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INNOVATION, IMITATION, AND THE NATURE OF ECONOMIC GROWTH*

YENİLİK, TAKLİT VE İKTİSADİ BÜYÜMENİN DOĞASI

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Abstract

This study demonstrates that the evolution of aggregate productivity in an economy, relative to a technology frontier such as the United States, determines the nature of economic growth for this economy, i.e., whether growth is driven primarily by innovation or imitation. The estimating equation is an autoregressive one and is structural in the sense that it identifies innovation and imitation parameters of an economy. The estimates for 85 countries that use UNIDO's relative productivity data for the period of 1960-2000 show that there exists an innovation-imitation curve over which countries with superior productivity growth performance are located, i.e., a growth frontier. The distance from this growth frontier for a country is a two-dimensional measure of how poorly this country performs with respect to productivity growth. Interestingly, countries in both groups, i.e., the ones located over the growth frontier and define it and the others located away, exhibit considerable within-group variation in terms of innovation and imitation parameters.

Keywords: Relative Productivity, Identification, Technology Frontier, Autoregression

JEL Classification: O30, O41, O47

Öz

Bu çalışma, bir ekonomideki bütüncül verimliliğin Birleşik Devletler gibi bir teknoloji uçsınırına göreli olarak evriminin, o ekonomi için iktisadi büyümenin doğasını belirlediğini göstermektedir, yani büyümenin birincil olarak yenilik ile mi yoksa taklit ile mi gerçekleştiğini. Tahmin eden denklem otoregresiftir ve bir ekonomi için yenilik ve taklit katsayılarını belirlemesi bakımından yapısaldır. 85 ülke için UNIDO'nun 1960-2000 dönemine ait göreli verimlilik verisini kullanan tahminler, daha

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iyi verimlilik büyümesi performansı gösteren ülkelerin, bir yenilik-taklit eğrisi tanımladığını ortaya koymaktadır, yani bir büyüme uçsınırı. Bu büyüme uçsınırına olan uzaklık, bir ülkenin verimlilik büyümesi bakımından ne denli zayıf bir performans gösterdiğinin iki boyutlu bir ölçüsüdür. İlginç biçimde, her iki gruptaki ülkeler, yani büyüme uçsınırında yerleşmiş ve onu tanımlamış olanlar ile buradan uzaktakiler, yenilik ve taklit parametreleri bakımından, dikkate değer grup-içi değişkenlik göstermektedirler.

Anahtar Kelimeler: Göreli Verimlilik, Belirlenim, Teknoloji Uçsınırı, Otoregresyon

JEL Sınıflaması: O30, O41, O47

1. Introduction

The first Industrial Revolution in Britain represents a major turning point in economic history, if not the most important economic event of the history of mankind. It surely admits a role analogous to the role played by the French Revolution in political history (Landes, 1969; Jones, 1981; Mokyr, 2002; Clark, 2007). Transitioning to sustained economic growth via industrialization has been associated with several other unprecedented economic, social, political, and demographic processes, both as a cause and as a consequence (Galor, 2011). The increase in urbanization rates, the rise of democracy and free society, and the demographic transition are among these transformations.

After the first Industrial Revolution in Britain, today's developed economies have realized their own takeoffs to a stage of sustained economic growth (Lucas, 2000, 2009). Given that the takeoff dates have differed across these economies, the story of economic growth of nations has been depicted as a story of a race where there are forerunners, latecomers, and, of course, the ones that yet to achieve a growth takeoff from the Malthusian trap (Landes, 1969).

There exists today a sizable literature on the sources of economic growth in per capita terms, i.e., intensive economic growth. This growth accounting literature has been initiated by pioneering works of Solow (1956, 1957) and Denison (1961), and the early results for the United States (US) economy have indicated the indispensable role of factors that shift the production frontier in time, e.g., an aggregate total factor productivity (TFP) term. Later studies conducted for other countries and for other time periods have usually differed in exactly what fraction of observed intensive economic growth is due to factor accumulation and what fraction of it is due to (unobserved) productivity growth. Generally, however, studies depict a definite role to long-run productivity growth in driving intensive economic growth in the long-run, and such a role receives strong support in models of economic growth ranging from Solow's (1956) simple model with exogenous productivity growth to highly sophisticated models of second-generation Schumpeterian growth (Peretto, 2016) and the Unified Growth Theory (UGT) (Galor, 2011).

