t}$ and country i's technological frontier in producing good j be given by $z_i(j)$. These $z_i(j)$ are assumed to be realizations of random variables Z_i drawn from a Fréchet distribution $F_{i,t}(z) = \Pr[Z_i \leq z] = e^{-T_{i,t} \cdot z^{\theta}}$, in which $T_{i,t}$ is country i's accumulated technology up to time t, which determines the country's average productivity (that is, its absolute advantage), whereas the parameter θ governs the variation of productivity around the country's mean (that is, its comparative advantage). As a consequence of these assumptions, the costs for residents of country n to buy one good j produced in country i amount to the random variable $c_{n,i,t}(j) = w_{i,t} d_{n,i} / z_i(j)$, which is drawn from the distribution given by $G_{n,i,t}(c) = 1 - e^{-T_{i,t}(w_{i,t} d_{n,i})^{-\theta} c^{\theta}}$.

We assume that Bertrand competition prevails between firms, which implies that residents of country n only buy good j from the cheapest source country. Consequently, the costs of buying good j in country n amount to a realization of a random draw from $G_n(c) = 1 - \prod_{i=1}^{N} e^{-T_{i,t}(w_{i,t}d_{n,i})^{-\theta}c^{\theta}} = 1 - e^{-\Phi_{n,t}\cdot c^{\theta}}$, with $\Phi_{n,t} = \sum_{i=1}^{N} T_{i,t}(w_{i,t}d_{n,i})^{-\theta}$ being the ability of residents in country n to benefit from the productivity of other countries by having lower consumption costs due to trade. The probability $\pi_{n,i,t}$ that country i is the cheapest source country for good j is given by i's share of $\Phi_{n,t}$; that is, $\pi_{n,i,t} = T_{i,t}(w_{i,t}d_{n,i})^{-\theta}/\Phi_{n,t}$. Because there is a continuum of goods and by the law of large numbers, $\pi_{n,i,t}$ also represents the *share* of goods that country n buys from country i.

2.2. Households

Consider individuals who live for two time periods, childhood and adulthood. Children do not make economic decisions and are educated by a fraction of the adult labor force called teachers. For convenience we follow Galor (2011) and conceptualize the utility function of adults as

$$U(t) = \log(c_t) + \alpha \log(b_t) + \eta \log(e_t), \qquad \textbf{(1)}$$

where c_t denotes the consumption aggregate; b_t is the number of children, with α being the weight of the number of children in parents' utility; and e_t is educational investment in each child, with η being the weight of children's education in parents' utility. This short-cut formulation follows Andreoni (1989) by assuming that individuals experience a "warm glow" from providing their children with a certain level of education. The implication of this formulation is a quality–quantity trade-off that is similar in nature to the one implied by the formulation of Galor and Weil (2000), in which education indirectly enters the parental utility function via the income of their children.[3]

The budget constraint is given by $h_t w_t(1 - \psi b_t) = e_t b_t + P_t c_t$, where P_t refers to the price index of the consumption aggregate, w_t is the nominal wage rate of adults, h_t represents the human capital level of adults, and ψ is the rearing cost of each child, measured in time units. The left-hand side of the budget constraint represents disposable income, with $h_t w_t$ being potential income if parents were childless and supplied all their available time on the labor market, whereas the right-hand side represents the household's expenditures on consumption goods and education. Similarly to Moav (2005), the costs of child care increase with parental human capital, whereas the costs of education are independent of parental human capital. In our formulation this follows naturally because child-rearing requires parental time as input, whereas the costs of education are represented by the household's spending on the wages of teachers. The solution of the optimization problem is given by the following expressions for optimal consumption, fertility, and education investments:

$$c_t = \frac{h_t w_t}{(1+\alpha) P_t}, \quad b_t = \frac{\alpha - \eta}{\psi(1+\alpha)}, \quad e_t = \frac{\eta \psi h_t w_t}{\alpha - \eta}, \qquad \textbf{(2)}$$

where the quality–quantity trade-off can easily be established: if parents want to have more children, they increase fertility and reduce education investments and vice versa.[4]

