Long-Run Development in the Open Economy

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Abstract

re open economies characterized by superior economic performance in the long-run? This paper revisits this important question from the point of the view of unified growth theory. Contrary to other recent attempts to study this question, the paper considers two distinct channels through which openness might affect growth, namely trade in final goods and technology transfer. Constructing a two-country two-sector unified growth model that incorporates both these channels, it is argued that although trade and the resulting specialization in production generate a force of divergence between the two economies, this can be mitigated or even countered by the effect of technology transfer. In this context, the paper identifies differences in the level of education between the two countries as the crucial factor in determining which of the two forces is going to dominate. The predictions of the theory are then confronted with empirical evidence from cross-sectional and panel growth regressions that span the period from 1870 to 2008. The obtained estimates indicate a strong pattern of convergence among open economies with high initial levels of human capital which is robust to various specification tests.

Keywords: Unified Growth Theory, International Trade, Technology Transfer, Human Capital, Convergence

JEL Classification: F10, F43, N70, O11, O14, O40.

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1 Introduction & Overview

Understanding the mechanics of long-run economic development has always posed a major challenge for economists. Any insight into why some countries or nations have managed to achieve high levels of income per capita, as well as sustained increases in those levels, while others seem to be condemned to live in poverty is of great importance for designing future policies. However, as recent research has demonstrated, obtaining such insights may often require that we turn our focus towards the past and investigate the historical experiences of different nations and regions[1].

This realization regarding the importance of history, together with meticulous efforts of economic historians to unearthed or reconstruct historical data, has led to the development of unified theories of economic growth that treat and analyze human economic development as a continuous process that started many centuries ago [2]. These theories intertwine key features of modern growth theory with elements of the Malthusian population theory to provide a framework for the analysis of all stages of economic development from pre-industrial stagnation to the modern state of sustained economic growth. Yet, most of these theories are focusing their analysis on a closed-economy setting[3]. This approach may be valid in understanding developments in 18th century England or in other early industrializing nations. Nevertheless, they are probably less relevant when it comes to the experience of subsequent industrializers and it may even lead to spurious inferences regarding the challenges currently faced by less developed nations in their quest for economic progress.

With that mind, the present paper aims at providing an open-economy unified model of economic growth that takes explicitly into account the interdependencies between developed

[1] Recent contributions which pointed at that direction include Acemoglu, Johnson, and Robinson (2005), who emphasize the colonial experiences of different nations, Nunn (2008), who underscores the legacy of slave trade in Africa, Comin, Easterly, and Gong (2010), who stress the importance of an early technological lead, and Spolaore and Wacziarg (2009), who discuss the role of genetic distance.

[2] Typical examples of unified growth theories include Galor and Weil (2000), Hansen and Prescott (2002), Lucas (2002), Cervellati and Sunde (2005), Voigtlaender and Voth (2006), Boucekkine, de la Croix, and Peeters (2007). For more information on this literature the readers is refer to Galor (2011).

[3] There are few notable exceptions to this general rule such as Galor and Mountford (2008) and O'Rourke, Rahman, and Taylor (2007) which will be discussed more extensively later on.

and less-development economies and the effects that such interdependencies may have on the process of economic development for both types of economies. Particularly, in this context, one of the paper's main innovation with respect to the existing literature is that the analysis takes into account two distinct channels through economic interactions between countries may influence their comparative development. Specifically, the paper focuses on both the role of trade in final goods and the resulting specialization in production as well as the role of technology transfers from more developed to less developed economies. The reasons for concentrating on these two channels has to do with the attention that both these channels have received in the literature, as well as the fact that existing work indicates that the effects of the two channels might not necessarily work in the same direction.

Economic integration of different countries and regions is reflected first and foremost in their openness to trade and there is a wide consensus that trade flows can generate large static gains for all regions. Yet, the implications of trade for the long-run economic development of different regions has been a source of great debates in the literature. For example, Acemoglu and Ventura (2002) and Cuñat and Maffezzoli (2004) have argued that in an interdependent world international trade flows lead to convergence in terms of growth rates between more and less developed economies, although not necessarily to convergence in their levels of income. Others, such as Young (1991), Baldwin, Martin, and Ottaviano (2001) and Galor and Mountford (2008), suggest that trade between countries that are in different stages of development may even result in lower growth rates for less developed economies, because the latter end up specializing in less dynamic industries. Moreover, Galor and Mountford (2008) as well as O'Rourke, Rahman, and Taylor (2007) attribute the great divergence in per capita incomes that has occurred since the Industrial Revolution partly to the above effects of trade[4].

Regarding technology transfer, the consensus in the literature that it can be a force of

[4]Both these papers derive their insights in the context of unified growth models, which share many of the features of the theoretical framework used in this paper. Yet, contrary to the present analysis both Galor and Mountford (2008) and O'Rourke, Rahman, and Taylor (2007) do not consider any other channel through which openness may affect the course of long-run economic development apart from trade.

convergence. This idea is associated with the well-known hypothesis of Gerschenkron (1962) regarding the *advantage of backwardness*, which was first formalized in the economics literature in Nelson and Phelps (1966) catch-up model of technology diffusion. In the recent years several authors such as Benhabib and Spiegel (1994) and Coe and Helpman (1995) have attempted to test this hypothesis empirically and have documented important technology transfer flows from developed to less developed countries. Yet, despite its potential in generating convergence, it is clear that technology transfers do not occur automatically and that the diffusion of technologies across countries may depend on several factors. One key factor that the literature has identified as an important determinant of the ability of less-developed economies to introduce technologies from more developed countries is human capital. Nelson and Phelps (1966) were the first to make this point forcefully, while more recently Benhabib and Spiegel (1994) have provided evidence that the rate of technology transfer from leading to following countries is positively associated with the level of education in the following country.

None of the existing work, however, has incorporated both channels into the same model and this is where the innovation of the present paper lies. With the aid of a two-country two-sector unified growth model with endogenous technological progress, along the line of Milionis and Klasing (2011), the effects of economic integration on the process of development will be analyzed. In this context, it is assumed that due to differential initial conditions the two economies are at different stages of economic development at the time of integration. As a result of that, when trade opens up the more advanced economy will specialize in manufacturing, while the less advanced one will specialize in agriculture. Because production in agriculture, though, is characterized by decreasing returns to scale due to the presence of land as a fixed production factor, the resulting specialization pattern implies that growth, once trade opens up, will be lower in the less developed economy triggering divergence between the two economies.

At the same time, however, economic integration enables the less developed economy to benefit from the transferring of advanced technologies from the more developed one. These

flows of technology transfers between the two economies have the potential of generating a strong force of convergence provided that the less developed economy is able to perform the necessary implementation investments. These investments, which make technology diffusion not automatic, are not assumed to take the form of reverse engineering. As a result of that this process of technology diffusion is greatly facilitated by the level of education in the following country. This is because a more educated workforce is in a better position to reverse-engineer advanced technologies.

This role of education in promoting technology diffusion implies that the long-run implications of economic integration for less developed economies crucially hinge on the education gap between the two economies at the time of integration. As long as this gap is relatively small, the force of technology transfer will be strong enough to overcome the adverse effects of specialization and hence economic integration will benefit both economies. As this gap widens, though, the costs of implementing technologies invented in the leading economy increase for the lagging economy. This weakens the force of technology transfer and will make divergence between the two economies the more likely scenario. Therefore, the theory yields the following testable prediction: The likelihood for a given open economy of catching up with the leading industrial nations or falling behind in terms income per capita should depend positively on the level of education of its workforce.

This main prediction of the theory is then tested empirically based on growth regressions employing both cross-country and panel data. The empirical analysis indicates that ceteris paribus countries that start off with a high initial level of human capital will converge faster in the subsequent period than countries characterized by low initial levels of human capital and that this effect is stronger in more open economies. In particular, the analysis indicates that the annual rate of convergence of countries whose initial human capital is in the 75th percentile of the human capital distribution is about 20% higher than that of countries whose human capital is equal to the median of the human capital distribution and that this effect is increased by another 25% if countries are relatively more open to trade. Moreover, these effects are robust to various specification tests and to the inclusion of a wide set of control

variables.

In what follows, I will first of all present a short summary of the historical evidence on the role of international trade and openness on economic development in Section 2. This is followed by the presentation of the theoretical model in Section 3. The model is then calibrated and simulated in Section 4 to match the patterns seen in historical evidence. Section 5 presents the empirical evidence regarding the role of human capital and trade for convergence. Finally Section 6 offers some concluding remarks.

2 Historical Evidence on Openness and Economic Development

Trade and other forms of economic interaction between different regions of the globe have been taking place since Antiquity. However, prior to the 19th century they were limited to very particular activities such as the exchange of luxury goods or the trading of slaves (Cameron and Neal 2002). The big expansion of international trade and the movement towards the integration of world markets -what Williamson coined the first wave of globalization - came with the world-wide transport revolution of the mid 19th century. This refers to a series of major transportation innovations including steamships, canals, railroads as well as refrigeration, which lead to sizeable reductions in the cost of transportation for goods (O'Rourke and Williamson 1999).

The link between the new industrial technologies, the falling transportation costs and subsequent expansion of trade has long been pointed out by economic historians such as North and Harley. The following graph, taken from Harley (1988), shows the magnitude of these reductions in terms of freight rates. This demonstrates not only the importance of industrialization in limiting the frictions associated with the long-distance movement of goods, but also the prohibitive nature of such costs prior to the industrial revolution. Of course, the cost of transportation constitutes only a fraction of the total cost associated

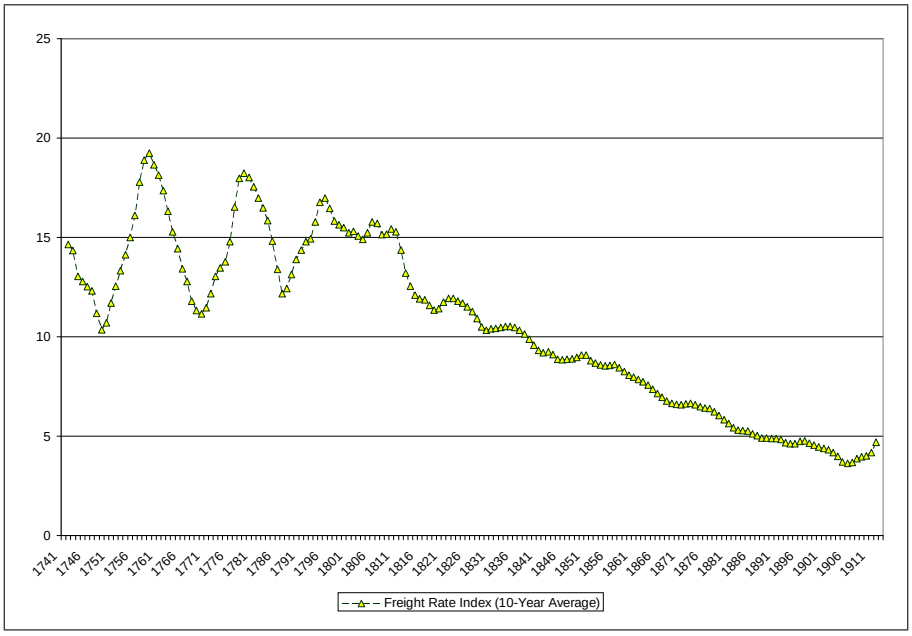

Figure 1: Harley's British Freight Rate Index Averaged Over 10-year Intervals

with trading across national borders. However, given the historical focus of this paper, it is natural to treat trade costs in this case as reflecting primarily the actual transportation expenses related to the international shipment of goods (Anderson and van Wincoop (2004)).

This expansion of trade that began in the late 19th century and continued during the 20th century has been instrumental in shaping economic geography over the whole world. The force of specialization, has led different countries to concentrate their production on specific economic activities and rely on global markets for the rest. Typical examples of this transformation were the expansion of manufacturing activities in the "Atlantic Economy" and the shift towards agricultural production in the Third World. This worldwide division of labor was driven primarily by the drastic changes in the terms of trade that took place during that period (Williamson 2005). To see this, the following two graphs present the evolution of trade flows between the British Empire and India over the period 1900-1960 with the data being from the United Nations Statistical Office. Here it should be noted that the expansion of trade that took place over that period led to an expansion of British manufacturing exports and at the same time of Indian manufacturing imports.