The main determinant of sustained productivity growth is technological progress once we assume away the bounded effect of sectoral reallocation of resources. To understand the nature of technological progress, economists focus on two sources: First, technological progress occurs when (domestic) firms create higher quality products and more productive technologies, i.e., innovation. Second, technology improves when (domestic) firms adopt already existing products and technologies from other (foreign) firms, i.e., imitation. In a world of technology leaders and followers, the productivity race continues as countries keep innovating and imitating.

The evolution of relative productivities is of prime importance in this world as technology leaders such as the US are successful in achieving a more or less stable positive growth of aggregate (absolute) productivity. Specifically, if a country's relative total factor productivity (TFP) grows in time, then this means that the country exhibits a *relative* success in technological progress. This success would be due either to innovation or to imitation or to both in parts.

This paper asks whether we can learn more about these sources of growth by looking at the relative TFP data. The paper demonstrates that an extremely simplified two-equation version of the model constructed by Acemoglu et al. (2006) allows us to uniquely identify structural imitation and innovation parameters of this economy from the evolution of its relative TFP in time. Specifically, the theory dictates that the evolution of relative TFP in a country is described as a first-order linear difference equation in the form of $x_{t+1} = mx_t + b$ with $m, b \quad \mathbf{R}$. The fixed slope and intercept terms m and b depend on innovation and imitation parameters of the economy, and estimates of m and b identify these two structural parameters.

The paper estimates the innovation and imitation parameters of 85 countries where the US is chosen as the world's technology leader. The source of relative TFP data used is UNIDO's World Productivity Database developed by Isaksson (2007). A growth accounting framework that uses an aggregate production function is adopted to filter out TFP relative to the US for each country (Isaksson, 2007). When the contribution of education and health on aggregate TFP is separated using available data, relative TFP panel covers 85 countries for the period running from 1960 to 2000 at annual frequency.

Results indicate that countries are separated into two broad categories. The first group is formed by countries whose relative TFP levels have exhibited tremendous growth from 1960 to 2000. The second group, on the other hand, is formed by other countries whose productivity growth performances are weaker. Countries in the first group exhibit a wide variation in the relative importance of innovation and imitation. Some in the first group have high innovation parameters but their imitation parameters are low. Some others have the opposite, with low innovation and high imitation parameters. The rest of the countries in this highest-growth group are distributed in between. The second group of countries also differ in innovation and imitation parameters, but it is more difficult to draw strict boundaries since some countries in this group, i.e., the growth disasters, have lowest innovation and imitation parameters.

Since innovation and imitation are substitute sources of relative TFP growth, the first group of countries with best productivity growth performances define a growth frontier. This frontier is represented as a negatively-sloped line over the plane where estimated innovation and imitation parameters are on the vertical and horizontal axes, respectively. The growth frontier thus represents the set of largest innovation potential that a country can achieve given her imitation potential and *vice versa*. Put differently, given the relative TFP panel for 85 countries and for the period of 1960-2000, no country can be located on the right of the frontier line. Clearly, the distance of a country to this growth frontier becomes a metric that shows how badly this country fails in achieving relative productivity growth. The estimated kernel density of the global cross-section distribution of the distance term indicates a largely skewed distribution towards smaller distances, but a group of growth disasters also exists.

The outline of the paper is as follows: Section 2 briefly reviews the related literature. Section 3 summarizes the main patterns of cross-country productivity differences. Section 4 introduces the theoretical foundations. Section 5 derives the estimated equation building upon the theoretical foundations and describes the data used in the estimations. Section 6 presents results. Finally, Section 7 concludes with some remarks.