2.3. Evolution of Human Capital

The adult population evolves according to $L_{t+1} = b_t L_t = (\alpha - \eta)L_t/[\psi(1+\alpha)]$. We assume that individual human capital of the next generation is produced by teachers $L_{t,\mathrm{E}}$ who also earn the wage rate w_t. Furthermore, human capital of children increases with education expenditure per child. According to the results of the household's optimization problem, economy-wide expenditures for teachers amount to $b_t e_t L_t = \eta h_t w_t L_t/(1+\alpha)$, whereas the wage bill of teachers is given by $w_t h_t L_{t,\mathrm{E}}$. Equating these expressions, we can calculate employment of teachers as $L_{t,\mathrm{E}} = \eta L_t/(1+\alpha)$. Assuming a unit labor input coefficient in schooling and recognizing that the productivity of teachers is given by their human capital h_t yields the following expressions for the evolution of average human capital and aggregate human capital:

$$h_{t+1} = \frac{h_t L_{t,\mathrm{E}}}{L_{t+1}} = \frac{\eta\psi}{\alpha-\eta} h_t, \quad H_{t+1} = b_t h_{t+1} L_t = \frac{\eta}{1+\alpha} h_t L_t. \tag{3}$$

The quality–quantity trade-off implies that aggregate human capital of the next generation grows faster if η is higher or if α is lower, that is,

$$\frac{\partial\left(g_{\mathrm{H}}+1\right)}{\partial\alpha} = -\frac{\eta}{(1+\alpha)^2} < 0, \quad \frac{\partial\left(g_{\mathrm{H}}+1\right)}{\partial\eta} = \frac{1}{1+\alpha} > 0,$$

with g_{H} denoting the growth rate of aggregate human capital.

2.4. Purchasing Power

Taking child-rearing and education expenditures into account, households spend a constant fraction $1/(1+\alpha)$ of potential income on consumption; that is, $w_t h_t(1-\psi b_t) - e_t b_t = w_t h_t/(1+\alpha) \equiv R_t/L_t$, where R_t represents aggregate expenditures that are tantamount to aggregate revenues of manufacturing firms, as given by $R_{\mathrm{T}} \equiv \int_0^1 p(j)x(j)dj$. From now on we refer to $\mathrm{RPP}_t = w_t h_t/[P_t(1+\alpha)]$ as the household's real purchasing power. Changes in the price index only affect this portion of household expenditures and do not impact on the resources diverted toward education or fertility. Consequently, the real income of households at time t is proportional to RPP_t. Let $x(j)$ be the quantity of good j consumed and the subutility function of the representative consumer be Cobb–Douglas, so that $c_t = \exp\int_0^1 \log[x(j)]dj$. The price index in country n is then given by

$$P_n = \exp\int_0^\infty \log(c)\, dG_n(c) = \gamma\Phi_{n,t}^{-1/\theta}, \tag{4}$$

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where γ is Euler's constant [see Eaton and Kortum (2001)]. Using this information, we calculate the real purchasing power in country n as $\text{RPP}_{n,t} = [\gamma(1+\alpha)]^{-1}[T_{n,t}/\pi_{n,n,t}]^{1/\theta}h_{n,t}$, which increases in the country's technological level ($T_{n,t}$), its openness as measured by the inverse of the fraction of goods that the country produces for the home market ($1/\pi_{n,n,t}$), and its average human capital stock ($h_{n,t}$).

2.5. Labor Market Equilibrium

Manufacturing labor income in country i is the sum of country i's manufacturing exports around the world plus sales at home, so that

$$w_{i,t}h_{i,t}\left(\frac{1}{1+\alpha}\right)L_{i,t} = \sum_{n=1}^{N}\pi_{n,i,t}w_{n,t}h_{n,t}\left(1-\frac{\alpha-\eta}{1+\alpha}\right)L_{n,t}$$

represents the labor market clearing condition. The left-hand side corrects for all workers who are not employed in manufacturing, whereas the right-hand side corrects only for the working hours missed because of child rearing (note that the child-rearing costs ψ enter b_t linearly in the denominator and hence they drop out after multiplication by $\psi \cdot b_t$).