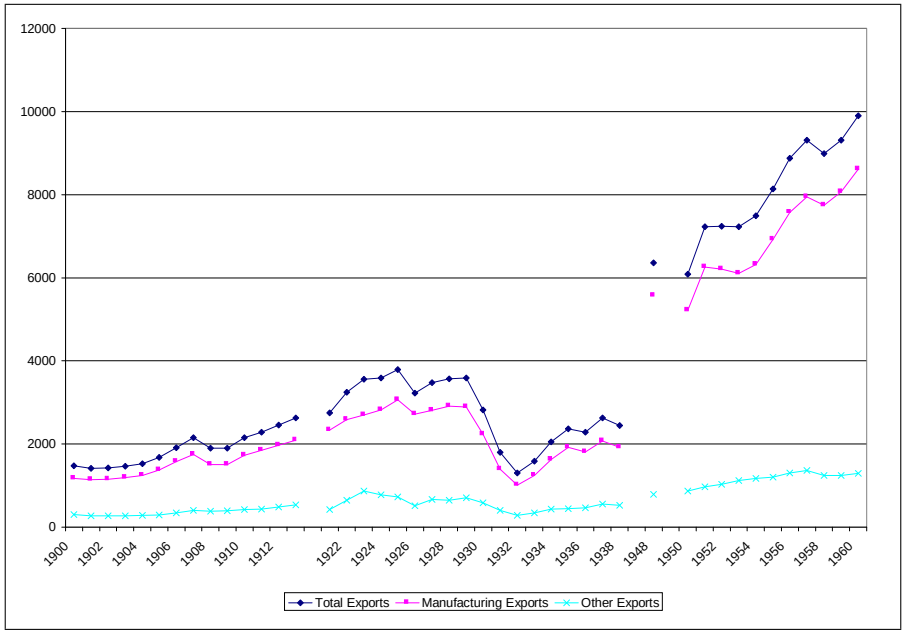

Figure 2: The Evolution of British Exports

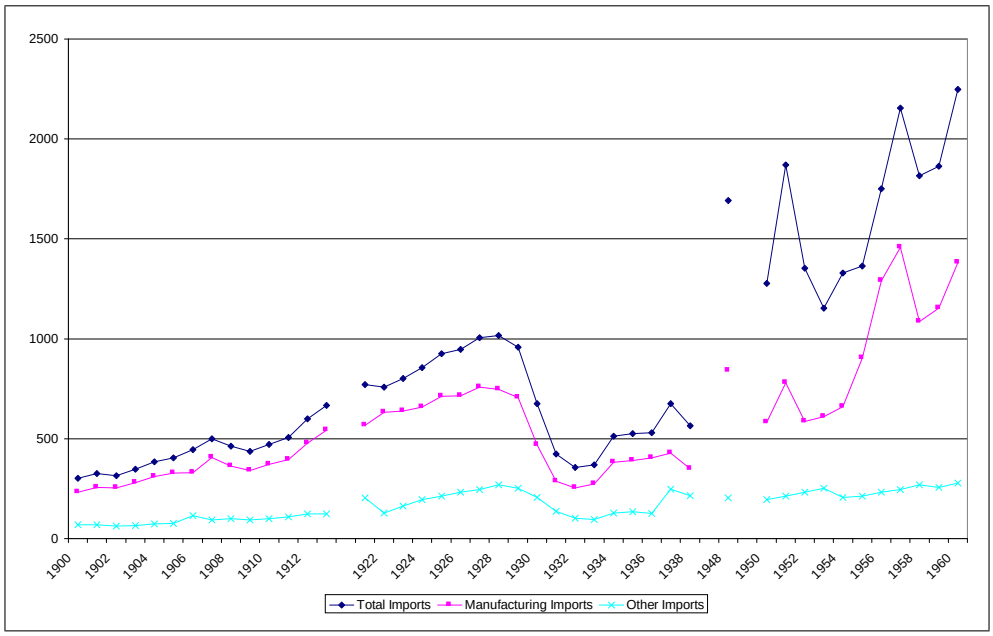

Figure 3: The Evolution of Indian Imports

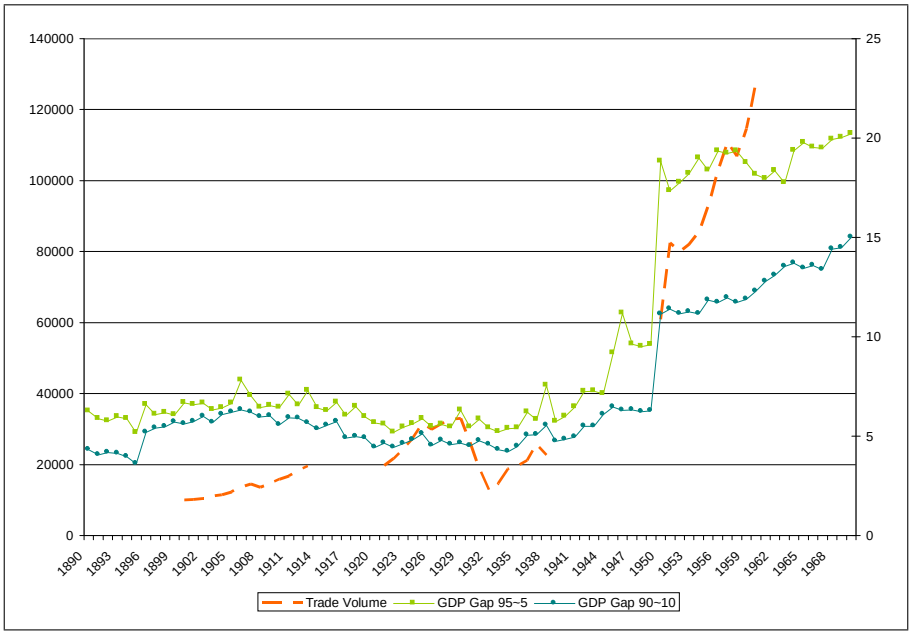

Figure 4: World Trade Volumes and the Great Divergence

Of course, these developments would not have attracted that much attention, had they not been followed by a dramatic broadening of the gap in terms of per capita income between the world's poorest and richest economies, a fact that is typically referred to as the great divergence (Pritchett 1997). This association between trade expansion and world income inequality can be seen from the next graph displaying the evolution of the volume of international trade together with the ratio of income of the 95th relative to the 5th as well as that of the 90th relative to the 10th percentiles of the world's income distribution[5].Despite the fact that the correlation observed between these two phenomena may not necessarily imply a causal link, it is still striking how the expansion of trade led to widening income gaps across countries that the world had never experienced before.

Together with the expansion of trade, though, the world also witnessed a global diffusion of various production technologies. For example, Mokyr (1993) discusses how many of the innovations of the British Industrial Revolution were quick to spread to Continental Europe and other parts of the world and Clark (1987) points out, that by 1910 textile machinery was

[5]The income per capita data are from Maddison (2001). The trade data are from the United Nations Statistical Office.

uniform around the world. Such flows have long been pointed out by economists to be an important force of convergence between countries (Grossman and Helpman 1991a, Barro 1995). At the same time, though, as it has become evident from the more recent literature on technology transfer (Howitt (2000), Keller (2004)), that a flow of advanced technologies to less developed economies does not happen automatically. Despite the presence of an advantage to the countries introducing existing technologies rather than inventing them from scratch [6], the implementation process may still imply some costs. These are estimated by Mansfield, Schwartz, and Wagner (1991) as corresponding to $60 - 80\%$ of the actual innovation cost in most cases. This is because new technologies are often *"tacit and circumstantially specific"* (Howitt and Mayer-Foulkes (2005)) and thus they may need to be adjusted before being employed in a different environment. This is an important point to which I will return later in the analysis

3 A Two-Country Unified Growth Model

3.1 Basic Structure

This section analyzes more formally the relationship between an economy's degree of openness and the process of long-run economic development, keeping in mind the historical facts described in the previous section. For this purpose, a theoretical unified growth model is constructed that comprises two separate economies that over time will begin to integrate economically with on another, as they both develop. Specifically, I focus here on two potential channels of interaction between the two economies, trade in final goods and transfers of technology. The basic structure of each individual economy is similar to the closed-economy setup of Milionis and Klasing (2011) with both of the economies encompassing two distinct production sectors, an agricultural and a manufacturing one.

Each economy consists of overlapping generations of households, who work, consume and raise children. These households constitute the basic unit of analysis and comprise one adult

[6] This is what Gerschekron has coined the "advantage of backwardness" (Gerschekron 1962).

agent together with his or her offspring. Time - denoted by the subscript t - is discrete and extends from an initial period 0 to infinity, with each generation of agents living for just two periods. In their first period of life, childhood, agents are assumed not to engage in any economic decision-making and simply consume a fraction of parental time. In the second period of life, adulthood, agents are active decision-makers who have to decide on the allocation of their time between productive and child-rearing activities[7].

3.2 The Two Production Sectors

Let L_{it} be the mass of agents entering adulthood in period t in country i, $i \in \{1, 2\}$. This mass constitutes the total labor force of the economy for that period. This labor force is allocated in two production sectors, an agricultural sector and a manufacturing sector. Each sector produces a distinct final good, which is denoted by Y_{it}^A and Y_{it}^M. The main difference between them is that the former operates under decreasing returns to scale due to the presence of a fixed factor of production, land, while the latter operates under constant returns. The production technologies for these two goods are given by,

$$Y_{it}^A = A_{it}^A (h_{it} L_{it}^A)^\alpha X_i^{1-\alpha}, \tag{1}$$

$$Y_{it}^M = A_{it}^M h_{it} L_{it}^M. \tag{2}$$

From the above variables, X_i corresponds to fixed amount of land available for agriculture in country i, h_i to the per capita level of human capital in country i and A_{it}^k to the current level of total factor productivity in sector k, $k \in \{A, M\}$, of country i. L_{it}^k denotes the amount of labor employed in sector k of country i, for which we have that:

$$L_{it}^A + L_{it}^M = L_{it}. \tag{3}$$

[7] Given that in each household there is one active decision-maker, in what follows the terms household and agent are going to be used interchangeably .

From the above expression it is evident that the model precludes movements of the labor force between the two countries. Finally, the exponent $\alpha \in (0,1)$, capturing the relative importance of land in the agricultural sector, is assumed to be the same in both countries. Thus, there is no difference in the factor intensity of agricultural production in the two economies.

Rewriting the two production functions in per capita terms, we obtain that,

$$y_{it}^{A} = A_{it}^{A} h_{it}^{\alpha} x_{it}^{1-\alpha}, \tag{4}$$

$$y_{it}^{M} = A_{it}^{M} h_{it}, \tag{5}$$

where $y_{it}^{k} = \frac{Y_{it}^{k}}{L_{it}^{k}}$ denotes output per worker in sector k of country i and $x_{it} = \frac{X}{L_t}$ corresponds to the amount of land per agriculturalist in country i. To avoid dealing with issues related to the ownership of land and its intergenerational allocation, I follow the assumption of Galor and Weil (2000), who let land earn zero returns. This means that the labor force employed in agriculture will earn its average product rather than its marginal product. Under this assumption, the wage rate earned by workers employed in the two production sectors in country i is given by:

$$w_{it}^{A} = A_{it}^{A} \left(\frac{X_i}{h_{it} L_{it}^{A}}\right)^{1-\alpha}, \tag{6}$$

$$w_{it}^{M} = p_{it}^{M} A_{it}^{M}. \tag{7}$$

Here w_{it}^{k} denotes the real wage rates in sector k of country i denominated by the price of the agricultural good, i.e. $w_{it}^{k} \equiv \frac{W_{it}^{k}}{P_{it}^{A}}$, and p_{it}^{M} the relative price of the manufacturing good in terms of the agricultural good in country i, i.e. $p_{it}^{M} \equiv \frac{P_{it}^{M}}{P_{it}^{A}}$. The absolute prices of two goods P_{it}^{A} and P_{it}^{M} will not play any role in the analysis and hence will be suppressed in the notation.

3.3 The Innovation Process

Technological progress in each sector of the economy is driven by small-scale innovations generated by individual agents employed within that sector. Specifically, following the approach first presented in Milionis and Klasing (2011), it is assumed that before engaging in any production activities agents employed in sector k in country i devote some fraction ω_{it}^k of their time to experiment with the existing production technology. The goal of this activity is to improve upon the current level of technology A_{it}^k in that sector, which the agents inherited from the previous generation[8].

Abstracting from the uncertainties of such a process, this experimentation is supposed to generate with certainty an innovation of magnitude ζ_{it}^k, which individual agents can subsequently utilize in order to enhance the productivity of their own labor. The magnitude of that innovation is linear in the time spent experimenting, ω_{it}^k, with the productivity of each agent in experimentation depending on his or her level of education e_{it} as well as some fixed factor B^{IN} :

$$\zeta_{it}^k = B^{IN}(\tilde{e} + e_{it})^{\beta}\omega_{it}^j. \tag{8}$$

The presence of the constant $\tilde{e}$ is justified by the existence of some basic cognitive skills which are innate to the individual. The exponent $\beta \in (0, 1)$, on the other hand, captures the presence of limitations to human cognition. This experimentation process, though, is costly, as the time that agents spent experimenting has to be taken away from their other activities, namely, working and child-rearing. Since agents need to work in order to provide themselves and their families with at least the means for their subsistence, agents can only devote to experimentation a small fraction of the total time available to them - which for simplicity is normalized to 1.

The overall technological improvement Z_{it}^k within period t in sector k of country i is the result of these small-scale individual innovations. However, because of the decentralized

[8]For more details on the historical relevance and the rationale behind this particular way of modeling technological innovation prior to the era of research and development the reader is referred to the discussion in Section 2 of Milionis and Klasing (2011).

and uncoordinated nature of the experimentation process, it is likely that the innovations generated by different agents will be substituting for rather than complementing one another. To captures this possibility, we let Z_{it}^k be given by the power mean of all individual innovations $\zeta_{it}^k(v)$,

$$Z_{it}^k = \{\int_0^{L_{it}^k} [\zeta_{it}^k(v)]^\varepsilon dv\}^{\frac{1}{\varepsilon}}, \tag{9}$$

with v corresponding to the positive measure set of all innovators and ε capturing the degree of substitutability among individual innovations.

3.4 The Diffusion of Technology

From the last expression it is apparent that in every period new technological innovations will be generated in any sector that employs some positive share of the economy's labor force. The diffusion of these innovations within the sector, though, is not instantaneous. Particularly, the underlying assumption is that in each period an agent employed in sector k has access to the level of technology inherited from the previous generation, A_{it}^k, coupled with any innovation ζ_{it}^k, that he or she alone may invent. Furthermore, it is postulated that due to the imperfect nature of property rights in the economy individual innovators are only able to appropriate a fraction λ^k of their innovations, with the remaining fraction being lost to other agents[9]. The imperfect protection of property rights implies that each innovator is also able to free-ride on innovations invented by others. Thus, the level of technology available to each individual agent in period t is given by,

$$[1 + \lambda^k \zeta_{it}^k + (1 - \lambda^k)\bar{\zeta}_{it}^k] A_{it}^k, \tag{10}$$

with ζ_{it}^k corresponding to the size of the innovation produced by the agent and $\bar{\zeta}_{it}^k$ to the average innovation size in the sector[10].

[9] This fraction λ^k is allowed to vary between the two sectors, but not across countries and time. I will further comment on this point in the subsequent section.

[10] This distinction is carried here for conceptual reasons. Under the simplifying assumption of all agents being identical, the actual innovation magnitudes ζ_{it}^k will end up being the same as the average $\bar{\zeta}_{it}^k$.

Over time, however, there is going to be diffusion of new innovations, first of all, within each sector. In this context, it is assumed that each innovation generated by an agent in period t will be freely available to all agents of the subsequent generation in period $t+1$. Similarly, it is also possible that some of these innovations may find uses in other sectors of the economy. This is captured by the presence of positive technological spillovers from the relatively more advanced sector to the less advanced one at a rate σ. Hence, following the approach of ?? the evolution of technology in sector k of country i is assumed to be governed by the expression,

$$A_{it+1}^k = (1 + Z_{it}^k)A_{it}^k + \sigma \max\{0, A_{it}^l - A_{it}^k\}, \tag{11}$$

This captures both the overall technological improvement within that sector as well as the potential spillovers from a more advanced sector l[11].

Based on this last expression, we can define the growth rate of technology in sector k of economy i as,

$$g_{it+1}^k = \frac{A_{it+1}^k - A_{it}^k}{A_{it}^k}, \tag{12}$$

and also the average rate of technological progress in the economy equals:

$$\bar{g}_{it+1} = g_{it+1}^A \frac{L_{it}^A}{L_{it}} + g_{it+1}^M \frac{L_{it}^M}{L_{it}}. \tag{13}$$

3.5 Household Decision-Making

As mentioned earlier, when describing the structure of the economy, each individual household is led by an adult agent who makes all the decisions regarding production, experimentation and child-rearing activities. The objective problem of each individual household head is basically an allocation problem of his or her ultimate resource, a unit time endowment, that has to be divided between the above three activities. The goal of the agent is to maximize

[11] The assumption of positive technological spillovers, although not necessary, is natural given the setup of our model. Moreover, as it will be pointed out in the following section, it makes the dynamics of the model more realistic.

his or her utility function, which takes the form:

$$u_{it} = \{[\chi(c_{it}^A - \tilde{c})]^\eta + [(1-\chi)c_{it}^M]^\eta\}^{\frac{1-\gamma}{\eta}}(n_{it}h_{it+1})^\gamma. \tag{14}$$

This function consists of two main components. The first one is a constant elasticity of substitution consumption index $\{[\chi(c_{it}^A - \tilde{c})]^\eta + [(1-\chi)c_{it}^M]^\eta\}^{\frac{1}{\eta}}$ reflecting the utility obtained from the consumption of c_{it}^A units of the agricultural good and c_{it}^M units of the manufacturing good, which are only imperfect substitutes. The parameter η captures the degree of substitutability between the two goods, while χ denotes the weight that each type of good carries in the consumption index. The second term corresponds to the quality-adjusted number of children n_{it}, where quality here is signified by their level of human capital h_{it+1}. The relative importance of the two components for the agent's utility is captured by the exponent $\gamma \in (0,1)$. It should be noted here that the employed function also includes a subsistence consumption requirement $\tilde{c} > 0$ regarding the consumption of the agricultural good. This reflects the existence of a minimum level of basic food consumption which is absolutely necessary in order for the agent to survive.

When maximizing the above function, each household head must naturally obey a budget constraint bounded by the household's potential income z_{it}^k. This reflects the income that an adult agent employed in sector k in country i would earn if he or she did not raise any children. This level, of course, depends also on the extent to the agent also engages in productivity-enhancing experimentation activities. Thus, conditional on the adult agent having spent a fraction ω_{it}^k of his or her time experimenting the household's potential income equals:

$$z_{it}^k = (1-\omega_{it}^k)[1 + \lambda^k\zeta_{it}^k + (1-\lambda^k)\bar{\zeta}_{it}^k]w_{it}^k h_{it}. \tag{15}$$

From the above expression it is apparent that the adult agent's optimal choice regarding the fraction of time $\omega_{it}^k \in [0,1]$ spent on experimentation activities must maximize the product $(1-\omega_{it}^k)[1+\lambda^k\zeta_{it}^k + (1-\lambda^k)\bar{\zeta}_{it}^k]$. This captures the net gain from experimentation in terms of productivity, which, using expression (8), can be rewritten simply in terms of ω_{it}^k.