2. Literature

This paper is related with two lines of research. The first one is the literature on catching up and technology diffusion. The catching up hypothesis originates from the early thoughts of Veblen (1915) on technology's diffusion from early – to late-industrializing countries. Building upon the 19th century experiences of such laggard economies including Russia and Japan, Gerschenkron (1962) has emphasized the advantage of relative backwardness. Early formal treatments of catching up have been proposed by Nelson and Phelps (1966) and Gomulka (1971) where relative backwardness, i.e., the distance to frontier, and education play key roles in determining the rate of technological progress in a country. Abramovitz's (1986) generalized account of the catching up hypothesis has emphasized the level of technology embodied in successive vintages of capital stock and a country's social capabilities in exploiting the full potential of catching up. Cohen and Levinthal (1989, 1990) have proposed the term *absorptive capacity* that reflects a firm's or organization's capability to adopt new technologies where the level of past R&D investment positively affects absorptive capacity. In contrast with the earlier theoretical literature, Verspagen (1991) has focused on the possibility of a country's falling behind that results from a very large distance to frontier or a very low level of absorptive capacity. Empirical results documented by Rogers (2004) for a large set of countries indicate that both absorptive capacity and the distance to frontier are statistically significant explanatory variables for economic growth and that high absorptive capacity is explained by relatively high numbers of students studying abroad in science and technology fields. Benhabib and Spiegel's (2005) analysis has provided a generalization of the catching up hypothesis that allows for follower countries to grow at a slower pace than the leader country. Besides, their empirical results have confirmed the key role of education and human capital accumulation for absorptive capacity. In an empirical paper that investigates the importance of R&D and education for the absorptive capacity levels of 12 OECD countries, Kneller and Stevens (2006) have found out that human capital differences across countries are the main driver of differences in inefficiency levels associated with technology adoption. This paper contributes to this literature by providing an estimate of what fraction of relative productivity growth has been due to technology adoption for each country in the sample.

The second line of research related with this paper is of poverty traps, multiple growth regimes, and club convergence. The mid-1980s have witnessed the rise of a literature that uses the Maddison Project database and the Penn World Tables' data to investigate whether there exists convergence among countries in terms of real GDP per capita and of its growth rate. Early work has focused on cross-section regressions without explicit theoretical foundations (Kormendi and Meguire, 1985; Baumol, 1986; DeLong, 1988; Barro, 1991), but the neoclassical growth theory has also been used to derive such cross-section regressions (Mankiw et al., 1992; Barro and Sala-i Martin, 1992; Romer, 1993). The results have not only been mixed but also been sensitive to additional controls and differing samples (Levine and Renelt, 1992; Sala-i-Martin, 1997). Besides, along with other problems such as endogenous covariates and measurement errors, multiple growth regimes have complicated the story with parameter heterogeneity (Durlauf and Johnson, 1995). Most decisively, the Galton fallacy has necessitated to analyze the entire world income distribution since faster growth of poorer countries may be observed along with non-decreasing or increasing inequality across countries (Friedman, 1992; Quah, 1993). The analysis of the entire world income distribution has revealed that the global distribution moved to a twin-peaked distribution with two clubs in the postwar period and that there existed increasing polarization between the poor and rich clubs (Quah, 1996; Bianchi, 1997; Desdoigts, 1999; Milanovic, 2010; Fiaschi and Lavezzi, 2003). Being similar to the poverty trap models of Becker et al. (1990) and Azariadis and Drazen (1990), the club convergence hypothesis has received theoretical support as well (Galor, 1996; Quah, 1997). More recent papers have also confirmed that multiple growth regimes exist (Graham and Temple, 2006; Castellacci, 2008; Owen et al., 2009; Bos et al., 2010). The UGT after Galor and Weil (2000) has focused on the notion that endogenous and gradual growth takeoffs occur at different dates in different countries, thereby giving rise to multiple growth regimes (Galor, 2010, 2011). This paper contributes to this literature by empirically locating the growth frontier that is formed by countries that have achieved highest growth performances with a diverse pattern of innovative-imitative parameters.

3. Relative TFP Dynamics

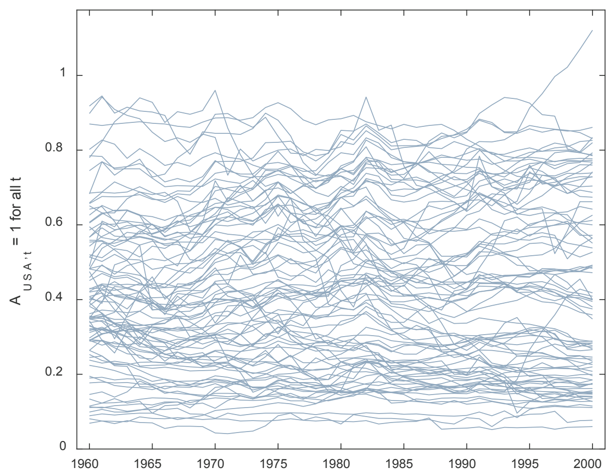
The source of relative TFP data used in this paper is UNIDO's World Productivity Database developed by Isaksson (2007). As explained with some detail in Subsection 5.2, TFP measures for a large number of countries and relative to the US are filtered out within a growth accounting framework that utilizes an aggregate production function. For the version that adjusts the labor input with education and health components, we have 85 countries for the period running from 1960 to 2000 at annual frequency. Relative TFP for country i at year t is defined as in