2.6. Intermediate Results

Following Eaton and Kortum (2001), we assume that population growth rates are the same for all countries, implying that their inhabitants share the same preference parameters. In autarky, all the goods that a country produces are consumed at home; that is, $\pi_{n,n,t} = 1$. Consequently, the relative real purchasing power between country i and country N amounts to

$$\frac{\text{RPP}_{i,t}}{\text{RPP}_{N,t}} = \frac{\frac{w_{i,t}h_{i,t}}{P_{i,t}}}{\frac{w_{N,t}h_{N,t}}{P_{N,t}}} = \left(\frac{T_{i,t}}{T_{N,t}}\right)^{\frac{1}{\theta}}\frac{h_{i,t}}{h_{N,t}}, \tag{5}$$

implying that, ceteris paribus, the absolute levels of technology and human capital determine a country's relative well-being. By contrast, under free trade (zero gravity), we have $d_{n,i} = 1$ and prices are the same everywhere. The labor-market clearing condition implies that the relative real purchasing power under free trade is given by

$$\frac{\text{RPP}_{i,t}}{\text{RPP}_{N,t}} = \frac{w_{i,t}h_{i,t}}{w_{N,t}h_{N,t}} = \left(\frac{\frac{T_{i,t}}{h_{N,t}L_{i,t}}}{\frac{T_{N,t}}{h_{i,t}L_{N,t}}}\right)^{\frac{1}{1+\theta}}\frac{h_{i,t}}{h_{N,t}}, \tag{6}$$

such that, ceteris paribus, the relative economic well-being of a country is determined by its absolute level of human capital and its *relative* productivity *per unit*

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of effective labor. The productivity of a country is itself endogenously determined by its R&D intensity, an issue to which we turn next.

3. TRADE AND GROWTH

As described in the R&D-based growth literature [cf. Romer (1990), Jones (1995), Kortum (1997)], researchers are employed to develop new ideas. Their productivity is denoted by λ_i, which is the Poisson arrival rate of new ideas that varies between countries but stays constant over time. Human capital employed in research in country i at time s is given by $H_{\mathrm{R},i,s} = h_{i,s} L_{\mathrm{R},i,s}$, with $L_{\mathrm{R},i,s}$ being the size of the workforce of researchers. An idea is the realization of two random variables: the good j to which it applies as drawn from the uniform distribution [0, 1], and the efficiency $q(j)$ with which the good is produced as drawn from a Pareto distribution $Q(q) = 1 - q^{-\theta}$. Eaton and Kortum (2001) refer to $z_i(j)$ as the best practice for producing good j in country i. Consequently, a new idea is not adopted if $q(j) < z_i(j)$. Furthermore, even for $q(j) > z_i(j)$ an idea still has to survive competition from abroad.

Following Eaton and Kortum (2001), we assume that the number of ideas that a country has at its disposal depends on its research history. The stock of ideas in country i at time t is thus given by $T_{i,t} = \lambda_i \sum_{s=1}^{t-1} H_{R,i,s}$. This stock of ideas reflects the technological frontier and represents the absolute advantage of a country.

3.1. Innovation

The probability that an idea of quality q will be competitive in country n, that is, that $w_{i,t} d_{n,i}/q$ is the lowest cost of the corresponding good in country n, is given by $1 - G(w_{i,t} d_{n,i}/q)$. The probability that the idea will be associated with costs that undercut those of the incumbent by a factor of $m \geq 1$ is given by $1 - G_{n,t}(m w_{i,t} d_{n,i}/q)$. Integrating over the Pareto distribution of idea quality gives the probability that an idea will be competitive by a margin of at least m as $b_{n,i,t}(m) = [\Phi_{n,t} \left(m w_{i,t} d_{i,t}\right)^{\theta}]^{-1}$. Consequently, the probability of an idea from country i being sold in country n is given by

$$b_{n,i,t}(1) = \frac{1}{\Phi_{n,t} \left(w_{i,t} d_{i,t}\right)^{\theta}} = \frac{\pi_{n,i,t}}{T_{i,t}}. \quad \textbf{(7)}$$

The intuition is that the probability of surpassing the state-of-the-art technology in country i is given by $1/T_{i,t}$, whereas the probability of being competitive in country n is given by $\pi_{n,i,t}$, and therefore $b_{n,i,t}(1)$ is represented by the product of these two terms. The mark-up, conditional on selling the good, is found to be Pareto distributed and given by

$$\Pr[M \leq m | M \geq 1] = \frac{b_{n,i,t}(1) - b_{n,i,t}(m)}{b_{n,i,t}(1)} = 1 - m^{-\theta} = Q(m).$$