Thus, each agent's decision can be understood as follows:

$$\underset{0\leq\omega_{it}^{k}\leq 1}{max}\{(1-\omega_{it}^{k})[1+\lambda^{k}B^{IN}(\tilde{e}+e_{it})^{\beta}\omega_{it}^{k}+(1-\lambda^{k})B^{IN}(\tilde{e}+e_{it})^{\beta}\bar{\omega}_{it}^{k}]\}. \tag{16}$$

Optimality here mandates that $\omega_{it}^{k}\geq\frac{1}{2}-\frac{1}{2\lambda^{k}B^{IN}(\tilde{e}+e_{it})^{\beta}}-\frac{1}{2}\frac{1-\lambda^{k}}{\lambda^{k}}\bar{\omega}_{it}^{k}$, which would hold with equality in case $\omega_{it}^{k}>0$. Moreover, under the simplifying assumption of all agents being identical, there is a unique symmetric equilibrium with each agent devoting to experimentation activities a fraction:

$$\hat{\omega}_{it}^{k}=\omega(e_{it})=\left\{\begin{array}{cc}\frac{\lambda^{k}}{\lambda^{k}+1}-\frac{1}{(\lambda^{k}+1)B^{IN}(\tilde{e}+e_{it})^{\beta}} & \text{if } e_{it}\geq(\lambda^{k}B^{IN})^{-\frac{1}{\beta}}-\tilde{e}\\ 0 & \text{if } e_{it}<(\lambda^{k}B^{IN})^{-\frac{1}{\beta}}-\tilde{e}\end{array}\right\}. \tag{17}$$

Using equation (8) we find the corresponding optimal magnitude of an innovation:

$$\hat{\zeta}_{it}^{k}=\zeta(e_{it})=\left\{\begin{array}{cc}\frac{1}{\lambda^{k}+1}[\lambda^{k}B^{IN}(\tilde{e}+e_{it})^{\beta}-1] & \text{if } e_{it}\geq(\lambda^{k}B^{IN})^{-\frac{1}{\beta}}-\tilde{e}\\ 0 & \text{if } e_{it}<(\lambda^{k}B^{IN})^{-\frac{1}{\beta}}-\tilde{e}\end{array}\right\}. \tag{18}$$

Finally, substituting these values into expression (15) we obtain the household's optimal conditional potential income:

$$\hat{z}_{it}^{k}=\left\{\begin{array}{cc}\frac{\lambda^{k}}{(\lambda^{k}+1)^{2}}[2+B^{IN}(\tilde{e}+e_{it})^{\beta}+\frac{1}{B^{IN}(\tilde{e}+e_{it})^{\beta}}]w_{it}^{k}h_{it} & \text{if } e_{it}\geq(\lambda^{k}B^{IN})^{-\frac{1}{\beta}}-\tilde{e}\\ w_{it}^{k}h_{it} & \text{if } e_{it}<(\lambda^{k}B^{IN})^{-\frac{1}{\beta}}-\tilde{e}\end{array}\right\}. \tag{19}$$

This expression represents the level of income that each household head would have at his or her disposal to purchase units of the agricultural and manufacturing goods in case he or she decided to not raise any children. However, from (14) it is clear that adult agents will also choose to have children, i.e some part of their time will also be devoted to child rearing. Particularly, suppose that the time cost for an adult agent of generation t in country i of raising one child with education level e_{it+1} is $\tau^{q}+\tau^{e}e_{it+1}$, where τ^{q} corresponds to the fixed time cost of rearing one child and τ^{e} to the unit cost of education. Thus, if the agent's choice

is to rear n_{it} number of children and to endow them with an education level of e_{it+1}, then the agents's ultimate budget constraint would be:

$$c_{it}^{A} + p_{it}^{M} c_{it}^{M} \leq \hat{z}_{it}[1 - n_{it}(\tau^{q} + \tau^{e} e_{it+1})] \tag{20}$$

3.6 Labor Market Clearing and Human Capital Formation

Note that in this last expression the superscript k over the conditional potential income variable $\hat{z}_{it}$ has been removed. This is because under the assumption of a competitive economy-wide labor market, the migration of labor between the two sectors of the economy must lead to the equality of the income earned in the agriculture and manufacturing, i.e.: $\hat{z}_{it}^{A} = \hat{z}_{it}^{M} = \hat{z}_{it}$. This means that as long as both sectors of the economy are active, we can derive, by combining equations (6), (7) and (19), that

$$\hat{z}_{it} = \Delta_{it}^{A} A_{it}^{A} (h_{it})^{\alpha} (\frac{X_i}{L_{it}^{A}})^{1-\alpha} = \Delta_{it}^{M} p_{it}^{M} A_{it}^{M} h_{it}, \tag{21}$$

with $\Delta_{it}^{k} \equiv \frac{\lambda^{k}}{(\lambda^{k}+1)^{2}}[2 + B^{IN}(\tilde{e} + e_{it})^{\beta} + \frac{1}{B^{IN}(\tilde{e}+e_{it})^{\beta}}]$ as obtained in equation (19). Thus, given the relative price of the manufacturing good p_{it}^{M}, the allocation of the total labor force L_{it} between the two production sectors is given by the following two expressions:

$$\hat{L}_{it}^{A} = (\frac{\Delta_{it}^{A} A_{it}^{A}}{p_{it}^{M} \Delta_{it}^{M} A_{it}^{M}})^{\frac{1}{1-\alpha}} \frac{X_i}{h_{it}}, \tag{22}$$

$$\hat{L}_{it}^{M} = L_{it} - \hat{L}_{it}^{A}. \tag{23}$$

The assumption of perfect labor mobility implies also that the children of agricultural and manufacturing workers may in their second period of life end up being employed in either sector of the economy. For this reason, the analysis refrains from making any distinction between the nature or the level of human capital of children raised in agricultural households and that of children raised in manufacturing ones. Otherwise, this would impose a restriction on the mobility of the labor force as agents raised in an agricultural household would find

themselves better suited for employment in the agricultural sector and vice versa[12].

With that in mind, the process of human capital formation for each individual agent is assumed to be guided by the same principles as in Galor and Weil (2000). Specifically, the per capita level of human capital is thought to be influenced by the amount of education received in the first period of life as well as the rate of technological progress between the two periods. To capture this, Galor and Weil let each agent's level of human capital, h_{it}, be an increasing and concave function of his or her education, e_{it}, and a decreasing and convex function of the economy's average rate of technological progress, $\bar{g}_{it}$[13]. Moreover, they postulate that the adverse effect of technological progress on human capital is assumed to be smaller, the higher is the level of education. These assumptions are reflected in the human capital formation function,

$$h_{it} = h(e_{it}, \bar{g}_{it}) > 0, \tag{24}$$

where $h_e(\cdot) > 0, h_{ee}(\cdot) < 0, h_g(\cdot) < 0, h_{gg}(\cdot) > 0 \wedge h_{eg}(\cdot) > 0$[14].

3.7 Household Demands

Once each adult agent has decided on what fraction of his or her time to devote to experimentation activities based on equation (17), the remaining choices that need to be made are the determination of the optimal level of consumption for the two goods, $\hat{c}_{it}^A$ and $\hat{c}_{it}^M$, the optimal number of children, $\hat{n}_{it}$, and their level of education, $\hat{e}_{it+1}$. These are chosen such that they maximize the household's level of utility given the household's conditional potential income $\hat{z}_{it}$ and the subsistence consumption requirement $\tilde{c}$. Thus, each adult agent

[12] Departing from the assumption of perfect labor mobility made by justified by the historical experience of different countries. However, in the context of the present model, this would alter the main mechanisms influencing the course of economic development.

[13] The former assumption seems intuitive in the presence of decreasing returns to education. The latter is justified by the "erosion" effect which was first suggested by Schultz (1964). For more details on the reader is referred to the discussion in Galor and Weil (2000).

[14] The assumption that $h(\cdot) > 0$ can be justified with the existence of a basic level of cognitive skills that even an uneducated individual would possess. Particularly it is assumed that $h(0, g_t) > 0$ and that $\lim_{g_t \to +\infty} h(0, g_t) \to 0$.

must solve the following optimization problem:

$$\max_{\{c_{it}^A, c_{it}^M, n_{it}, e_{it+1}\}} u_{it} = \{[\chi(c_{it}^A - \tilde{c})]^\eta + [(1-\chi)c_{it}^M]^\eta\}^{\frac{1-\gamma}{\eta}} [n_{it} h(e_{it+1}, \bar{g}_{it+1})]^\gamma,$$
$$s.t. \left\{ \begin{array}{c} \hat{z}_{it}[1 - n_{it}(\tau^q + \tau^e e_{it+1})] \geq c_{it}^A + p_{it}^M c_{it}^M \\ (c_{it}^A, c_{it}^M, n_{it}, e_{it+1}) \geq 0 \end{array} \right\}. \tag{25}$$

This yields the following two demand functions for the agricultural and the manufacturing good, which reflects the presence of subsistence consumption requirement:

$$\hat{c}_{it}^A = \frac{1-\gamma}{1 + (\frac{\chi}{1-\chi} p_{it}^M)^{\frac{\eta}{\eta-1}}} \hat{z}_{it} + \frac{\gamma}{1 + (\frac{\chi}{1-\chi} p_{it}^M)^{\frac{\eta}{\eta-1}}} \tilde{c} + \frac{1}{1 + (\frac{\chi}{1-\chi} p_{it}^M)^{-\frac{\eta}{\eta-1}}} \tilde{c}, \tag{26}$$

$$\hat{c}_{it}^M = \frac{1-\gamma}{1 + (\frac{\chi}{1-\chi} p_{it}^M)^{-\frac{\eta}{\eta-1}}} \frac{\hat{z}_{it} - \tilde{c}}{p_{it}^M}. \tag{27}$$

Similarly, the optimal number of children is governed by the following expression :

$$\hat{n}_{it} = \frac{\gamma}{\tau^q + \tau^e e(\bar{g}_{it+1})} (1 - \frac{\tilde{c}}{\hat{z}_{it}}). \tag{28}$$

This incorporates the typical Malthusian feature that as the household's income increases, so does the desired number of children. At the same time, though, this number of children also depends on the choice that the parent is making regarding the education of his or her offspring. Providing better education to each child can only come at the cost of decreasing the total number of children[15].

Finally, the optimal solution for $\hat{e}_{it+1}$, is dictated by the first order condition,

$$G(e_{it+1}, g_{it+1}) \equiv [(\tau^q + \tau^e e_{it+1}) h_e(e_{it+1}, g_{it+1}) - \tau^e h(e_{it+1}, g_{it+1})] \leq 0,$$

with the proviso that $e_{it+1} = 0$ if $G(e_{it+1}, g_{it+1}) < 0$. This is the same first-order condition as in Galor and Weil (2000). Hence, using the Implicit Function Theorem one can verify

[15] Thus, the model incorporates a trade-off between offspring quantity and offspring quality, as it was first suggested by Becker and Lewis (1973).

the existence of a strictly positive and monotonically increasing implicit function $e(\cdot)$ such that[16]:

$$\hat{e}_{it+1} = e(\bar{g}_{it+1}) = \left\{ \begin{array}{cc} 0 & \text{if } \bar{g}_{it+1} \leq g^* \\ e'(\bar{g}_{it+1}) & \text{if } \bar{g}_{it+1} > g^* \end{array} \right\}. \tag{29}$$

where $g^* > 0$. Thus, the optimal choice of each adult agent regarding the education of his or her offspring is independent of the household's income and only influenced by the pace of technological progress.

3.8 Goods Market Clearing under Autarky

Before considering the possibility of trade in agricultural and manufacturing goods between the two economies, let us concentrate first on the autarkic equilibrium of each economy. In such an equilibrium, it must be that the demand for both types of goods coming from the households is met by the actual production in both sectors. Thus, in order for the goods markets to clear in country i, it is required that,

$$\hat{Y}_{it}^A \equiv \Delta_{it}^A A_{it}^A (h_{it} \hat{L}_{it}^A)^\alpha \hat{l}_{it} X_i^{1-\alpha} = L_{it} \hat{c}_{it}^A, \tag{30}$$

$$\hat{Y}_{it}^M \equiv \Delta_{it}^M A_{it}^M h_{it} \hat{L}_{it}^M \hat{l}_{it} = L_{it} \hat{c}_{it}^M, \tag{31}$$

with $\hat{Y}_{it}^k$ denoting the actual level of production in sector k of country i and $\hat{l}_{it}$ the optimal fraction of time devoted by households to labor force participation. Based on the budget constraint (20), this fraction equals $[1 - \hat{n}_{it}(\tau^q + \tau^e \hat{e}_{it+1})]$. Using this fact and performing a few basic algebraic manipulations, the above two expressions can be simplified to the requirement that,

$$\hat{c}_{it}^A \hat{L}_{it}^M = \hat{p}_{it}^M \hat{c}_{it}^M \hat{L}_{it}^A. \tag{32}$$

This mandates that the total value of the manufacturing goods consumed by agricultural households be equal to the value of agricultural goods consumed by manufacturing house-

[16] Note that the absence of any discrepancies in the education decision across households verifies the existence of a common economy-wide level of per capita human capital h_t.

holds. Substituting in the demands for both goods and bearing in mind the fact that, $\hat{z}_{it} = p_{it}^M \Delta_{it}^M A_{it}^M h_{it}$, we obtain the goods market clearing condition:

$$[\frac{1-\gamma}{1+(\frac{\chi}{1-\chi}p_{it}^M)^{\frac{\eta}{\eta-1}}} p_{it}^M \Delta_{it}^M A_{it}^M h_{it} + \frac{\gamma}{1+(\frac{\chi}{1-\chi}p_{it}^M)^{\frac{\eta}{\eta-1}}}\tilde{c} + \frac{1}{(\frac{\chi}{1-\chi}p_{it}^M)^{-\frac{\eta}{\eta-1}}+1}\tilde{c}]L_{it} =$$

$$= [(1-\gamma)p_{it}^M \Delta_{it}^M A_{it}^M h_{it} + \gamma\tilde{c}]L_t^A.$$

Combining this last expression with the labor marker clearing equation (21) we obtain a non-linear system of two equations, which can be solved for the relative price $\hat{p}_{it}^M$ that clears the market as well as the corresponding amount of labor $\hat{L}_{it}^A$ devoted to agriculture:

$$\begin{aligned} \hat{p}_{it}^M &= p^M(h_{it}, A_{it}^A, A_{it}^M, \Delta_{it}^A, \Delta_{it}^M, L_{it}), \\ \hat{L}_{it}^A &= L^A(h_{it}, A_{it}^A, A_{it}^M, \Delta_{it}^A, \Delta_{it}^M, L_{it}). \end{aligned} \tag{33}$$

The above solution, though, may not necessarily be interior. Particularly, given the size of the economy's labor force, the state of technology, and the level of human capital, the economy might not be able to support a manufacturing sector. This occurs whenever the size of the total labor force is such that it falls short of the level demanded at any market clearing price, i.e. if $\hat{L}_{it}^A = (\frac{\Delta_{it}^A A_{it}^A}{\hat{p}_{it}^M \Delta_{it}^M A_{it}^M})^{\frac{1}{1-\alpha}} \frac{X_i}{h_{it}} > L_{it}$. In this case, the economy ends up in a corner solution where all of the economy's labor force is employed in agriculture and no production or consumption of the manufacturing good is taking place. Hence, the allocation of labor in economy i can be described by the following pair of expressions:

$$\hat{L}_{it}^A = \left\{ \begin{array}{cc} L_{it} & L^A(h_{it}, A_{it}^A, A_{it}^M, \Delta_{it}^A, \Delta_{it}^M, L_{it}) > L_{it} \\ L^A(h_{it}, A_{it}^A, A_{it}^M, \Delta_{it}^A, \Delta_{it}^M, L_{it}) & otherwise \end{array} \right\}, \tag{34}$$

$$\hat{L}_{it}^M = \left\{ \begin{array}{cc} 0 & L^A(h_{it}, A_{it}^A, A_{it}^M, \Delta_{it}^A, \Delta_{it}^M, L_{it}) > L_{it} \\ L_{it} - L^A(h_{it}, A_{it}^A, A_{it}^M, \Delta_{it}^A, \Delta_{it}^M, L_{it}) & otherwise \end{array} \right\}. \tag{35}$$

3.9 Goods Market Clearing with International Trade

Let us now turn to the case where there is also trade in final goods between the two economies. In this case, market clearing in the global markets for the agricultural and the manufacturing goods mandates that demand for each type of good coming from the households in both countries is met by the quantity of both goods produced in the two countries. This can be written as:

$$\hat{Y}_{1t}^{A} + \hat{Y}_{2t}^{A} = L_{1t}\hat{c}_{1t}^{A} + L_{2t}\hat{c}_{2t}^{A}, \tag{36}$$

$$\hat{Y}_{1t}^{M} + \hat{Y}_{2t}^{M} = L_{1t}\hat{c}_{1t}^{M} + L_{2t}\hat{c}_{2t}^{M}. \tag{37}$$

However, in the presence of non-negligible trade costs, the price at which the two goods are sold in each country cannot be the same.