$$\text{Relative TFP}_{i,t} \equiv \frac{\text{TFP}_{i,t}}{\text{TFP}_{USA,t}} \quad (1)$$

where $\text{TFP}_{USA,t}$ in turn is normalized to unity for all t.

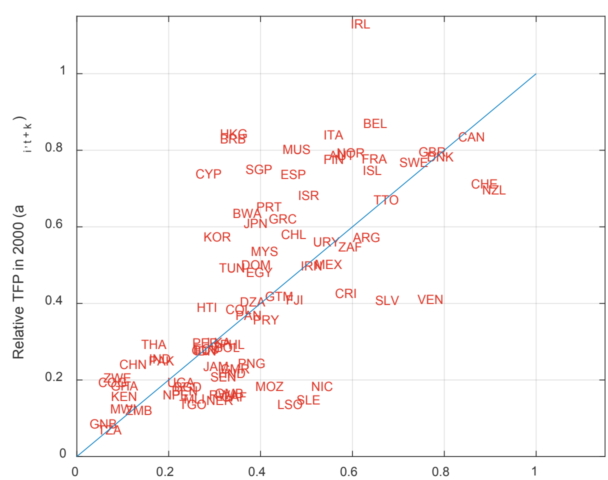
The global picture returns a rather diverse pattern in relative TFP. There exist many countries that forge ahead in time, simply growing faster than the US in absolute TFP terms. There also exist some countries falling behind with poor growth performances. Relative TFP levels in some other countries fluctuate and do not exhibit significant growth or decline.

Figure 1: Global Non-Convergence of Relative TFP



Source: UNIDO.

Figure 2: Relative TFP Transition from 1960 to 2000

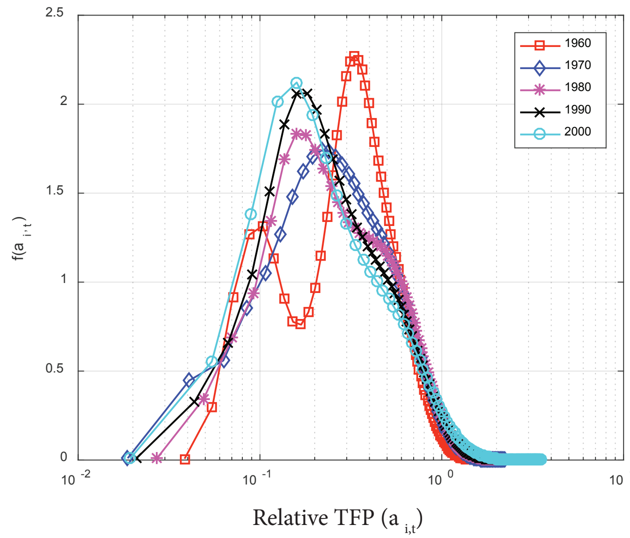


Relative TFP in 1960 ($a_{i,t}$)

Source: UNIDO.

Figures 1, 2, and 3 summarize the main patterns and regularities. The first one pictures the entire balanced panel, indicating a very strong non-convergence result: While some countries have largely closed their distance to frontier from 1960 to 2000, the global economy is described by the persistence of inequality in relative TFP.

Figure 3: Density Estimates of Relative TFP: 1960 to 2000



Source: UNIDO.

Figure 2 clarifies the cases of forging ahead and falling behind by plotting relative TFP in 1960 on the horizontal axis and corresponding 2000 values in the vertical axis. The blue line is the 45-degree line, and countries located above this line are the ones forging ahead relative to their 1960 position and the ones located below are falling behind.