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3.2. Profits

Recall that aggregate expenditures are denoted by $R_{n,t}$. Firms selling in country n charge a mark-up drawn from $Q(m)$. Aggregate profits are therefore given by

$$\Pi_{n,t} = R_{n,t} \int_1^\infty \left[1 - m(j)^{-1}\right] dj = R_{n,t} \int_1^\infty \left[1 - m^{-\theta}\right] dQ\,(m) = \frac{R_{n,t}}{1+\theta},$$

where $1/(1+\theta)$ is the common profit share in the economy. Firms producing in country n have a market share of $\pi_{k,n,t}$ in country k. Consequently, their worldwide profits are given by the same expression,

$$\sum_{k=1}^{N} \pi_{k,i,t} \Pi_{k,t} = \sum_{k=1}^{N} \frac{\pi_{k,i,t} R_{k,t}}{1+\theta} = \frac{R_{n,t}}{1+\theta},$$

where $\sum_{k=1}^{N} \pi_{k,i,t} R_{k,t} = R_{n,t}$ follows from assuming balanced trade.

3.3. Research Incentives

The expected discounted value of an idea from country i that succeeds in country n at time t is

$$V_{n,i,t} = P_{i,t} \sum_{s=t}^{\infty} \left(\frac{1}{1+\rho}\right)^s \frac{\Pi_{n,s}}{P_{i,s}} \frac{b_{n,i,s}}{b_{n,i,t}}, \tag{8}$$

where ρ is the discount rate, $b_{n,i,s}/b_{n,i,t}$ is the probability of still being in the market at time $s > t$, and $\sum_{s=t}^{\infty}(\Pi_{n,s}/P_{i,s})$ is the real profit stream associated with that particular idea. The price index is normalized to 1 at time $s = t$, which is reflected by the presence of the term $P_{i,t}$ outside the sum. Summing across all markets and recalling that the probability of being successful in market n at time t is given by $b_{n,i,t}(1)$ yields

$$V_{i,t} = \sum_{n=1}^{N} b_{n,i,t}(1) V_{n,i,t} = \frac{P_{i,t}}{1+\theta} \sum_{s=t}^{\infty} \left(\frac{1}{1+\rho}\right)^s \frac{R_{i,t}}{P_{i,s}} \frac{1}{T_{i,s}}. \tag{9}$$

Wages of scientists are equal to the expected return on research; that is, $w_{i,t} = \lambda_i V_{i,t}$. Because of labor market clearing, the wages of workers in the manufacturing sector and the wages of teachers in the education sector must be equal to the wages of scientists.

3.4. Steady-State Growth

In the steady state of economy i, a constant share of human capital r_i is employed in the research sector, implying that $r_i = H_{\mathrm{R},i,t}/H_{i,t}$. In line with Eaton and Kortum (2001), population *levels* might differ between countries but preference parameters are such that the population grows at the same rate in all of them. In contrast to Eaton and Kortum (2001), however, the population growth rate is allowed to be zero, which is the most reasonable assumption for the very long run, in particular, in light of the fertility projections of the United Nations (2011). Additionally, we allow the levels of human capital to differ across countries. From $T_{i,t} = \lambda_i \sum_{s=1}^{t-1} H_{\mathrm{R},i,s}$, it follows that

$$T_{i,t+1} - T_{i,t} = \lambda_i r_i H_{i,t} \Rightarrow g_{\mathrm{T},i,t} = \frac{\lambda_i r_i H_{i,t}}{T_{i,t}}. \quad \textbf{(10)}$$

Along a balanced growth path it holds that $g_{g_{\mathrm{T},i,t}} = 0$, implying a steady-state growth rate of $g_{\mathrm{T},i} = g_{\mathrm{H}} = \eta/(\alpha - \eta) - 1$. At this stage we can formulate the following lemma, which establishes a negative relationship between population growth and technological progress and a positive relationship between human capital accumulation and technological progress.

LEMMA 1. *The steady-state growth rate of technology increases in the desire of parents for educating their children (η) and decreases in the desire of parents for the number of children (α).*

The proof follows immediately from the comparative statics of the growth factor of aggregate human capital.