To account for the costs associated with international trade, a trade cost function d is introduced. This is assumed to be of the standard iceberg type (Samuelson (1954)), meaning that the cost is paid with some fraction of the transported good and not any other resource. Moreover, given the historical context of this paper, these costs are treated as reflecting primarily the actual transportation expenses related to the movements of goods from one country to the other. With that in mind, the magnitude of these costs is assumed to be declining over time as new technologies are revolutionizing the available means of transportation. This is captured in the following functional form:

$$d_t = d(\bar{A}_t^M), \tag{38}$$

where trade costs are treated as a function of the frontier level of the manufacturing technology $\bar{A}_t^M \equiv \max\{A_{1t}^M, A_{2t}^M\}$[17]. Moreover, this cost is supposed to decline at an increasing rate as the frontier expands, which in the limit should bring the world closer to frictionless

[17] Here it should be pointed out that this assumption is actually not restrictive at all. Alternative formulations of transportation costs which treat them as a function of worldwide technology frontier or which introduce asymmetries between countries or between goods are not going to affect the paper's main results.

trade. This means that for the functional form in hand the underlying assumptions are that: $d(\cdot) > 1$, $d'(\cdot) < 0$, $d''(\cdot) > 0$, $\lim_{\bar{A}^M \to \infty} d(\cdot) = 1$.

The presence of positive trade costs, of course, not only leads to discrepancies in the prices at which the goods are being sold in the two economies, but also imposes, depending on their magnitude, limits to the possibilities for trade between the two countries. To see this, note that trade in manufacturing goods from country 1 to country 2, for example, will only take place if $p_{2t}^M > p_{1t}^M d_t$, while trade from country 2 to country 1 if $p_{1t}^M > p_{2t}^M d_t$. From the above inequalities we can compute the bounds between which the relative price ratio can vacillate without triggering any trade flows:

$$\frac{1}{d(\bar{A}_t^M)} \leq \frac{p_{2t}^M}{p_{1t}^M} \leq d(\bar{A}_t^M). \tag{39}$$

These bounds -often referred to as the Heckscher commodity points- depend naturally on the current state of the manufacturing technology with their range shrinking as technology improves.

If the relative price ratio exceeds those bounds, this triggers trade flows between the two countries until the relative price of manufactures in the importing country j returns to the value $p_{it}^M d_t$, with p_{it}^M being the price in the exporting country. Hence, trade results in a reallocation of factors of production in the two economies, so that the share of the labor force employed in agriculture in the exporting country i and the importing country j in equilibrium equal to,

$$\hat{L}_{j\backslash it}^A = \left(\frac{\Delta_{it}^A A_{it}^A}{p_{Wt}^M \Delta_{it}^M A_{it}^M}\right)^{\frac{1}{1-\alpha}} \frac{X_i}{h_{it}}, \tag{40}$$

$$\hat{L}_{jt}^A = \left(\frac{\Delta_{jt}^A A_{jt}^A}{p_{Wt}^M d_t \Delta_{jt}^M A_{jt}^M}\right)^{\frac{1}{1-\alpha}} \frac{X_j}{h_{jt}}. \tag{41}$$

Combining the last two expressions with the goods market clearing conditions (36) and (37) we can identify the solution for the world market clearing relative price $\hat{p}_{Wt}^M$.

3.10 The Transferring of Technology

In addition to the flows of final goods traded between the two countries, the economic integration of the two economies also generates another force that should matter for our analysis of the long-run economic development. This is the opportunity for transfers of advanced technologies from the technologically-leading economy to the technologically-lagging one. This force has been modeled in the literature in several different ways[18]. However, for our purposes it is assumed that technology transfers between the two economies take the form of reverse engineering.

This means that the transferring of existing technologies is governed by the same principles as the actual innovation process. Thus, the implementation in country j of an innovation ζ^* produced in country i requires the implementing agent to devote a fraction of time ω_{jt}^{IM} such that:

$$\omega_{jt}^{IM} = \frac{\zeta^*}{B^{IM}(\tilde{e} + e_{jt})^{\beta}}. \tag{42}$$

Regarding the economy-wide exogenous productivity parameter B^{IM} the underlying assumption is that $B^{IM} > B^{IN}$. This captures the fact that, ceteris paribus, the productivity of this implementation activity per unit of time must be higher than that of the actual innovation process. Otherwise innovation would always be the most efficient strategy. Nevertheless, the actual time input necessary for the implementation of innovation ζ^* should also reflect the potential discrepancies in the corresponding levels of education between the two countries. Thus, if $\zeta^*$was produced one generation ago in country i as the result of time input ω^*, then we should have that:

$$\frac{\omega_{jt}^{IM}}{\omega^*} = \frac{B^{IN}}{B^{IM}} \cdot \left(\frac{\tilde{e} + e_{it-1}}{\tilde{e} + e_{jt}}\right)^{\beta}. \tag{43}$$

Therefore, as the above expression demonstrates, the presence of substantial differences in the levels of education between the two countries reduces the Gerschekronian "advantage of backwardness." Since agents in each sector in the technologically-lagging country have also the option of innovating new technologies rather than implementing existing ones, the

[18] See for example Keller (2004) or Aghion and Howitt (2005).

transferring of technologies invented in sector k of country i is going to take place if and only if:

$$(1-\omega_{jt}^{IM})(1+\lambda^k\zeta^*) > (1-\hat{\omega}_{jt}^k)(1+\lambda^k\hat{\zeta}_{jt}^k). \tag{44}$$

These constitute important observations regarding the implications of technology transfer to which we will return in the following section.

4 The Development Paths of the Two Economies

4.1 The Scope of our Quantitative Exercise

Having described all the dimensions of our theoretical unified growth model, we can now proceed to utilize its power in order to generate valuable insights regarding the relationship between openness and long-run economic development. To do so, let us turn to a calibrated version of the model in order to generate predictions regarding the dynamic equilibrium paths of the two economies. The discussion is going to cover the implied dynamics both under autarky as well as of various forms of economic interaction. Based on these predictions, I will try to assess how the different aspects of openness under consideration, namely trade in final goods and technology transfer, may influence the process of development in each economy. Of course, the implications of the model in hand extend beyond the scope of this particular exercise. Nevertheless, in this paper the focus of the analysis will be limited to the issue of openness and the reader is referred to Milionis and Klasing (2011) for a discussion of other closed-economy-related issues.

4.2 The Calibration Strategy

The approach followed in the calibration of the theoretical model is very much in line with the recent body of literature that has aimed at providing quantitative growth models that can account for the long-transition from the stagnation of preindustrial times to the recent phenomenon of sustained economic growth. Such efforts include Hansen and Prescott (2002),

Lagerlof (2006) and Voigtlaender and Voth (2006). The calibration strategy begins with the determinations of the long-run equilibrium values for the model's main endogenous variables of the model, which correspond to the economy's steady state in the modern growth regime. This is because the Malthusian quasi-steady state will endogenously vanish (Galor and Weil (1999)) over the course of economic development.

With that in mind, let us consider a long-run equilibrium value for the optimal number of children $\bar{n}$ of 1, so that the population over time converges to a constant level. For the long-run value of education $\bar{e}$, let us take it to equal 0.075, which is the approximate share of education expenditure in the national accounts among the leading OECD countries[19]. Also, regarding the steady state rate of technological progress, this can be set to a value of 2.5% per annum, so that it is consistent with modern growth accounting data.

Turning to the model parameters, let us begin by seeking values for the time costs of children, τ^q and τ^e, that do not make child-rearing too "expensive" during the early stages of development. With the above considerations in mind, the time cost of education τ^e is normalized to 1 as in Galor (2005), while the fixed time cost τ^q is set equal to 0.15, based on the rationale of Lagerlof (2006). Given these choices, the value of the exponent of children in the utility function, γ, has to be fixed at 0.225, so that it is consistent with our steady state choices of $\bar{n} = 1$ and $\bar{e} = 0.075$. As for the remaining parameters of the utility function η and χ,I make choices based on the historical evidence presented by Clark (2005, 2007) regarding the consumption patterns of the working class in England over the long period from 1209 to 1914. Based on his evidence, a value of 0.8 for the parameter η and a value of 0.75 for χ seem reasonable.

For the exponent α of efficiency units of labor in the production function, a choice of 0.4 seems to be in line with the consensus view, as pointed out in Hansen and Prescott (2002). For β, the exponent of human capital in the innovation function, I pick a value of 0.2 which lies at the lower bound of the estimates that Barro (2001) and Barro and Lee

[19] Of course, this figure might miss some of the actual educational attainment taking place within the economy. However, given that in this model education is only an input to the process of the human capital formation, I believe that this constitute an reasonable choice.

(2001) provide for the importance of human capital for economic growth. Regarding ε, the parameter that captures the degree of complementarity or substitutability of the different individual innovations, one can think a value of 2 as a reasonable choice. This is because it balances out between two important considerations, the need for a declining role of the scale effect over the course of human economic development on the one hand, and a limited reliance on the assumption of substitutability of the individual innovations produced by different agents. Moreover, for the spillover rate σ, I resort to a contemporary value of 0.3 from Bottazzi and Peri (2003), estimated from European patent data.

In parametrizing the abstract human capital function $h(e_{it}, g_{it})$, hypothesized by Galor and Weil (2000), I follow Lagerlof (2006), who suggests the choice of,

$$h(e_{it}, g_{it}) = \frac{e_{it} + \rho\tau^q}{e_{it} + \rho\tau^q + g_{it}}.$$

Regarding the parameter ρ, I calibrate it in the same way as Lagerlof, based on the choice of the steady state values for education $\bar{e}$ and the growth rate $\bar{g}$. For the parametrization of the trade cost function $d(\bar{A}_t^M)$, there is hardly any pre-existing work in the literature on which one could rely. Given this, I proposes the following specification,

$$d(\bar{A}_t^M) = \tilde{d}^{(\bar{A}_t^M)^{-\delta}},$$

where for the two parameters, $\tilde{d}$ and δ, the values 10 and 0.01 are chosen so that evolution of d_t seems in line with the evidence presented by Harley (1988).

For the remaining model parameters there is less concrete evidence on which we can rely on. Given that, the selection is made as follows. The quantity of land in both countries X_i is normalized to 1, as in Hansen and Prescott (2002), and the same is done for the level of subsistence consumption $\tilde{c}$, as in Lagerlof (2006). Regarding the degree of property rights' protection λ^k I follow the motivation presented in Section 1 and postulate that it differs between the two sectors of each economy. Thus, for the manufacturing sector I choose the

value of 0.66, which seems in line with the contemporary evidence presented by Rajan and Zingales (2003)[20],while for the agricultural sector I take it to be slightly lower, namely 0.6, in light of the evidence presented by Khan (1995).

With respect to $\tilde{e}$, I consider a baseline estimate of 0.0375. This is exactly half the steady state level of education, a choice that clearly underplays the role of further human capital accumulation in influencing the course of economic development. Nevertheless, as it is discussed later on, I start with this high baseline value for this parameter to make sure that the ability of the technologically-lagging economy to implement advanced technologies from abroad is not inhibited. In any case though, in what follows I also perform a careful sensitive analysis with respect to this particular parameter.

The last parameter of the model that needs to be calibrated is the economy-wide experimentation productivity parameter B. Its value is set to 2 for the case of innovation as in Milionis and Klasing (2011), so that together with the remaining parameters the model is able to match the stylized facts of total factor productivity growth summarized in Galor (2005). For the implementing country, though, this value is taken to be 2.5, a choice which seems in line with the evidence presented by Mansfield, Schwartz, and Wagner (1991).

Finally, before proceeding to present the simulations results, I also need to set the initial conditions for the two economies. In this I follow the strategy of Lagerlof (2006) and Voigtlaender and Voth (2006) and let the economy begin at a "quasi steady state," i.e. in an equilibrium in which it would remain if there was no technological progress. This, given the nature of our model, should be a stagnant Malthusian equilibrium with low levels of per capita income. In such an environment, parents would rationally choose not to invest in the education of their children, as it is evident from (29). In the absence of any educational investment, the initial level of human capital should reflect a basic skill level, and hence it is normalized to 1. The initial number of children n_{i0} is also taken to be equal to 1, so that there is no population growth in the first period. Given the previous choices, z_{i0} is chosen

[20]The chosen value implies that the benefits from an innovation to the innovator are approximately twice the benefits to non-innovators.

based on (28).

As p_{i0}, L_{i0}^A and L_{i0}^M are equilibrium values pinned down by (33) and (23), we simply need to choose the initial values for L_{i0}, A_{i0}^A and A_{i0}^M $-\Delta_{i0}^A$ and Δ_{i0}^M are very much predetermined from the choice of e_{i0}. Regarding the total factor productivity parameters, a natural assumption is to force them to be equal at the initial period, $A_{i0}^A = A_{i0}^M = A_{i0}$, in both countries and have them determined by the labor market clearing condition, $p_0 \Delta_0^M A_0 = \Delta_0^A A_0 (\frac{X}{h_0 L_0^A})^{1-\alpha}$, once the initial level of population, L_{i0}, has been set. Finally, in order to allow for trade between the two country to take place, I let the initial population in Country 1 to be twice the size of Country 2 and set the latter to 0.01 so that per capita consumption in the first period is exactly at subsistence level.

[$w_0 = z_0 h_0 = 3$

$w_0 = p_0 \Delta_0^M A_0 = \Delta_0^A A_0 (\frac{X}{h_0 L_0^A})^{1-\alpha}$

The former expression is particularly important as it governs the evolution of population in the economy given that $L_{t+1} = \hat{n}_t L_t$.]

4.3 Development under Autarky

Having described the details of the calibration strategy, let us now turn to the presentation of the simulation results for the development paths of the two economies. As mentioned in the previous subsection, in the initial time period the two countries are assumed to be identical in all dimensions with a sole exception. Country 1 starts off with a larger population compared to Country 2. This makes, in the absence of any differences in land areas, Country 1 the relatively labor-abundant one with a comparative advantage in the production of the manufacturing good and Country 2 the relatively land-abundant with a comparative advantage in the production of the agricultural good. Hence, the natural pattern of trade between the two countries would have Country 1 specializing in the production of manufacturing goods and exporting them to Country 2 in return for agricultural ones.