Finally, Figure 3 shows the estimated kernel density of relative TFP for 85 countries in 1960, 1970, 1980, 1990, and 2000. The Gaussian kernel smoother is used with the optimal bandwidth, and the support of the distribution is assumed to include strictly positive real numbers. The x-axis has a logarithmic scale for better readability of the figure. Three messages originating from this figure are that the distribution is highly skewed, that the variance is slightly increasing in time, and that the distribution has moved from a twin-peaked one in 1960 to a single-peaked distribution in the following decades.

4. Theory

This section introduces an extremely simple, two-equation theory of the wealth of nations. The main theoretical foundation is the innovation-imitation framework originally formulated by Acemoglu et al. (2006).

In what follows, $i \in \{1,2,\ldots,I\}$ and $t \in \{1,2,\ldots,T\}$ index countries and time periods, respectively. $A_{i,t}$ denotes the absolute level of aggregate productivity for the country-time pair (i,t). The initial value $A_{i,0} > 0$ is exogenous and given for all i.

A country not included in the set $\{1,2,\ldots,I\}$, e.g., $i = 0$, is the world's technology leader. The absolute level of aggregate productivity in the leader country, denoted by $\bar{A}_t$, is called the world's technology frontier. This frontier grows exogenously as in

$$\bar{A}_{t+1} = (1+g)\bar{A}_t \qquad (2)$$

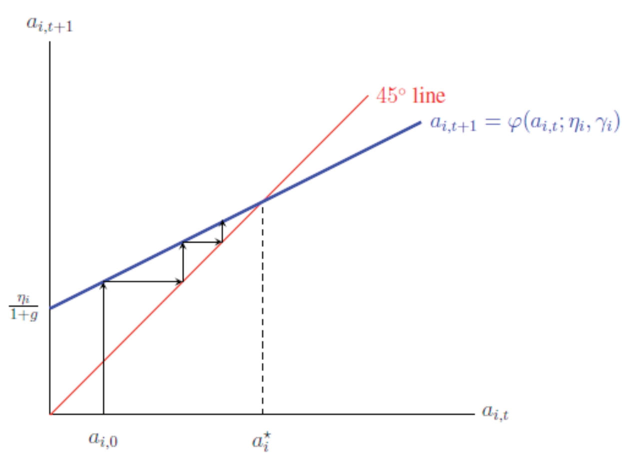
where $g > 0$ denotes the fixed growth rate. This is the first equation of the simple model.

The evolution of country i's absolute productivity $A_{i,t}$ from t to $t+1$ is governed by two distinct mechanisms. First, $A_{i,t+1}$ depends on $\bar{A}_t$ as domestic firms/industries adopt some of the more advanced foreign technologies, i.e., imitation. Second, it also depends on $A_{i,t}$ as domestic firms/industries create some more advanced technology on their own, i.e., innovation. Formally, we have the second equation that defines $A_{i,t+1}$ as in

$$A_{i,t+1} = \eta_i \bar{A}_t + \gamma_i A_{i,t} \qquad (3)$$

where η_i and γ_i denote the imitation and innovation parameters of country i, respectively.

Figure 4: Asymptotically Stable Relative Productivity Dynamics



One can easily extend the analysis of the wealth of nations using these two equations. The growth rate of absolute productivity $A_{i,t}$ is of prime interest and defined simply as in

$$g_{i,t} \equiv \frac{A_{i,t+1}}{A_{i,t}} - 1 = \frac{\eta_i}{a_{i,t}} + \gamma_i - 1 \qquad (4)$$

where $a_{i,t} \equiv A_{i,t}/\bar{A}_t$ denotes the relative productivity of country i at time t.

Economic growth in country i depends entirely on innovation with growth rate being equal to $\gamma_i - 1$ if country i does not imitate ($\eta_i = 0$). When imitation is active ($\eta_i > 0$), on the other hand, the distance to frontier has a positive effect on growth rate as $g_{i,t}$ is a decreasing function of $a_{i,t}$; an economy that imitates foreign technologies enjoys the advantage of relative backwardness.