Noticing that the real purchasing power in country n is given by $w_{n,t}h_{n,t}/[(1+\alpha)P_{n,t}]$, we find that all increases in real purchasing power stem from falling prices and rising average human capital levels. By plugging in the expression for the price level $P_{n,t}$ and substituting for $\Phi_{n,t}$, it is straightforward to derive the growth rate of real purchasing power as

$$\frac{\mathrm{RPP}_{n,t}}{\mathrm{RPP}_{n,t-1}} = \frac{1}{(g_T+1)^{1/\theta}(g_h+1)} \quad \Rightarrow g_P = \frac{1}{(g_H+1)^{1/\theta}(g_h+1)} - 1$$
$$= \frac{(\alpha-\eta)\left(\frac{\eta}{1+\alpha}\right)^{-1/\theta}}{\eta\psi} - 1.$$

At this stage we can formulate the following proposition, which establishes a negative relationship between population growth and real income growth and a positive relationship between human capital accumulation and real income growth.

PROPOSITION 1. *The steady-state growth rate of the household's purchasing power (and consequently, the growth rate of real income) increases in the desire of parents for educating their children (η) and decreases in the desire of parents for the number of children (α).*

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Proof. We take the derivatives of the growth rate of real purchasing power with respect to η and γ:

$$\frac{\partial g_{\mathrm{P}}}{\partial \eta} = \frac{[\eta - \alpha(1+\theta)]\left(\frac{\eta}{1+\alpha}\right)^{-1/\theta}}{\eta^2\theta\psi} < 0,$$

$$\frac{\partial g_{\mathrm{P}}}{\partial \alpha} = \frac{(\alpha\theta + \alpha - \eta + \theta)\left(\frac{\eta}{1+\alpha}\right)^{-1/\theta}}{(1+\alpha)^2\theta\psi} > 0.$$

■

Together with (2), the result implies that growth is positively associated with education and negatively associated with the level of fertility. This is consistent with the stylized facts on the relation between population growth and economic development on the one hand, and between education and economic development on the other [cf. Cohen and Soto (2007), Li and Zhang (2007), Herzer et al. (2012)]. In addition, Proposition 1 generalizes results from Strulik et al. (2013) for an open economy setup.

Finally, we can obtain the relative technological levels of two different countries i and N as

$$\frac{T_{i,t}}{T_{N,t}} = \frac{\frac{\lambda_i r_i}{g_{\mathrm{H}}} H_{i,t}}{\frac{\lambda_N r_N}{g_{\mathrm{H}}} H_{n,t}} = \frac{\lambda_i h_{i,t} L_{i,t}}{\lambda_N h_{N,t} L_{N,t}},$$

which shows that a country's accumulated technology depends not only on the size of its labor force but also on the human capital level of its workers. We can now establish the relative well-being of these two countries under autarky and under free trade. In the latter case, (6) implies that

$$\frac{w_{i,t}h_{i,t}}{w_{N,t}h_{N,t}} = \left(\frac{\lambda_i}{\lambda_N}\right)^{\frac{1}{1+\theta}} \frac{h_{i,t}}{h_{N,t}}, \qquad \textbf{(11)}$$

and, similarly to Eaton and Kortum (2001), scale—as measured by population size—does not matter. In contrast to Eaton and Kortum (2001), however, the relative average human capital levels of both countries influence their relative economic well-being.

Under autarky, (5) implies that

$$\frac{w_{i,t}h_{i,t}/P_{i,t}}{w_{N,t}h_{N,t}/P_{N,t}} = \left(\frac{\lambda_i L_{i,t}}{\lambda_N L_{N,t}}\right)^{\frac{1}{\theta}} \left(\frac{h_{i,t}}{h_{N,t}}\right)^{\frac{1+\theta}{\theta}}, \qquad \textbf{(12)}$$

and, again similarly to Eaton and Kortum (2001), scale matters. However, in our case, scale is augmented by average human capital. Altogether, we can summarize our results by means of the following proposition, which shows that human capital is important irrespective of a country's openness, whereas scale is important only for a closed economy.

PROPOSITION 2.

(i) In the case of free trade, the size of a country's labor force does not affect its relative real per capita income.

(ii) In the case of autarky, an increase in the size of a country's labor force raises its relative real per capita income.

