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Technology, Trade, and Growth: The Role of Education

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Abstract. We generalize a trade model with firm-specific heterogeneity and R&D-based growth to allow for an endogenous education decision of households and an endogenously evolving population. Our 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. Interestingly, however, the average human capital level of a country influences its relative economic prosperity irrespective of its trade-openness. While being consistent with the empirical evidence, our framework has the additional advantage that steady-state growth of income does not hinge on the unrealistic assumption of an ever expanding population.

JEL classification: F10, I25, O31, O41.

Keywords: technological progress, globalization, demographic change, education, human capital accumulation.

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1. Introduction

Conventional R&D-based growth theory and conventional trade theory with firm-specific heterogeneity predict a positive association between population growth on the one hand and economic prosperity and trade intensities on the other (cf. Romer, 1990; Jones, 1995; Kortum, 1997; Eaton and Kortum, 2001). This prediction has not been confirmed by empirical evidence for the twentieth century (cf. Li and Zhang, 2007; Herzer et al., 2012; Prettner and Strulik, 2013). However, some studies indicate that countries and regions that were closed to international trade and factor movements benefited from scale to a certain extent (Kremer, 1993; Alesina et al., 2005). Furthermore, there is evidence that human capital accumulation is positively affecting economic growth and trade intensities (cf. de la Fuente and Domenéch, 2006; Cohen and Soto, 2007; Gennaioli et al., 2013; Prettner and Strulik, 2013).

To reconcile the theoretical predictions with the empirical findings, we generalize the trade model of Eaton and Kortum (2001) with firm-specific heterogeneity and R&D-based technological progress to allow for endogenous human capital investments and endogenous population growth. We show that the quality-quantity trade-off with respect to 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 on technological progress, economic prosperity, and trade, as well as for the positive effect of education on these variables. While being consistent with the cited empirical findings, 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.

2. The model

2.1. **Basic assumptions.** Consider a discrete-time version of the multi-country 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 $n, i = 1, ..., N$. 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 the 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, while 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), while 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 between firms prevails, 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, $\pi_{n,i,t} = T_{i,t}(w_{i,t}d_{n,i})^{-\theta}/\Phi_{n,t}$. Since 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

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

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 are educational investments with η being the weight of children's education in parents' utility. 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 are the rearing costs 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 in case that parents were childless and would supply all their available time on the labor market, while the right hand side represents the household's expenditures on consumption goods and education. The solution of the optimization problem is given by the following expressions for optimal consumption, fertility, and education investments

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

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.

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 $L_{t,E}$ who also earn the wage rate w_t. Furthermore, human capital of children increases with education expenditures per child. According to the results of the household's optimization problem, economy-wide expenditures for teachers amount to $b_t e_t L_t = \eta h_t w_t L_t / (1+\alpha)$, while the wage bill of teachers is given by $w_t h_t L_{t,E}$. Equating these expressions, we can calculate employment of teachers as $L_{t,E} = \eta L_t / (1+\alpha)$. 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, respectively

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

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,

$$\frac{\partial \left(g_H+1\right)}{\partial \alpha} = -\frac{\eta}{(1+\alpha)^2} < 0, \qquad \frac{\partial \left(g_H+1\right)}{\partial \eta} = \frac{1}{1+\alpha} > 0$$

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, $w_t h_t \left(1-\psi b_t\right) - e_t b_t = w_t h_t/(1+\alpha) \equiv R_t/L_t$, where R_t represents aggregate expenditures being tantamount to aggregate revenues of manufacturing firms as given by $R_T \equiv \int_0^1 p(j)x(j)dj$. From now on we refer to $RPP_t = w_t h_t/[P_t(1+\alpha)]$ 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 and/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 sub-utility function of the representative consumer be Cobb-Douglas such that $c_t = \exp \int_0^1 \log\left[x(j)\right] dj$. The price index in country n is then given by

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

where γ is Euler's constant (see Eaton and Kortum, 2001). Using this information, we calculate the real purchasing power in country n as $RPP_{n,t} = \left[\gamma(1+\alpha)\right]^{-1} \left[T_{n,t}/\pi_{n,n,t}\right]^{\frac{1}{\theta}} h_{n,t}$, 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 such 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 that are not employed in manufacturing, while the right hand side corrects only for the working hours missed due to child rearing (note that the child rearing costs ψ enter b_t linearly in the denominator and hence they drop out after multiplying 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 they 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

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

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

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

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

Following 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 $H_{R,i,s} = h_{i,s} L_{R,i,s}$, with $L_{R,i,s}$ 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 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 $b_{n,i,t}(m) = [\Phi_{n,t}(m w_{i,t} d_{i,t})^{\theta}]^{-1}$. Consequently, the probability for an idea from country i to be sold in country n is given by

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

The intuition is that the probability to surpass the state-of-the-art technology in country i is given by $1/T_{i,t}$, while 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

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

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

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

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 world-wide 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, $w_{i,t} = \lambda_i V_{i,t}$. Due to 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.** At the steady state of economy i, a constant share of human capital r_i is employed in the research sector, implying $r_i = H_{R,i,t}/H_{i,t}$. 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 $T_{i,t} = \lambda_i \sum_{s=1}^{t-1} H_{R,i,s}$, it follows that

$$T_{i,t+1} - T_{i,t} = \lambda_i r_i H_{i,t} \Rightarrow g_{T,i,t} = \frac{\lambda_i r_i H_{i,t}}{T_{i,t}}. \tag{10}$$

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

Proposition 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 the real purchasing power stem from falling prices and increasing average human capital levels. 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 the real purchasing power as

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

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

Proposition 2. *The steady-state growth rate of 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).*

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

$$\frac{\partial g_P}{\partial \eta} = \frac{\xi[\eta - \alpha(1+\theta)] \left(\frac{\eta}{1+\alpha}\right)^{-1/\theta}}{\eta^2 \theta \psi} < 0, \qquad \frac{\partial g_P}{\partial \alpha} = \frac{(\alpha\theta + \alpha - \eta + \theta) \left(\frac{\eta}{1+\alpha}\right)^{-1/\theta}}{(1+\alpha)^2 \theta \psi} > 0.$$

□

Together with (2) the result implies that growth is positively associated with education and negatively associated with the level of fertility of a country. 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, they generalize the theoretical results from Strulik et al. (2013) for an open economy set-up.

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

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

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, Equation (6) implies

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

and, similar to Eaton and Kortum (2001), scale — as measured by the population size —

does not matter. In contrast to Eaton and Kortum (2001), however, the relative average human capital levels of both countries influences their relative economic well-being.

Under autarky, Equation (5) implies

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

and, again similar 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 that shows that human capital is important, irrespective of a country's openness, while scale is only important for a closed economy.

Proposition 3.

Under free trade:

i) *The size of a country's labor force does not affect its relative real per capita income.*

ii) *An increase in the average human capital level of a country's labor force raises its relative real per capita income.*

In autarky:

i) *An increase in the size of a country's labor force raises its relative real per capita income.*

ii) *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 Equations (11) and (12). □

This result is consistent with the findings of Kremer (1993) and Alesina et al. (2005) that population size matters as long as countries are relatively isolated, while 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 Hanushek and Woessmann (2012) that education matters in general for the economic prosperity of countries.

4. Conclusions

We 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 the one hand, and between human capital accumulation and economic prosperity on the other. In particular, we showed that there is a positive effect of education on economic growth, while there is a negative effect of population growth on economic growth. 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. However, irrespective of the openness of a country, its average human capital level positively affects its relative economic prosperity.

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