Dividing both sides of (3) and invoking (2) and $a_{i,t+1} \equiv A_{i,t+1}/\bar{A}_{t+1}$ imply the first-order linear difference equation:

$$a_{i,t+1} = \frac{\eta_i}{1+g} + \frac{\gamma_i}{1+g} \times a_{i,t} = \varphi(a_{i,t}; \eta_i, \gamma_i) \quad (5)$$

Figure 4 pictures how $a_{i,t}$ converges to a steady-state under stability: If $\gamma_i/(1+g)$ is less than unity, $a_{i,t}$ converges to the asymptotically stable steady-state a_i^* that uniquely solves $a_i^* = \varphi(a_i^*; \eta_i, \gamma_i)$ $a_i^* = \varphi(a_i^*; \eta_i, \gamma_i)$:

$$a_i^* = \frac{\eta_i}{1+g-\gamma_i} \quad (6)$$

This solution indicates that both innovation and imitation parameters are positively associated with the steady-state level of relative productivity.

5. Estimation and Data

5.1. From Theory to Empirics

The equation separately estimated for each country directly follows from (5). Extending the right-hand side with a zero-mean error term $\xi_{i,t}$ allows us to define the parsimonious auto-regressive model with one lag, i.e., AR(1), as in

$$a_{i,t+1} = \beta_{0,i} + \beta_{1,i} a_{i,t} + \xi_{i,t} \quad (7)$$

where $\beta_{0,i}$ and $\beta_{1,i}$ identify η_i and γ_i given the frontier growth rate g, respectively. Formally, we simply have

$$\eta_i = \beta_{0,i}(1+g) \quad \text{and} \quad \gamma_i = \beta_{1,i}(1+g) \quad (8)$$

The benchmark results reported below in Section 6 simply originate from the OLS estimator. Results report the point estimates whose standard errors are corrected for serial correlation via the Newey-West procedure. It is useful to note at this point that statistical insignificance of parameters $\beta_{0,i}$ and $\beta_{1,i}$ is of particular interest since these regression coefficients identify η_i and γ_i; the appendix provides a detailed discussion of statistical significance issues.

5.2. Data

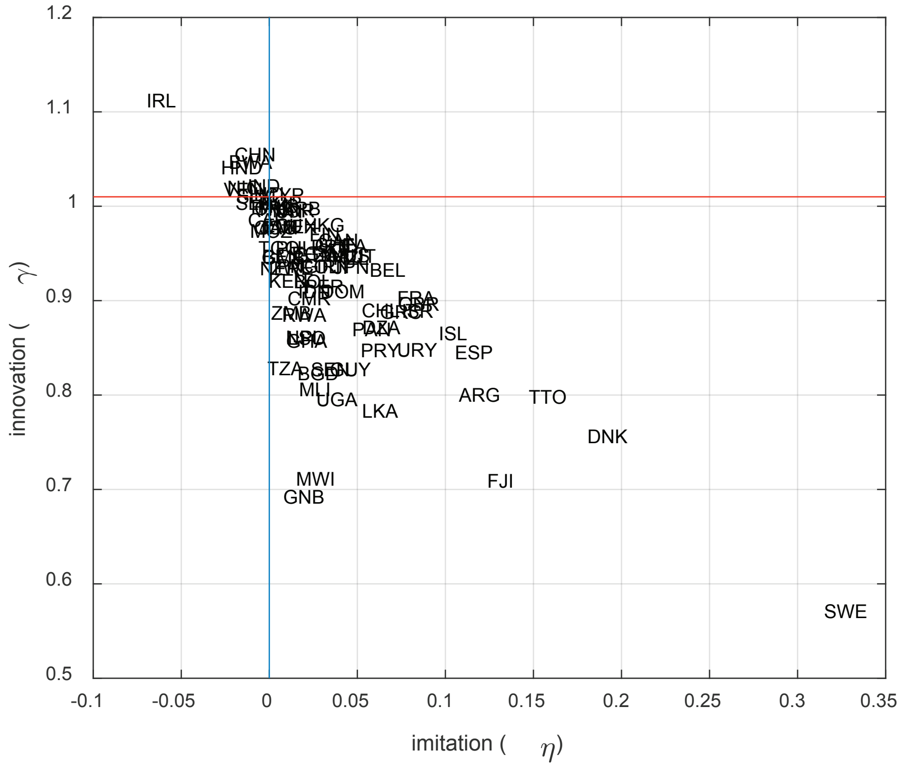
Data required to estimate (7) is readily available from UNIDO's World Productivity Database. Of all the available relative TFP measures generated with several types of econometric and statistical analyses, the benchmark estimations whose results are reported here build upon a measure of relative TFP originating from a static growth accounting exercise that utilizes a constant returns to scale Cobb-Douglas production function with Harrod-neutral technological progress and that adjusts the labor input via schooling and health data to account for the human capital dimensions. When the labor input is adjusted in this way, the dataset covers 85 countries and the period from 1960 to 2000 at annual frequency.