However, before considering how trade is going to take place between the two economies

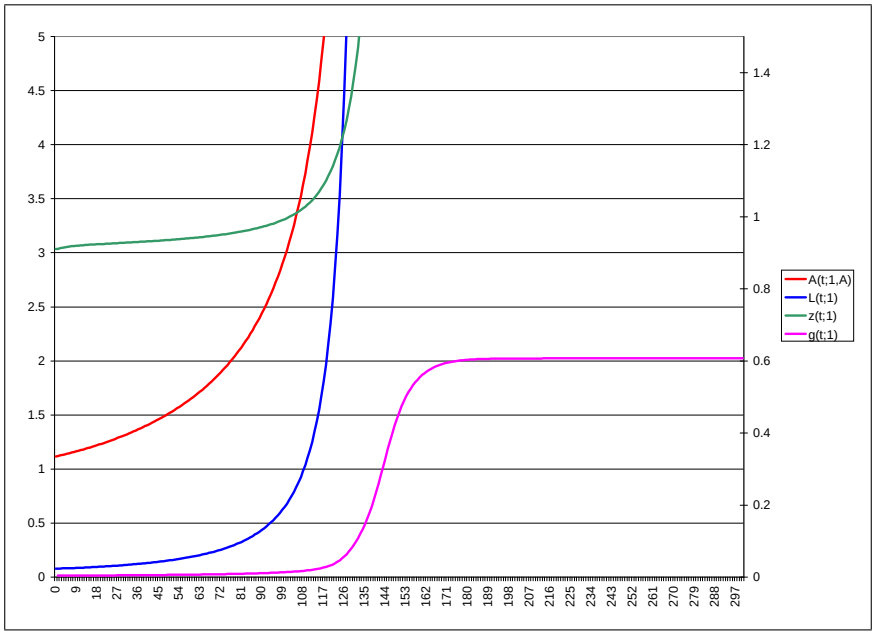

Figure 5: The Autarkic Path of Country 1 (A)

and proceeding to analyze its dynamic effects, let us begin by discussing first the development paths of the two economies under autarky. Understanding this particular equilibrium is important since it may emerge even in an interdependent world in the presence of prohibitively high trade costs, which render any trade flows unprofitable. At the same time, the autarkic equilibrium, also constitutes a useful benchmark for the comparison of all subsequent results.

Under autarky, the time-paths implied by the model for the two economies share many of the features of those described in the closed-economy setup of Milionis and Klasing (2011). Each economy starts off in a Malthusian equilibrium with income per capita close to subsistence levels. Over time, though, there is technological progress driven by individual innovations. Yet, the resulting productivity gains will primarily be reflected in increases in the size of each economy's population with income per capita continuing to stagnate.

The increase in population, however, generates a scale effect as in each subsequent period there are going to be more innovators whose experimentation activities will lead to larger gains in productivity. This spurt in productivity growth is also enhanced by the gradual shift of economic activity from agriculture to manufacturing, that takes place as land-labor

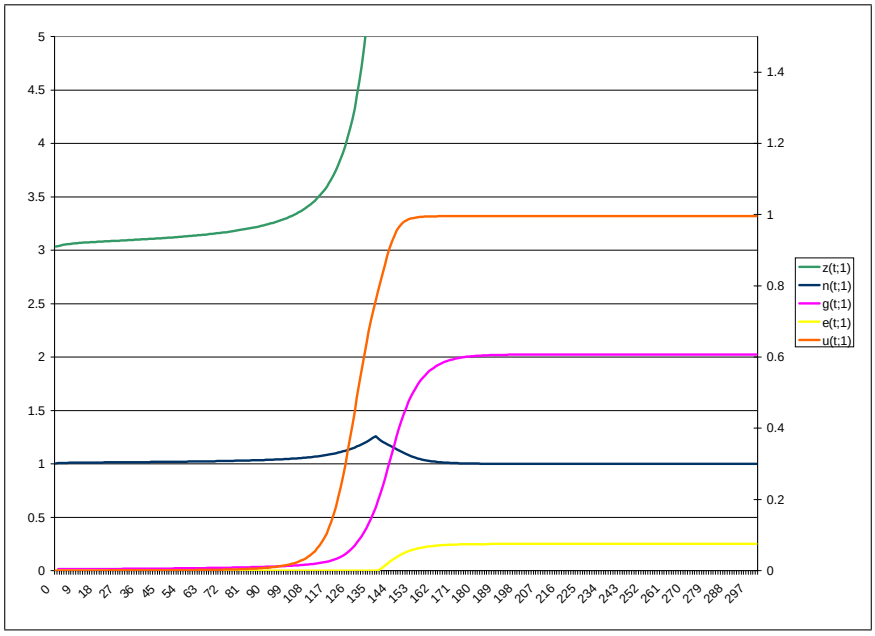

Figure 6: The Autarkic Path of Country 1 (B)

ratios fall[21]. More importantly, this ever-increasing pace of technological progress eventually triggers investments in education by parents who then choose to endow their offspring with a larger amount of human capital enabling them to prosper in a rapidly-changing economic environment. Yet, the shift of households towards children of higher "quality" comes at the expense of "quantity," namely the actual number of children that they decide to have. This change in the parents' behavior, thus, generates a demographic transition, which allows the economy to restrain population growth and channel most of the gains from technological progress towards sustained increases in per capita income.

These features can be seen in Figures 5, 6, 7 and 8 that present the evolution of several of the key endogenous variables for Country 1 and Country 2 under autarky. The figures include the economies' population L_{it}, productivity in agriculture A_{it}^{A}, income per capita z_{it}, the relative size of the manufacturing sector u_{it}, the level of education e_{it}, the fertility rate n_{it}, and the growth rate of technology $\bar{g}_{it}$[22]. By comparing the two time paths it becomes

[21] Thus, this model shares the feature of Hansen and Prescott (2002) that the decreasing return to agriculture over the course economic development eventually trigger a structural transformation of the economy towards manufacturing. Nevertheless, it needs to be pointed out that this feature by itself is not sufficient to generate sustained economic growth.

[22] Note that the horizontal axis corresponds not to time periods but to generations, where each generation

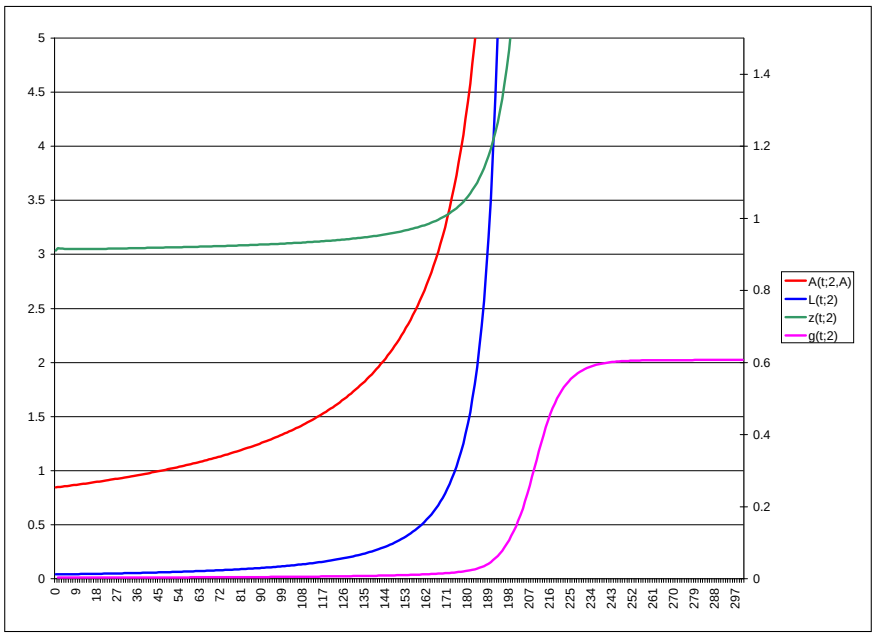

Figure 7: The Autarkic Path of Country 2 (A)

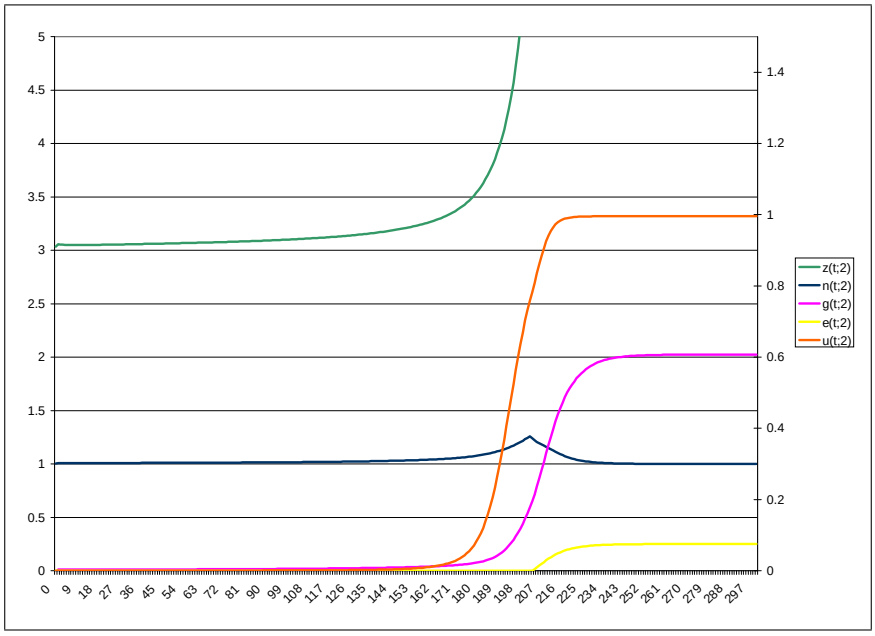

Figure 8: The Autarkic Path of Country 2 (B)

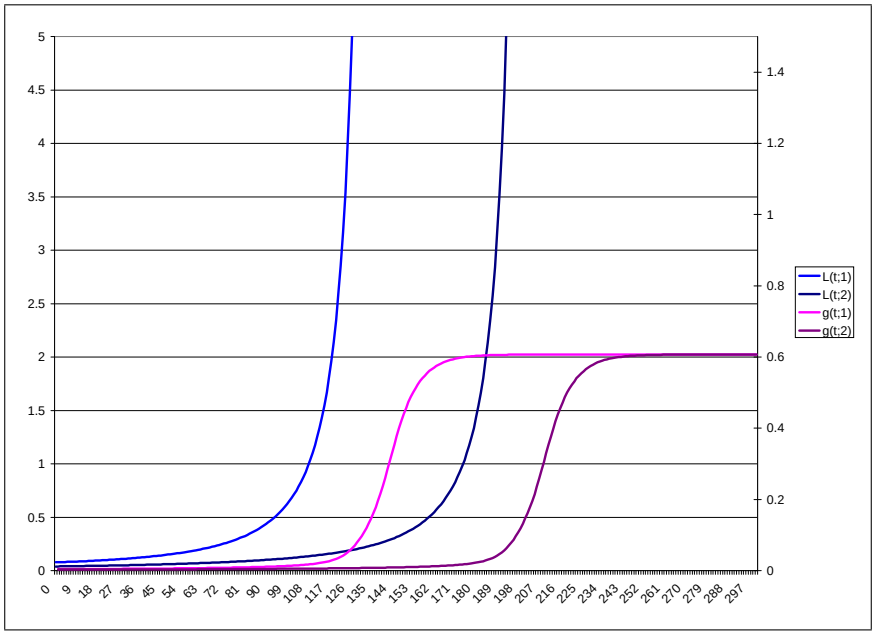

Figure 9: Comparing the Autarkic Paths of Countries 1 and 2

apparent that, despite their qualitative similarities, they imply a differential timing of the structural transformation, the demographic transition and the "take-off" of per capita income for the two economies. This is because Country 1, that starts off with a higher population, will benefit from a larger scale of economic activity, and thus, experience faster growth at any given point in time. Therefore, we should keep in mind that, although in the long-run the two economies are going to converge to the same steady state, their distinct initial conditions mean that they will experience different development paths. This fact is better demonstrated in Figure 9 where the time paths of population and the growth rate of technology for the two countries are superimposed.

4.4 The Effect of International Trade

Having presented how development takes place in each economy under autarky, let us now turn to the case where the two economies also trade with each other. As explained earlier, given the differential factor endowments, it is expected that Country 1, which is in relative

should roughly be thought as corresponding to 20 years.

terms more labor-abundant, will specialize in the production of the manufacturing good and exports it to Country 2. However, in the presence of positive trade costs this pattern is only going to materialize if the resulting relative price difference is high enough to also compensate for these costs. Otherwise, no trade will take place and the countries will remain in the autarkic equilibrium.

Nevertheless, even in the absence of any trade flows between the two countries during the early stages of development, it is likely that over time such flows will be observed due primarily to two forces. First of all, the faster pace of technological progress in Country 1 and the resulting expansion of the manufacturing sector will trigger a more precipitous fall of the relative price of manufacturing good than in Country 2 increasing the relative price dispersion. At the same time, the global expansion of the technological frontier will reduce the cost of trading between the two economies making it easier for foreign producers to sell their products in each country. These two forces can be seen in Figure 10 that depicts the evolution of the relative price ratio as well as the Heckscher commodity points and demonstrates how economic development leads to the emergence of international trade. It should be noted also that once the two economies start trading, the resulting flows will prohibit any further increases in the relative price ratio beyond the current level of the trade cost.

Trade between the two countries will follow the pattern described previously with Country 1 specializing in manufacturing goods and Country 2 in agricultural goods. Over time though, the resulting specialization in production will facilitate the structural transformation process in Country 1, while in Country 2 it will cause its deceleration or even reversal. Of course, as long as both sectors of the economy can serve equally well as engines of growth, the resulting specialization pattern will not be detrimental for Country 2's economic development. However, under our working assumption that property rights are better defined and protected in the manufacturing sector, Country 2 will experience slower growth rates along the trade equilibrium in comparison to what the country would have experienced under autarky. Moreover, these slower growth rates in our framework will further delay the

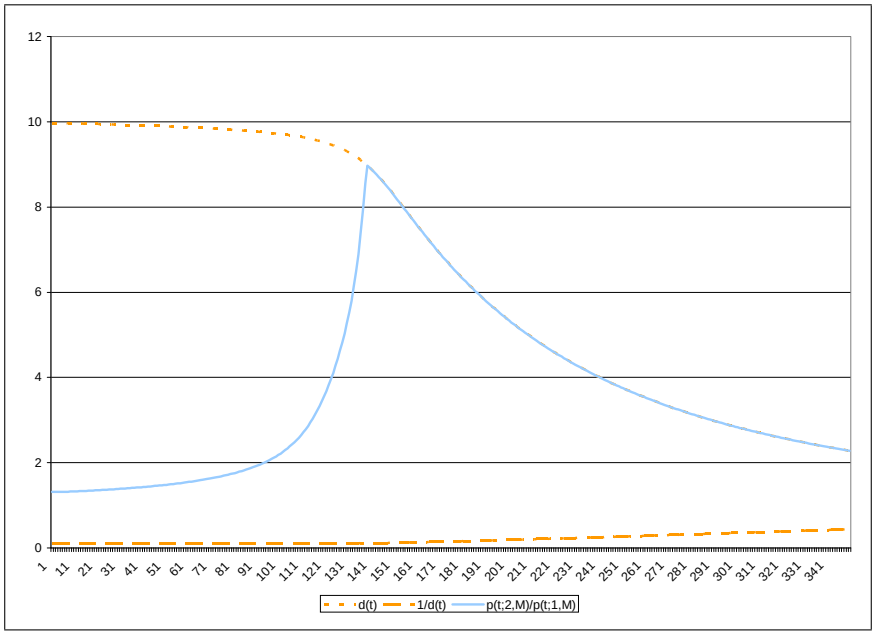

Figure 10: The Relative Price Ratio and the Heckscher Commodity Points

demographic transition in the economy and inhibit the emergence of sustained economic growth. To demonstrate this Figure 11 presents the evolution of the level of income per capita z_{2t} and the growth rate of technology $\bar{g}_{2t}$ of Country 2 under autarky as well as in the case of trade. As it becomes apparent from the figure, trade with Country 1 causes a slow-down of the transition process in Country 2 by almost 40 generations.