(iii) In both cases (free trade and autarky), an increase in the average human capital level of a country's labor force raises its relative real per capita income.

Proof. Follows immediately from (11) and (12). ■

This result is consistent with the findings of Kremer (1993) and Alesina et al. (2005), as well as with the data presented in Figure 1 that population size matters as long as countries are relatively isolated, whereas it does not impact economic growth in countries that are highly internationally integrated. Furthermore, the result is also consistent with the finding of Glaeser et al. (2004), Cohen and Soto (2007), and Breton (2013) that education matters in general for the economic prosperity of countries.

Notice that our results are based on the assumption that preferences are the same in all countries. If preferences and thus population growth rates differed across countries, the model would predict diverging incomes, in line with standard models of endogenous and semi-endogenous growth. Here, however, divergence would be mitigated to a certain extent: in the case of open economies, a country that invests less in education can import goods from abroad and by doing so take advantage of the innovations that are developed in the rest of the world. This will reduce the price level of all goods consumed in this country and therefore ceteris paribus raise the purchasing power of its inhabitants. In the very long run, however, it seems unlikely that population growth rates differ across countries. For physical reasons, population growth cannot be positive as time goes to infinity, at least not as long as the earth is considered as a closed system, suggesting that fertility converges toward the replacement level everywhere eventually. Strulik and Weisdorf (2008) have shown in a two-sector unified growth model that fertility rates eventually converge to the replacement level, irrespective of the weight of fertility in utility, once child nutrition and food prices are explicitly taken into account. We leave it as a challenging task for future research to extend the model toward country-specific preferences and eventually converging behavior across countries.

4. CONCLUSION

We have proposed a trade model with firm-specific heterogeneity, endogenous technological progress, endogenous educational investments, and endogenous population growth. Our framework explains the stylized facts of the cross-country relationships between population growth and economic prosperity on one hand, and between human capital accumulation and economic prosperity on the other.

We showed that there is a positive effect of education on economic growth and a negative effect of population growth on economic growth. Moreover, consistent with the empirical evidence presented in Kremer (1993), in Alesina et al. (2005), and in Figure 1, scale (population size) matters for relative economic prosperity as long as countries are closed, whereas scale does not matter in a fully globalized world. However, irrespective of the openness of a country, its average human capital level positively affects its relative economic prosperity.

NOTES

1. This result is robust against the expansion of the sample to include more open and more closed economies. The results of this exercise are available from the authors upon request.
2. For Unified Growth Theory that analyzes the dynamics of fertility, education, and growth over the very long run in a closed economy setting see Galor (2005, 2011).
3. Note that we abstract from child mortality. For a framework that takes child mortality into account see Strulik and Weisdorf (2014).
4. For a similar quality–quantity trade-off effect that is induced by rising adult longevity see Yasui (in press).

REFERENCES

Alesina, Alberto, Enrico Spolaore, and Romain T. Wacziarg (2005) Trade, growth and the size of countries. In P. Aghion and S.N. Durlauf (eds.), *Handbook of Economic Growth*, Vol. 1B, pp. 1500–1542. Amsterdam: Elsevier, North-Holland.

Andreoni, James (1989) Giving with impure altruism: Applications to charity and Ricardian equivalence. *Journal of Political Economy* 97, 1447–1458.

Barro, Robert J. and Jong-Wha Lee (2013) A new data set of educational attainment in the world, 1950–2010. *Journal of Development Economics* 104, 184–198.

Becker, Gary S. and Gregg H. Lewis (1973) On the interaction between the quantity and quality of children. *Journal of Political Economy* 81, 279–288.

Breton, Theodore R. (2013) Were Mankiw, Romer, and Weil right? A reconciliation of the micro and macro effects of schooling on income. *Macroeconomic Dynamics* 17, 1023–1054.

Cohen, Daniel and Marcelo Soto (2007) Growth and human capital: Good data, good results. *Journal of Economic Growth* 12, 51–76.

Eaton, Jonathan and Samuel Kortum (2001) Technology, trade, and growth: A unified framework. *European Economic Review* 45, 742–755.

Galor, Oded (2005) From stagnation to growth: Unified growth theory. In P. Aghion and S. N. Durlauf (eds.), *Handbook of Economic Growth*, Vol. 1A, pp. 171–293. Amsterdam: Elsevier, North-Holland.