Clearly, the US economy is not in this sample since all the other country-wise TFP measures are expressed as ratios to the US level where the latter is normalized to unity for all years in the sample. The Penn World Tables data of Feenstra et al. (2015) indicate that the absolute level of TFP in the US exhibits long-run growth at a pace of around 1% per annum. The remainder of the analysis accordingly assumes that the frontier growth rate is equal to $g = 0.01$.

6. Results

This section presents the results in two subsections. This separation is dictated by a problem of modeling regarding the set from which imitation parameter η_i takes values. Intuition suggests that, if country i does imitate frontier technologies, η_i for this economy must be strictly positive even though it may be extremely close to zero, i.e., $\eta \in (0, +\infty)$. On the other hand, if estimated η_i is (extremely) close to zero whether it is positive or negative, then sound econometric practice that takes theory as its guidance necessitates the estimation of a restricted model with $\eta_i = 0$ for countries with estimated η_i values that are insignificant or negative when not restricted. It turns out that the two sets of results differ considerably since, for a large number of countries, unrestricted η_i estimates are either insignificant or negative.

Figure 5: Innovation and Imitation Parameters (Unrestricted Model)



Source: Author's own estimation

6.1. The Unrestricted Model

6.1.1. Innovation and Imitation Parameters

Figure 5 pictures the estimated values of η_i and γ_i in the unrestricted model for 85 countries in the sample, and Tables 1 and 2 list the point estimates, respectively.

The red horizontal line in Figure 5 represents the gross growth rate of the frontier at $1 + g = 1.01$ $1 + g = 1.01$. Countries with $\gamma_i > 1 + g$ are therefore the ones with highest innovation parameters. The vertical blue line on the other hand is the $\eta_i = 0$ curve. The distance to the blue line indicates a larger level of imitation parameter.

A result originating from Figure 5 is that 85 countries in the sample segregate into two distinct groups. First, there exists a group of fast growing economies located in the northeast portion of the figure by forming a more or less well-shaped line with a negative slope. These countries range from Ireland with highest γ_i in the northwest to Sweden with largest η_i in the southeast.

Table 1: Innovation Parameters in the Unrestricted Model

Country	γ_i	Country	γ_i	Country	γ_i
Ireland	1.1061	Philippines	0.9499	Israel	0.8836
China	1.0497	Singapore	0.9475	Greece	0.8829
Botswana	1.0411	Egypt	0.9449	Zambia	0.8814
Honduras	1.0352	Guatemala	0.9429	Rwanda	0.8792
Nicaragua	1.0144	Mauritius	0.9428	Algeria	0.8656
Venezuela	1.0121	South Africa	0.9424	Panama	0.8638
Haiti	1.0072	Austria	0.9415	Iceland	0.8602
Cyprus	1.0066	Benin	0.9411	Nepal	0.8553
South Korea	0.9982	Gambia	0.9403	Lesotho	0.8553
Malaysia	0.9951	New Zealand	0.9394	Ghana	0.8520
Pakistan	0.9937	Papua New G.	0.9316	Uruguay	0.8423
Costa Rica	0.9928	Colombia	0.9308	Paraguay	0.8415
Barbados	0.9918	Philippines	0.9499	Spain	0.8397
Thailand	0.9912	Singapore	0.9475	Tanzania	0.8225
Norway	0.9902	Egypt	0.9449	Guyana	0.8220
Tunisia	0.9895	Japan	0.9304	Senegal	0.8217
Cen. Afr. Rep.	0.9804	Iran	0.9303	Bangladesh	0.8178
Hong Kong	0.9746	Zimbabwe	0.9287	Mali	0.8000
Ecuador	0.9741	Niger	0.9283	Argentina	0.7951
Mexico	0.9727	Belgium	0.9270	Trin. & Tob.	0.7925
Congo	0.9721	Kenya	0.9150	Uganda	0.7902
Jamaica	0.9719	Bolivia	0.9148	Sri Lanka	0.7771
Mozambique	0.9684	Peru	0.9093	Denmark	0.7506
Finland	0.9643	Dom. Rep.	0.9043	Malawi	0.7055
Canada	0.9582	Indonesia	0.9039	Fiji	0.7033
Switzerland	0.9535	France	0.8973	Guinea-Bissau	0.6870
Italy	0.9521	Cameroon	0.8969	Sweden	0.5656
Portugal	0.9517	United King.	0.8914		
Togo	0.9504	Chile	0.8842		