This finding is very much in line with the view of Galor and Mountford (2008), who also show that trade between two countries that are at different stages of economic development and the resulting specialization pattern adversely affect the process of economic development in the following country. Of course, in their case the mechanism in play is different. Specifically, Galor and Mountford emphasize the differential complementarity of human capital as an input in the agricultural and manufacturing production, which alters the incentives for investment in education in a manufacturing-based economy compared to a predominantly agricultural one. Nevertheless, this result as well as theirs are clearly both pointing in the same direction, namely that trade between developed and less developed economies may have asymmetric effects on the long-run development potential of each economy and be a source of divergence. The only substantial difference between this and their analysis is the fact that

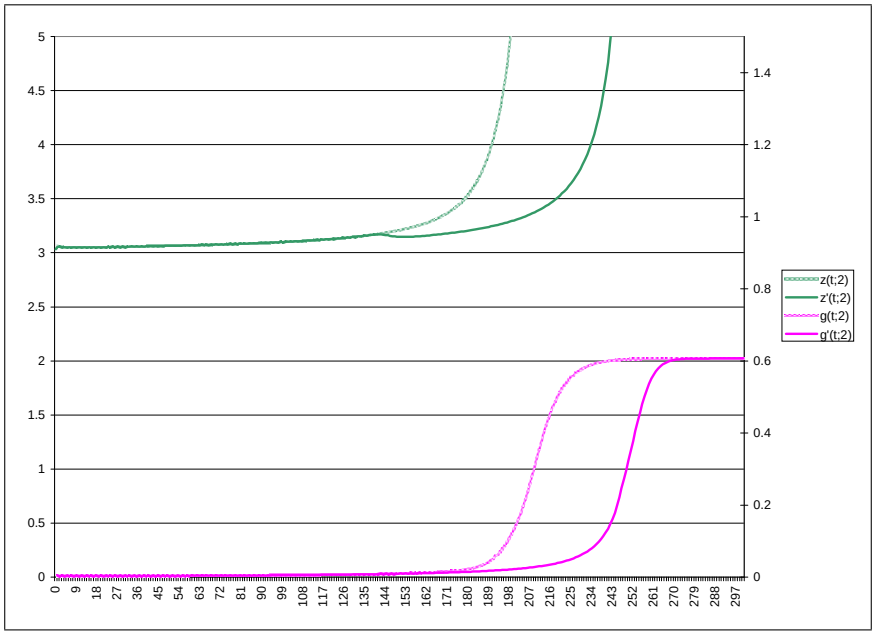

Figure 11: Development in Country 2 under Autarky and Trade

in this model the adverse effect of trade is not caused by variations in nature of technological progress. Thus it can occur even among countries that would otherwise converge to the same steady state equilibrium[23].

4.5 The Combined Effect of Trade and Technology Transfer

The analysis up until now is supportive of the view that international trade -particularly when taking place among countries which are at different stages of economic development- can lead to diverging development paths for the trading parties. This view has strong implications for the debate on appropriate trade policies for developing countries. It suggests that such countries should aim at raising barriers to any form of trade with more economically advanced countries that naturally have the comparative advantage in the more dynamic industries.

Nevertheless, in what follows I would like argue that, despite the presence of this nega-

[23] With that in mind let us note here that, although in the model trade is triggered by differences in factor endowments between the two economies, it is not a pure Heckscher-Ohlin effect. This is because, given the endogenous nature of technological progress, these differences in factor endowments will over time be reflected in distinct comparative advantages. Thus, our model encompasses also Ricardian elements when accounting for the emergence of international trade.

tive effect coming from trade and specialization, the overall effect of economic openness on development may actually be positive. Hence, it is not the case that developing countries should always refrain from liberal trade policies and seek to protect their manufacturing sectors. The reason for this is due to the fact that economic interaction with more advanced countries carries also an additional positive effect for developing countries. This is the flow of advanced technologies that takes place from the countries that are closer to the cutting-edge frontier.

Incorporating technology transfer in our simple two-country setup allows whichever country is a technological follower to implement technologies invented by the technological leader. Based on the assumptions regarding initial endowments, it must be that Country 1 here constitutes the technological leader. This is due to its larger size and the resulting scale effect that leads the country to experience faster growth, particularly in the early stages of development. Thus, if the opening up of the two economies to trade is accompanied by technology transfers from Country 1 to Country 2, then this flow would increase the pace of technological progress in Country 2, as it enables the implementation of already invented technologies from Country 1.

As it was argued in Section 3, though, there is an important condition which is necessary in order for the beneficial effect of technology transfer to materialize. This is the absence of any substantial differences in the level of education between the two countries. Otherwise, as it was shown above, the innovations produced in the leading economy, which embody the level of education of their innovators, will be too complex to be implemented in a follower economy given the workforce's own education.

This factor is reflected in the effective education gap ratio,

$$E_t \equiv \frac{\tilde{e} + e_{it-1}}{\tilde{e} + e_{jt}},$$

as expression (43) reveals. The evolution of this ratio over the course of economic development is presented in Figure 12 The expansion of the gap reflects the early demographic

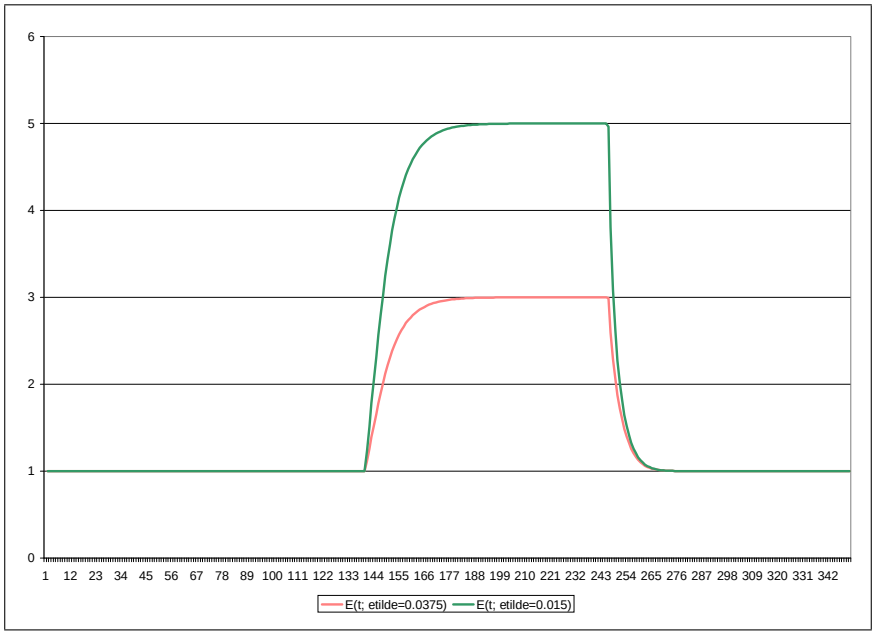

Figure 12: The Effective Education Gap

transition in Country 1, while the contraction begins once the demographic transition in Country 2 is on the way. Of course, the size of this gap depends on a wide set of factors, given that any variable that influences the rate of technological progress in each economy should indirectly affect also the education choices made by the agents. To simplify the analysis, however, in what follows I will concentrate on changes triggered by differential values of the parameter $\tilde{e}$. These are changes which increase or decrease the effective gap but which do not come from the actual education choices made in the leading and the following country. Instead of that, they reflect the importance of basic cognitive skills not transmitted via formal education.

To begin with, let us consider the baseline case where $\tilde{e} = 0.0375$. This, as we argued previously, constitutes a relatively high value, since the effective education gap will be at most twice that number. Hence, the importance of the education gap between the two economies is mitigated and the transferring of technologies from Country 1 to Country 2 is facilitated. This case corresponds to the red line in Figure 12. The results from the baseline case is then compared with an alternative scenario where $\tilde{e} = 0.015$. This scenario corresponds to the green line in Figure 12 where the effective education gap between Country 1 and Country

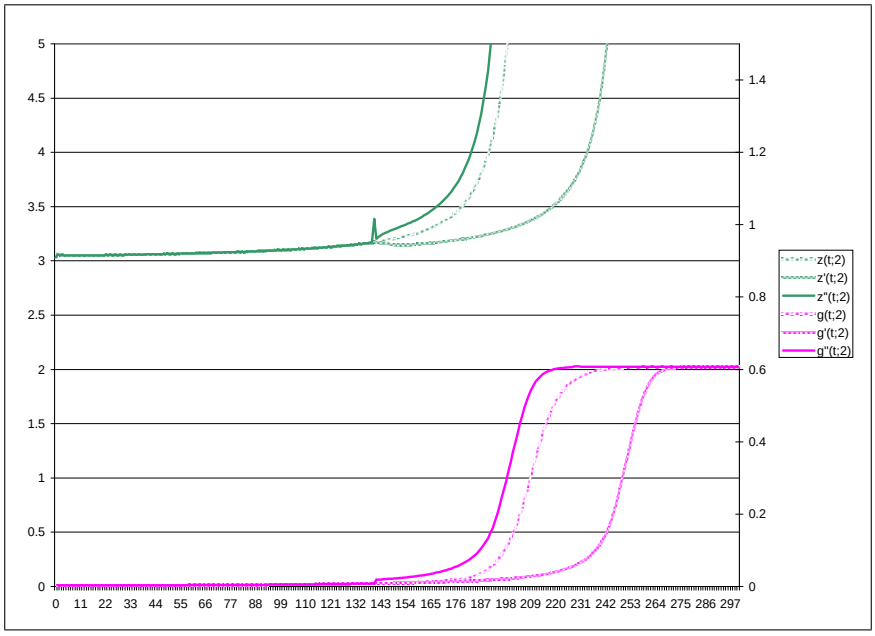

Figure 13: Development in Country 2 under Autarky, Trade and Technology Transfer (Case I)

2 may grow to five-fold ratios. As a consequence the transferring of advanced technologies from Country 1 becomes more costly and this limits the positive influence of technology transfer on Country 2's economic development.

To assess now the combined effect of trade and technology transfer, Figures 13 and 14 present the evolution of the level of income per capita z_{it} and the growth rate of technology $\bar{g}_{it}$ in Country 2 in the world where the opening up of trade between the two countries is accompanied with opportunities for the transferring of advanced technologies. These time paths are then contrasted with the case of autarky and the case of trade without technology transfer which are reflected in the two dimmer lines. Figure 13 corresponds to the case where $\tilde{e} = 0.0375$ leading to a smaller effective education gap. As a result, the incorporation of technology transfer generates a strong positive effect on the rate of technological progress in Country 2. This overcomes the detrimental effect of trade making the combined effect of the two forces positive, and thus, allows for a faster development process in Country 2 compared to autarky. On the other hand, Figure 13 corresponds to the case where $\tilde{e} = 0.015$ leading to a large effective education gap. This limits the possibilities for technology transfer

	Open-Economy Solution						Autarky
$\tilde{\mathbf{e}}$	*0.0375*	*0.025*	*0.01875*	*0.015*	*0.0125*	*0.01*	*0.0375*
$\mathbf{t}^*$	*195*	*201*	*220*	*234*	*245*	*245*	*205*

Notes:

t^* corresponds to the first generation of adult agents deciding to invest in the education of of their children.

Table 1: The Combined Effect of Trade and Technology Transfer

causing the negative effect of trade to dominate. Therefore, in this case Country 2 ends up experiencing a slower development process when opening up than under autarky.

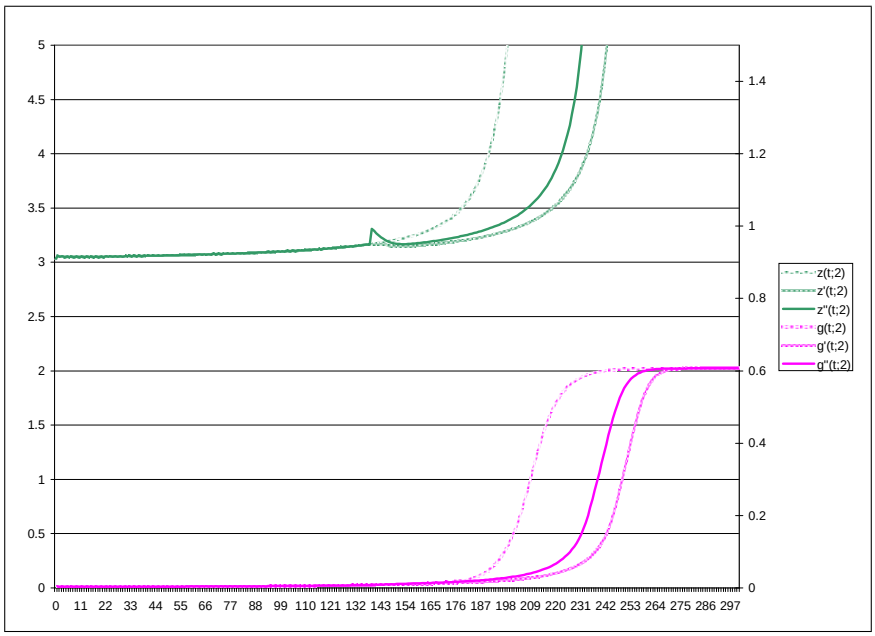

Figure 14: Development in Country 2 under Autarky, Trade and Technology Transfer (Case II)

To make this point clearer, the following table presents the combined effect that trade and technology transfer have on the development process of Country 2 for different values of the $\tilde{e}$ parameter. To capture this effect we focus on how changes in $\tilde{e}$ are reflected in the timing of the demographic transition, namely the number of generations, denoted by t^*, that have to elapse before the growth rate of technology in Country 2 reaches the crucial threshold g^*, above which parents start investing in the education of their children.

This last exercise demonstrates more formally two important facts. First of all, it confirms

the intuition mentioned earlier that as the effective education gap between the two countries widens, this limits the possibilities for technology transfer from the leading to the following one and thus reduces its beneficial effect. The reason is that advanced technologies embody the education level of their innovator. As more educated individuals are able to produce more complex innovations, an expansion of the education gap imposes further limits to who is able to implement these new innovations of increasing complexity. Furthermore, a rising education gap between the two economies will not only make the transferring of technology a more difficult process, it may also render it unprofitable. This is due to the threshold (44) below which agents in the following country would prefer to create new technologies themselves, rather than implementing existing one from abroad. Thus, between countries that differ vastly in their level of human capital, there may be no possibilities for technology transfers, in which case economic interaction is only going to carry the detrimental effect of trade.

5 Empirical Evidence

Having discussed the model and its main predictions, in this section I will make an attempt to confront the predictions with empirical evidence based on growth regressions. I will begin with a set of standard cross-country growth regressions focusing on the period between 1950 and 2008, that include an interaction term between the log of initial income and the initial level of human capital as well as the extent to which countries are engaged in international trade. I will then present a set of panel regressions for the same time-period that will allow for the inclusion of both country and time fixed effects. Furthermore, given the paper's focus on long-run economic development, I will also look for supporting evidence over a longer time-horizon extending the panel regression setup to include also the period 1870 to 1949. This longer time-period has the advantage of spanning three different eras. These are the first globalization era (1870-1913) characterized by the expansion of world trade (O'Rourke and Williamson (2005)), the interwar period (1919-1939) that was marked by a

global retreat to economic protectionism and the post-World-War-II era that has been the focus of the bulk of the empirical growth literature following the early contributions of Barro 1991 and Mankiw, Romer, and Weil (1992).

5.1 Data Sources

My main source for data on population and GDP per capita across countries is Maddison (2001). I use the Maddison dataset as it is the only one that provides information on both variables for a substantial number of countries going back to 1870[24]. As an alternative source, I also use the information on both population and GDP per capita from Penn World Tables version 7. However, the data of Penn World Tables only cover the period from 1950 to 2009 and are available for a smaller number of countries. For this reason and given that these sample restrictions do not affect the main empirical results presented below, in what follows I will only be reporting results based on the Maddison dataset.

In addition, I use Penn World Tables to obtain a measure of trade openness, which corresponds to the sum of imports and exports over total GDP. To measure openness prior to 1950, I construct a similar measure based on the historical import and export data provided by the Correlates of War project combined with the GDP estimates from Maddison[25].