Galor, Oded (2011) *Unified Growth Theory*. Princeton, NJ: Princeton University Press.

Galor, Oded and Andrew Mountford (2006) Trade and the great divergence: The family connection. *American Economic Review* 96, 299–303.

Galor, Oded and Andrew Mountford (2008) Trading population for productivity: Theory and evidence. *Review of Economic Studies* 75, 1143–1179.

Galor, Oded and David Weil (2000) Population, technology, and growth: From Malthusian stagnation to the demographic transition and beyond. *American Economic Review* 90, 806–828.

Glaeser, Edward L., Rafael La Porta, Florencio Lopez-de-Silanes, and Andrei Shleifer (2004) Do institutions cause growth? *Journal of Economic Growth* 9, 271–303.

Hanushek, Eric A. and Ludger Woessmann (2012) Do better schools lead to more growth? Cognitive skills, economic outcomes, and causation. *Journal of Economic Growth* 17, 267–321.

Herzer, Dierk, Holger Strulik, and Sebastian Vollmer (2012) The long-run determinants of fertility: One century of demographic change 1900–1999. *Journal of Economic Growth* 17, 357–385.
Jones, Charles I. (1995) R&D-based models of economic growth. *Journal of Political Economy* 103, 759–783.
Kortum, Samuel (1997) Research, patenting and technological change. *Econometrica* 65, 1389–1419.
Kremer, Michael (1993) Population growth and technological change: One million B.C. to 1990. *Quarterly Journal of Economics* 108, 681–716.
Li, Hongbin and Junsen Zhang (2007) Do high birth rates hamper economic growth? *Review of Economics and Statistics* 89, 110–117.
Manasse, Paolo and Alessandro Turrini (2001) Trade, wages, and superstars. *Journal of International Economics* 54, 97–117.
Moav, Omer (2005) Cheap children and the persistence of poverty. *Economic Journal* 110, 88–110.
Romer, Paul (1990) Endogenous technological change. *Journal of Political Economy* 98, 71–102.
Strulik, Holger, Klaus Prettner, and Alexia Prskawetz (2013) The past and future of knowledge-based growth. *Journal of Economic Growth* 18, 411–437.
Strulik, Holger and Jacob L. Weisdorf (2008) Population, food, and knowledge: A simple unified growth theory. *Journal of Economic Growth* 13, 195–216.
Strulik, Holger and Jacob L. Weisdorf (2014) How child costs and survival shaped the Industrial Revolution and the demographic transition. *Macroeconomic Dynamics* 18, 114–144.
United Nations (2011) World Population Prospects: The 2010 Revision. United Nations, Department of Economic and Social Affairs. Population Division, Population Estimates Section.
World Bank (2014) World Development Indicators & Global Development Finance Database. Available at http://data.worldbank.org/data-catalog/world-development-indicators.
Yasui, Daishin (in press) Adult longevity and growth takeoff. *Macroeconomic Dynamics*.
Yeaple, Stephen R. (2005) A simple model of firm heterogeneity, international trade, and wages. *Journal of International Economics* 65, 1–20.

APPENDIX A

A.1. LIST OF COUNTRIES INCLUDED IN FIGURE 1.

The thirty countries with the lowest trade share in the sample are Afghanistan, Australia, Bangladesh, Benin, Brazil, Burundi, Cameroon, Central African Republic, Colombia, Cuba, Egypt, France, Greece, Indonesia, Italy, Japan, Nepal, Pakistan, Peru, the Russian Federation, Rwanda, Sierra Leone, South Africa, Sri Lanka, the Sudan, Turkey, Uganda, the United States, Uruguay, and Venezuela.

The thirty countries with the highest trade share in the sample are Bahrain, Belgium, the Republic of the Congo, the Czech Republic, Estonia, Fiji, Hong Kong, Hungary, Ireland, Jordan, the Kyrgyz Republic, Lesotho, Lithuania, Luxembourg, Macao, Malaysia, Maldives, Malta, Mauritania, Moldova, Mongolia, the Netherlands, Panama, Singapore, the Slovak Republic, Slovenia, Swaziland, Thailand, the United Arab Emirates, and Vietnam.