To measure human capital during the period 1950-2008, I use the average years of schooling in the population above 25 years of age reported by Barro and Lee (2010). To measure human capital in periods prior to 1950 I resort to the historical dataset of Benavot and Riddle (1988). They provide information on primary school enrollments rates for several years during the period 1870 to 1940. In order to analyze the importance of human capital for convergence for the entire period 1870 to 2008, I need to resort to a measure of primary

[24] Maddison continued to update this dataset until the time of his death in 2010. As a result of all this meticulous effort, the population series in the latest version was extended to 2009 and the per capita GDP series until 2008.

[25] The construction of this historical openness indicator requires the conversion of the PPP-adjusted constant-price per capita GDP series of Maddison to its corresponding current price series to match the current price data on imports and exports. To do this conversion I rely on a technique proposed by Prados 2000, which allows for the estimation of historical PPP factors from a regression of real GDP on nominal GDP. Details on how this conversion was performed can found in Appendix II.

school enrollment rates also for the period 1950 and 2008. For this latter period, the primary school enrollment rate is proxied by the fraction of people between the age of 15 and 19 having at least some schooling and reported in Barro and Lee 2010[26].

Finally, in all empirical specifications, I control for a number of additional variables that have been identified in the empirical growth literature as being significantly correlated with the rate of economic growth. These include investment rates and government consumptions measures obtained from Penn World Tables, population growth rates calculated from Maddison, the constraints placed on the executive index available from the Polity IV Project data set - a widely used measure of institutional quality - and geographical variables such as the absolute degrees of latitude of each country.

5.2 Cross-Sectional Estimates (1950-2008)

As a starting point, I estimate a standard growth regression for a cross-section of countries over the period from 1950 to 2008. Specifically, given the predictions of the theory regarding how human capital differences can permit convergence or trigger divergence among developed and less developed economies, I estimate the following specification, which similar to that employed by Aghion, Howitt, and Mayer-Foulkes (2005):

$$g_i - g_{US} = \beta_0 + \beta_1 \frac{\ln y_i^{50}}{\ln y_{US}^{50}} + \beta_2 h_i^{50} + \beta_3 h_i \frac{\ln y_i^{50}}{\ln y_{US}^{50}} + \beta_4 OPEN_i \cdot h_i \cdot \frac{\ln y_i^{50}}{\ln y_{US}^{50}} + \gamma X_i + \varepsilon_i. \quad (45)$$

g_i denotes average growth rate of per capita GDP in country i over the period, y_i^{50} denotes the level of per capita GDP in the year 1950. g_{US} and y_{US}^{50} are the corresponding variables for the United States, which we take to be the technology leader. h_i^{50} is human capital in 1950, measured as the average years of schooling reported by Barro and Lee (2010) and $OPEN_i$ is

[26] This proxy is employed due to the lack of alternative data. It can be considered an upper bound of the true primary school enrollment rate, as some of the people in the age group 15 to 19 years of age might have just recently aquired some education, but might have not been enrolled in primary school as children. However, the bias resulting from this is negligible, as in fact this so proxied primary enrollement rate in 1960 is correlated with the true primary school enrollement rate in 1960, provided by Barro (2001), at a level of 88%.

a dummy variable taking a value of 1 if a country's average level of trade openness is above the sample mean and 0 otherwise. Finally, X_i denotes a set of control variables that will be discussed below.

Table 1: Cross-Sectional Regressions, 1950-2008

Dep Var.: g_i - g_{US}	(1)	(2)	(3)	(4)
$\ln(y_i)$- $\ln(y_{US})$	-0.179	-0.156	-0.195	-0.153
	[0.178]	[0.175]	[0.166]	[0.170]
avg. years of schooling, age 25+	0.166*	0.173**	0.0268	0.0178
	[0.0847]	[0.0823]	[0.0878]	[0.0973]
dlny * school	-0.128**	-0.108**	-0.122**	-0.142***
	[0.0533]	[0.531]	[0.0504]	[0.0528]
dlny * school * high trade		-0.133**	-0.164***	-0.102*
		[0.0594]	[0.0567]	[0.0586]
absolute latitude			0.0312***	
			[0.00831]	
executive constraints				0.226***
				[0.0791]
Observations	114	114	114	114
Adj. R-squared	0.2419	0.2686	0.3469	0.3136

The results from the estimation of the above specification are reported in Table 1. As can be seen in the second column of the table all four coefficients $\beta_1, \beta_2, \beta_3$ and β_4 have the expected signs, and, with exception of β_1, are statistically significant at the 5% level. Specifically, we observe that human capital has a positive effect on the country's growth rate relative to the United States. Also this growth rate is negatively related to the gap in terms of initial level of income with the United States, which indicates that countries are converging in per capital GDP with the United States. Moreover, the negative estimates β_3 and β_4 indicate that convergence is faster for countries with a higher level of initial human capital and that this convergence force is amplified if a country is relatively more open to trade. This finding indicates that in the post-World-War-II period convergence was fastest for open economies that started off with a relatively high level of human capital.

Using the estimated coefficients of column 2 it is also possible to calculate the rate of

convergence. Specifically, the results documented in column 2 imply that a country with a level of initial human capital equal to the mean, which is close to the human capital levels of Spain, Paraguay or Namibia in our sample, were converging at an annual rate of 0.4% if they were relatively less open to trade -which is the case the Paraguay and Spain- and at a rate of 0.8% if they were relatively more open to trade -which is the case for Namibia. These estimates are close to cross-sectional convergence rates documented by Islam 1995 that lie between 0.5% and 1% depending on the set-up. Moreover, the coefficients imply that a country that is relatively more open to trade and whose level of human capital is equal to the 75th percentile of the human capital distribution in this sample will experience a convergence rate of 1% which is twice the speed at which an open economy with human capital equal to the median of the human capital distribution would converge.

Turning now to columns 3 and 4, we can see that the above results are robust to the inclusion of other variables such as absolute latitude and the average value of constraints on the executive over the sample period. I focus on these two variables as they capture key geographical and institutional aspects that may be important determinants of comparative economic development. Yet, it should be pointed out that the estimates are robust to the inclusion of a wide set of other control variables which I do not report here for the sake of brevity, as the issue of robustness will be discussed more thoroughly in the next subsection.

As an alternative to the specification of equation (45) I can consider a setup where I do not distinguish between more and less open economies, but rather allow the effect of human capital in fostering convergence to vary with the degree of openness. With that in mind I estimate the following equation:

$$g_i - g_{US} = \beta_0 + \beta_1 \frac{\ln y_i^{50}}{\ln y_{US}^{50}} + \beta_2 h_i^{50} + \beta_3 op_i \cdot h_i \cdot \frac{\ln y_i^{50}}{\ln y_{US}^{50}} + \gamma X_i + \varepsilon_i, \tag{46}$$

where op_i denotes the average degree of openness of country i over the period. The results for this specification are displayed in Table 2 and are very similar to those of Table 1 with

coefficient β_3 being always negative and statistically significant[27]. Moreover, as demonstrated in columns (2), (3) and (4), the interaction term retains its sign, magnitude and statistical significance even when additional controls variables are included in the model[28].

Table 2: Cross-Sectional Regressions, 1950-2008

Dep Var.: g_i - g_{US}	(1)	(2)	(3)	(4)
$\ln(y_i)$- $\ln(y_{US})$	-0.261*	-0.291*	-0.298*	-0.272
	[0.156]	[0.148]	[0.152]	[0.299]
avg. years of schooling, age 25+	0.226***	0.0744	0.103	0.134
	[0.0662]	[0.0751]	[0.0774]	[0.115]
dlny * school * trade	-0.00148**	-0.00189***	-0.00159***	-0.00239***
	[0.000573]	[0.000555]	[0.000557]	[0.000813]
absolute latitude		0.0312***		
		[0.00850]		
executive constraints			0.220***	
			[0.0776]	
private credit				0.0216***
				[0.00622]
Observations	114	114	114	63
Adj. R-squared	0.2475	0.324	0.2929	0.3851

The results of the above documented regressions lend some support to the predictions of the theory regarding the role of human capital in facilitating convergence, particularly among open economies. However, given the cross-country setting, the regression results may suffer from an endogeneity bias, driven by the potential omission of other important factors correlated with both initial human capital and growth. To mitigate this potential problem, in what follows, I will re-estimate the above model using panel data, including both country and time fixed effect, which would eliminate any bias stemming from the presence of time-

[27] This is a more indirect test of the model prediction as this set-up does not allow me to distinguish whether trade itself fosters convergence directly or whether it amplifies convergence taking place through human capital. The regression results, though, indicate that they results of Table 1 are not driven by the possibly artificial separation of country into more or less open. However, given that this second specificiation is probably less meaningful as a means of testing the model prediction in what follows, I will no longer report regressions based on this interaction term with the level of trade openness.

[28] The table only reports the robustness of the specification to same controls introduced in Table 1. Yet, it should be mentioned that this specification is also robust to the inclusion of a wide set of other control variables.

invariant country specific factors or time trends that may influence the growth performance of the countries in this sample.

5.3 Panel Estimates (1950-2008)

Focusing on the same period, 1950-2008, I turn in this section to a similar specification as that of equation (45) in a panel setting where growth is now measured as the average growth rate over 10 year intervals. Specifically, I estimate the following equation,

$$g_{i,t} - g_{US,t} = \beta_0 + \beta_1 \frac{\ln y^0_{i,t}}{\ln y^0_{US,t}} + \beta_2 h^0_{i,t} + \beta_3 h^0_{i,t} \frac{\ln y^0_{i,t}}{\ln y^0_{US,t}} + \beta_4 OPEN_{i,t} \cdot h_{i,t} \frac{\ln y^0_{i,t}}{\ln y^0_{US,t}} + \gamma X_{i,t} + \delta_i + \delta_t + \varepsilon_{i,t}, \tag{47}$$

where $g_{i,t}$ denotes growth in country i over the interval t, $y^0_{i,t}$ per capita GDP in country i in the initial year of period t, $h^0_{i,t}$ human capital in country i in the initial year of period t, and $OPEN_{i,t}$ a dummy variable taking the value of 1 if country i has an average value of openness in period t above the mean and zero otherwise.

Table 2: Panel Regressions, Decades, 1950-2008

Dep Var.: g_i - g_{US}	(1)	(2)	(3)	(4)	(5)	(6)	(7)
$\ln(y_i)$ - $\ln(y_{US})$	-1.954***	-2.034***	-2.137***	-2.050***	-2.074***	-2.475***	-1.925***
	[0.504]	[0.501]	[0.504]	[0.504]	[0.502]	[0.487]	[0.492]
avg. years of schooling, age 25+	-0.324	-0.324*	-0.322	-0.321	-0.363*	-0.157	-0.406**
	[0.197]	[0.196]	[0.195]	[0.196]	[0.199]	[0.190]	[0.193]
dlny * school	-0.168**	-0.129*	-0.152**	-0.127*	-0.126*	-0.110*	-0.174**
	[0.0679]	[0.0686]	[0.0700]	[0.0690]	[0.0686]	[0.0661]	[0.0682]
dlny * school * high trade		-0.0994***	-0.0797**	-0.0989***	-0.0995***	-0.0834***	-0.0912***
		[0.0329]	[0.0352]	[0.0330]	[0.0329]	[0.0318]	[0.0324]
trade in % of GDP			0.00817				
			[0.00520]				
executive constraints				0.022			
				[0.0830]			
population growth					-18.97		
					[16.70]		
investment in % of GDP						0.107***	
						[0.0171]	
government spending in % of GDP							-0.150***
							[0.0349]
Time Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	618	618	618	618	618	618	618
Adj. R-squared	0.458	0.467	0.4686	0.4660	0.4673	0.5062	0.4857

The estimation results for the above specification are reported in Table 3. As can be seen from columns (1) to (9), the coefficient β_1 of initial income differences is always negative

and statistically significant, and so are the coefficients β_3, β_4 of the interaction terms. As it becomes apparent by looking at columns (3) to (9) of Table 3, the main results -namely that of trade fostering convergence via the channel of human capital- are robust to the inclusion of various control variables that are typically considered in the empirical growth literature. These include the aforementioned constraints on the executive, government consumption, investment rate, population growth and the rate of inflation. Moreover, in column (3) I also control for the level of trade to test for a possibly more direct effect of trade on economic growth driven, for example, by specialization or economies of scale. Again, the inclusion of this variable does not alter the effect of our main variables of interest.

This fact together with the presence of country and time fixed effects makes one more confident that the estimation results are indeed pointing to an important channel through which human capital influences growth and not a spurious relationship. To give an idea of the magnitude of these coefficients, I recalculate the rate of beta convergence based on the estimates for β_1, β_2 and β_4. For a country whose human capital is equal to the mean of human capital over the entire sample period, and that is not much engaged in international trade the annual implied convergence rate is 2.7 percent, while if this country had instead been relatively more open to trade, it could converge at a rate of 3.2 percent. On the other hand, a country whose level human capital is 70 percent higher - which corresponds to the difference in human capital between the 75th percentile and the median of the human capital distribution, would converge at rates of 3.1% and 4% respectively, i.e. its convergence rate would be 17 to 48 percent higher depending on whether it is open to trade or not[29].

Finally, following Aghion, Howitt, and Mayer-Foulkes (2005), I also consider the possibility that one or more of the other control variables may influence the speed of convergence of countries. Specifically, in Table 4, I allow for interactions of the ratio of initial incomes with the control variables. As the table documents, these interactions have no effect on our

[29] The fact that the rate of convergence seems to be much faster in the panel data regression than in cross-country data is in line with the evidence documented by Islam 1995. Islam finds an average annual rate of convergence of about 4 percent in his 1960-1985 panel data model that includes human capital, which is close to the value found here.

main channel and in fact most of these possible alternative convergence channels seem to not be significant.

5.4 Panel Estimates 1870-2008

Finally, given the long-run focus of the analysis, it would be worthwhile to investigate whether the predictions of the theory also hold true when looking at a longer time period. To do so, I extend the above panel regression to include observations starting from the year 1870, to capture the "first globalization era" that started in the late 1870s and ended with the First World War. The employed regression specification is identical to that of equation (47) and uses differences in growth rate between each country and that of the United Stated averaged over each 10 year interval as the dependent variable. In contrast to the previous regressions, though, the measure of human capital employed here is the primary school enrollment rate reported by Benavot and Riddle (1988). This is because data on average years of schooling are not widely available for the years prior to 1950.

The results of this extended panel regression are documented in Table 5. Column (2) shows the baseline model, and in columns (3) to (5) trade openness, executive constraints and population growth are added as control variables[30]. As Table 5 shows the coefficient β_4 is again significantly negative, indicating that a high level human capital fosters convergence in countries that are open to trade. Interestingly, in contrast to the previously documented panel results based on data from the period 1950 to 2008, the interaction term between initial log per capita income and human capital is here not significant, indicating that this channel of convergence is only available to countries that are relatively open to trade, but that this effect is not present in countries that are relatively closed. The rate of convergence for trading economies implied by the coefficients shown in Table 5 is 2.7 percent -evaluated at the mean of human capital over the entire sample period- slightly lower than the estimate of 3.2 percent which I found based on the 1950-2008 panel estimates. This is not surprising

[30] Due to the lack of data, the investment rate, government consumption and inflation used as controls in the previous tables cannot be employed in this sample.

Table 4: Panel Regressions, Decades, 1950-2008

Dep Var.: g_i - g_{US}	(1)	(2)	(3)	(5)	(6)	(7)
$\ln(y_i)$- $\ln(y_{US})$	-2.213***	-1.834***	-0.367	-2.102***	-0.157	-2.029***
	[0.538]	[0.551]	[0.726]	[0.650]	[0.607]	[0.530]
avg. years of schooling, age 25+	-0.342*	-0.258	-0.591***	-0.166	-0.476**	-0.329*
	[0.202]	[0.207]	[0.209]	[0.191]	[0.189]	[0.198]
dlny * school	-0.161**	-0.106	-0.237***	-0.118*	-0.194***	-0.126*
	[0.0736]	[0.0724]	[0.0763]	[0.0666]	[0.0668]	[0.0694]
dlny * school * high trade	-0.0837**	-0.0992***	-0.0988***	-0.0835***	-0.0830***	-0.0994***
	[0.0365]	[0.0330]	[0.0326]	[0.0318]	[0.0317]	[0.0331]
trade in % of GDP	0.0107					
	[0.00819]					
dlny * trade	0.00155					
	[0.00386]					
executive constraints		-0.148				
		[0.194]				
dny * executive constraints		-0.0831				
		[0.0858]				
population grow th			-113.3***			
			[33.58]			
flny * population grow th			-43.76***			
			[13.56]			
investment in % of GDP				0.0773**		
				[0.0383]		
dlny * investment				-0.0142		
				[0.0163]		
government spending in % of GDP					-0.461***	
					[0.0735]	
dlny * government spending					-0.147***	
					[0.0307]	
inflation						0.0872
						[0.102]
dlny * inflation						0.00583
						[0.0414]
Time Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Country Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	651	651	651	651	651	651
Adj. R-squared	0.4677	0.4659	0.4767	0.506	0.5081	0.4661

*** p<0.01, ** p<0.05, * p<0.1; standard errors in brackets

Table 5: Panel Regressions, Decades, 1870-2008

Dep Var.: g_i - g_{US}	(1)	(2)	(3)	(4)	(5)
$\ln(y_i)$- $\ln(y_{US})$	-2.027***	-2.093***	-2.137***	-2.092***	-1.973***
	[0.503]	[0.501]	[0.502]	[0.501]	[0.503]
primary school enrollment rate	-0.0134	-0.0114	-0.0112	-0.0112	-0.0149
	[0.0117]	[0.0117]	[0.0117]	[0.0117]	[0.0118]
dlny * school	-0.00454	-0.00263	-0.00319	-0.00256	-0.0048
	[0.00544]	[0.00545]	[0.00547]	[0.00546]	[0.00554]
dlny * school * high trade		-0.00537***	-0.00446**	-0.00540***	-0.00529***
		[0.00176]	[0.00191]	[0.00177]	[0.00176]
trade in % of GDP			0.0051		
			[0.00414]		
executive constraints				-0.013	
				[0.0578]	
population grow th					-24.58**
					[11.78]
Time Fixed Effects	Yes	Yes	Yes	Yes	Yes
Country Fixed Effects	Yes	Yes	Yes	Yes	Yes
Observations	900	900	900	900	900
Adj. R-squared	0.3966	0.4032	0.4036	0.4024	0.4058

given that the mean of human capital in the latter period is significantly greater and given that the long sample period also includes the turbulent war and interwar years.

Furthermore, utilizing the fact that the period from 1913 to 1945, that encompasses the two World Wars and the Great Depression, was marked by sharp reduction of international trade and a return to economic protectionism, I consider an alternative test of the proposed theory. Specifically, if the convergence fostering effect of human capital operate via technology transfer which depends on the degree of openness, then one would expect this channel to be absent during the turbulent war and interwar periods. With that in mind, I re-estimate the specification of (47) with growth now measured over the three periods 1870-1912, 1913-1949 and 1950-2008. In this specification I also replace the openness indicator with a dummy that takes the value of 1 for the periods 1870-1912, 1950-2008 and the value of 0 for the period 1913-1949.

The results of this specification are reported in Table 6 and indicate that while the effect of human capital in fostering convergence was present in both the 1870-1912 and 1950-2008 periods, it doesn't seem to play much of a role during the 1913-1949 period. Given that

Table 6: Panel Regressions, Periods, 1870-2008

Dep Var.: g_i - g_{US}	(1)	(2)	(3)	(4)	(5)
$\ln(y_i)$- $\ln(y_{US})$	-0.059	0.0343	-0.0209	0.153	0.0806
	[0.366]	[0.331]	[0.324]	[0.340]	[0.369]
primary school enrollment rate	-0.0209***	-0.0203***	-0.0192***	-0.0212***	-0.0209***
	[0.00694]	[0.00626]	[0.00612]	[0.00625]	[0.00660]
dlny * school	-0.0151***	-0.00107	-0.00132	-0.00209	-0.00137
	[0.00392]	[0.00527]	[0.00513]	[0.00528]	[0.00541]
dlny * school * pre/post-war dummy		-0.0150***	-0.0138***	-0.0150***	-0.0150***
		[0.00415]	[0.00409]	[0.00412]	[0.00420]
trade in % of GDP			0.00771*		
			[0.00400]		
executive constraints				-0.0536	
				[0.0396]	
population growth					-2.996
					[10.08]
Period Fixed Effects	Yes	Yes	Yes	Yes	Yes
Country Fixed Effects	Yes	Yes	Yes	Yes	Yes
Observations	169	169	169	169	169
Adj. R-squared	0.8645	0.8899	0.8955	0.8916	0.8879

*** p<0.01, ** p<0.05, * p<0.1; standard errors in brackets

the events leading to the two World Wars and the Great Depression were exogenous to the development paths of most of the countries in our sample, this finding seems to indicate that also the results of Table 5 and also those of Table 4 are unlikely to driven by a potential time-varying country-specific omitted variable bias.

6 Concluding Remarks

The dynamic relationship between the degree of openness of a given economy and its long-run economic performance has been at the centre of attention for economists since the emergence of economics as a science. This is no wonder given the fundamental nature of such a relationship for the analysis of issues related to international trade and economic development, as well as for the design of appropriate policies in such areas. Despite the presence of an extensive literature on this topic, though, there is still no consensus view among economists regarding both the positive and the normative dimensions of the issue.

In this paper I have attempted to offer a novel perspective on this important debate, utilizing the framework provided by unified growth theory. Focusing on two distinct ways in which openness may influence a country's course of economic development, namely via specialization and trade as well as via technology transfer, the analysis offered the following conclusions. For developed economies that have already gone through the first stage of the industrialization process, openness has an unambiguously positive effect for long-run economic development. This is due to the effect of trade fostering further specialization in the production of manufacturing goods, which accelerates the structural transformation and boosts growth. For less developed economies, however, where industrialization is still at a nascent stage, the effect of openness and economic integration with developed economies was shown to be ambiguous. This is because trade integration, for such economies, leads to specialization in agriculture and thus inhibits the structural transformation process. Yet, this adverse effect of openness can be countered by the gains that less developed economies may have from technology diffusion.

Particularly, with respect to this last point, the paper argued that the combined effect of trade and technology transfer is more likely to be positive for less developed economies characterized by relatively high levels of human capital at the time of economic integration. This is because the economy-wide level of human capital affects crucially the ability of such countries to access and implement advanced technologies from the frontier. Hence, in less developed economies with high levels of human capital the benefits from technology transfer dominate the adverse effects of specialization and economic integration over time can lead to convergence with more developed economies. Yet, as the analysis demonstrated, convergence is not expected to be universal. Less developed economies characterized by relatively low levels of human capital at the time of economic integration will not necessarily benefit from joining the global economy and may diverge in terms of per capita income. This is because a low level of human capital reduces the ability of such economies to utilize existing technologies developed elsewhere. Thus, the gains from technology transfer in this case will be smaller and the negative effect of trade and specialization dominates.

This main prediction of the theoretical analysis regarding convergence was tested empirically using data from1870, which marked the beginning of the first globalization era, until today. Employing both cross-sectional and panel data specifications, it was shown that there is a strong positive effect of human capital fostering convergence across countries and that this effect is even stronger among open economies, exactly as the theory would predict. Moreover, this effect was shown to be robust to the inclusion of various control variables that the empirical growth literature has identified as important determinants of the growth performance of different countries. These findings demonstrate the potential of the proposed theory in accounting for the comparative economic performance of various countries and regions of the world in the long run. At the same time, the findings suggest an explanation why the relationship between openness and growth, which has received a lot of attention in the empirical literature, may be more subtle than what previous research has considered it to be.

7 Appendix

In this appendix discuss how I construct the measure of openness for the periods prior to 1950 which is used in the empirical analysis of Section 5. To do so I resort to data on imports and exports going back to 1870 taken from the Correlates of War (COW) project. These data are expressed in current U.S. Dollars. In order to derive estimates of trade openness, the total value of trade has to be divided by GDP. However, for the period prior to 1950 I have no value for nominal GDP. The data from Maddison (2001) are expressed in constant prices (using the year 1990 as the base year) and also corrected for differences in purchasing power parity. Hence, the trade data cannot be directly compared with the available GDP data. Thus, in order to calculate the ratio of trade to GDP, first of all, the GDP data from Maddison have to be converted from constant U.S. Dollars (with base year 1990) to current U.S. Dollars. Secondly, these still PPP-adjusted estimates of GDP per capita have to then be converted into their corresponding non PPP-adjusted values.

Regarding the first point - the conversion of the constant price GDP series into a current price series - this can be achieved by multiplying the series with the Consumer Price Index of the U.S., using the year 1990 as the base year. This correction was done using the CPI estimates provided by MeasuringWorth[31], a standard source for historical price data.

Regarding the second point - the conversion of PPP adjusted GDP into non PPP adjusted GDP - I follow Prados de la Escosura (2000) and estimate a structural relationship between non PPP-adjusted GDP and GDP adjusted for PPP, plus an additional set of explanatory variables. The estimated parameters from this relationship are then used to make out of sample forecasts of the level of non PPP-adjusted GDP for countries and years where only the independent variables - i.e. PPP-adjusted GDP and other control variables - are observed but not the non PPP-adjusted values of GDP. Following Prados, I estimate this structural relationship using data from the period 1950-1990 and then use the estimated relationship to make out of sample predictions for the years 1870 to 1949.

[31] The data are available only at http://www.measuringworth.com/.

Prados originally estimates the following relationship between PPP-factors -or the PPP-adjusted value of GDP per capita- and nominal non-PPP adjusted GDP per capita:

$$\ln\left(\frac{y_{i,t}^{PPP}}{y_{US,t}^{PPP}}\right) = \alpha_0 + \alpha_1 \ln\left(\frac{y_{i,t}}{y_{US,t}}\right) + \alpha_2 \left[\ln\left(\frac{y_{i,t}}{y_{US,t}}\right)\right]^2 + \alpha_3 \ln\left[\frac{(EX_{i,t} + IM_{i,t})/Y_{i,t}}{(EX_{US,t} + IM_{US,t})/Y_{US,t}}\right]$$
$$+ \alpha_3 \left\{\ln\left[\frac{(EX_{i,t} + IM_{i,t})/Y_{i,t}}{(EX_{US,t} + IM_{US,t})/Y_{US,t}}\right]\right\}^2 + XR_t + \varepsilon_{i,t}$$

$y_{i,t}^{PPP}$ is the PPP-adjusted level of GDP per capita in country i in year t, $y_{i,t}$ is nominal non-PPP adjusted GDP per capita, $EX_{i,t}$ is exports, $IM_{i,t}$ is imports and $Y_{i,t}$ is aggregate nominal GDP. The variables with a subscript "US" indicate the corresponding variables for the United States. XR_t is a dummy variable for the exchange-rate regime. This variable takes a value of 1 during the post-1969 period and the inter-war period (1914-1949), where flexible exchange rate systems were in place, and a value of 0 during the periods 1950-1969 and the years prior to 1914, which were characterized by fixed exchange rate systems and the gold standard, where the latter effectively imposed fixed exchange rates and hence is comparable to the Bretton Woods era. The squared terms in the regression are used to allow for non-linear relationships.

This structural relationship implies that the true relationship underlying this regression is of the following form, where $L_{i,t}$ indicates the population in country i in year t:

$$\begin{aligned}
\frac{y_{i,t}^{PPP}}{y_{US,t}^{PPP}} &= \left(\frac{y_{i,t}}{y_{US,t}}\right)^a \left(\frac{(EX_{i,t} + IM_{i,t})/Y_{i,t}}{(EX_{US,t} + IM_{US,t})/Y_{US,t}}\right)^b \\
&= \left(\frac{y_{i,t}}{y_{US,t}}\right)^a \left(\frac{(EX_{i,t} + IM_{i,t})/(y_{i,t}L_{i,t})}{(EX_{US,t} + IM_{US,t})/(y_{US,t}L_{US,t})}\right)^b \\
&= \left(\frac{y_{i,t}}{y_{US,t}}\right)^{a-b} \left(\frac{(EX_{i,t} + IM_{i,t})/L_{i,t}}{(EX_{US,t} + IM_{US,t})/L_{US,t}}\right)^b \\
&= \left(\frac{y_{i,t}}{y_{US,t}}\right)^{a-b} \left(\frac{(EX_{i,t} + IM_{i,t})}{(EX_{US,t} + IM_{US,t})}\right)^b \left(\frac{L_{i,t}}{L_{US,t}}\right)^{-b}
\end{aligned}$$

Taking logs we get that,

$$\ln\left(\frac{y_{i,t}^{PPP}}{y_{US,t}^{PPP}}\right) = (a-b)\ln\left(\frac{y_{i,t}}{y_{US,t}}\right) + b\ln\left(\frac{EX_{i,t}+IM_{i,t}}{EX_{US,t}+IM_{US,t}}\right) - b\ln\left(\frac{L_{i,t}}{L_{US,t}}\right),$$

which can be rewritten as:

$$\ln\left(\frac{y_{i,t}}{y_{US,t}}\right) = \frac{1}{a-b}\ln\left(\frac{y_{i,t}^{PPP}}{y_{US,t}^{PPP}}\right) - \frac{b}{a-b}\ln\left(\frac{EX_{i,t}+IM_{i,t}}{EX_{US,t}+IM_{US,t}}\right) + \frac{b}{a-b}\ln\left(\frac{L_{i,t}}{L_{US,t}}\right).$$

Thus, the structural equation estimated by Prados de la Escosura (2000) implies at the same time a structural relationship between non PPP-adjusted GDP per capita, PPP-adjusted GDP per capita, the level of trade, and the size of a country's population of the form:

$$\begin{aligned}\ln\left(\frac{y_{i,t}}{y_{US,t}}\right) &= \beta_0 + \beta_1\ln\left(\frac{y_{i,t}^{PPP}}{y_{US,t}^{PPP}}\right) + \beta_2\left[\ln\left(\frac{y_{i,t}}{y_{US,t}}\right)\right]^2 + \beta_3\ln\left[\frac{(EX_{i,t}+IM_{i,t})}{(EX_{US,t}+IM_{US,t})}\right] \\ &+ \beta_4\left\{\ln\left[\frac{(EX_{i,t}+IM_{i,t})/Y_{i,t}}{(EX_{US,t}+IM_{US,t})/Y_{US,t}}\right]\right\}^2 + \beta_5\ln\left(\frac{L_{i,t}}{L_{US,t}}\right) + XR_t + e_{i,t}\end{aligned}$$

I estimate this regression for the years 1950-1990, using data on PPP-adjusted and non-PPP adjusted GDP per capita, population and the total volume of trade from the Penn World Tables. Based on the estimated coefficients, I then make out of sample predictions of $\ln(y_{i,t}/y_{US,t})$ for the period 1870-1949[32]. These estimates are based on PPP-adjusted data on GDP per capita and population data from Maddison and the import and export data from COW.

After this non-PPP adjusted current price series of GDP has been obtained, I estimate the PPP factor for the period 1870-1949 which is expressed in U.S. dollars per international dollar -i.e. this variable has a value of 1 in the U.S. in any year- by dividing the predicted values of $y_{i,t}/y_{US,t}$ by $y_{i,t}^{PPP}/y_{US,t}^{PPP}$. This so estimated PPP factor is then used to derive a PPP-adjusted series of the COW trade data which can then be used together with the GDP

[32] The regression is based on 5103 observations (unbalanced panel). Out of sample predictions are generated for 2080 observations. The adjusted R-squared of this regression is very high at 0.92 and the original dependent variable and its predicted value have a correlation of 0.964 for those countries and years where both the original dependent variable and its predicted value are observed.

data from Maddison (in current prices) to estimate the degree of trade openness as the ratio of total value of trade to GDP. This measure of openness is the one used in the regressions presented in section 5 for the periods prior to 1950.

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