Source: Author's own estimation

The other group is formed by economies that exhibit a relatively weaker growth performance. Countries in this group are located away from the other group in non-systematic ways. Some with weakest performances in relative TFP dynamics, e.g., Guinea-Bissau, Fiji, Malawi, Sri Lanka, Tanzania, Mali, Senegal, and Uganda, are widely scattered to the (η, γ) plane. The rest of the slow growing economies have larger innovation parameters but lower imitation parameters and located relatively closer to the reference point of $(0, 1.01)$.

6.1.2. The Steady-State Distribution

The implied distribution of relative TFPs in the very long run, i.e., at the steady-state, is of interest. Recall that (6) allows us to calculate a_i^* for all *i* given η_i, γ_i, and g.

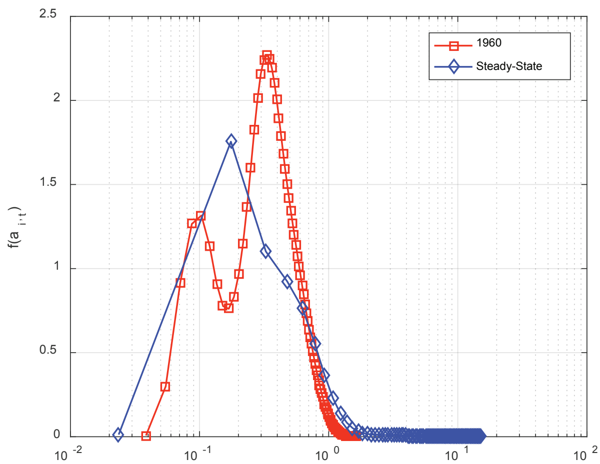
Table 2: Imitation Parameters in the Unrestricted Model

Country	η_i	Country	η_i	Country	η_i
Sweden	0.3317	Iran	0.0397	Zimbabwe	0.0172
Denmark	0.1961	South Africa	0.0395	Zambia	0.0166
Trin. & Tob.	0.1617	Senegal	0.0386	Kenya	0.0147
Fiji	0.1343	Portugal	0.0382	Tanzania	0.0128
Argentina	0.1238	Hong Kong	0.0355	Cyprus	0.0125
Spain	0.1203	Peru	0.0351	Gambia	0.0122
Iceland	0.1073	Finland	0.0344	Tunisia	0.0118
United King.	0.0892	Colombia	0.0324	Ecuador	0.0118
Uruguay	0.0880	Bangladesh	0.0321	South Korea	0.0113
Israel	0.0873	Malawi	0.0301	Benin	0.0110
France	0.0871	Guatemala	0.0301	Niger	0.0102
Greece	0.0789	Mali	0.0291	Togo	0.0099
Belgium	0.0708	Iran	0.0397	Malaysia	0.0095
Chile	0.0674	South Africa	0.0395	Jamaica	0.0091
Algeria	0.0672	Senegal	0.0386	Congo	0.0079
Paraguay	0.0669	Indonesia	0.0291	Thailand	0.0070
Sri Lanka	0.0666	Bolivia	0.0289	Mozambique	0.0051
Panama	0.0620	Egypt	0.0283	Pakistan	0.0046
Austria	0.0533	Cameroon	0.0270	Costa Rica	0.0043
Italy	0.0503	Ghana	0.0255	Haiti	0.0029
Guyana	0.0503	Lesotho	0.0254	Cen. Afr. Rep.	0.0022
Japan	0.0503	Rwanda	0.0244	China	-0.0037
New Zealand	0.0501	Guinea-Bissau	0.0240	Botswana	-0.0063
Mauritius	0.0493	Nepal	0.0239	Venezuela	-0.0110
Dom. Rep.	0.0462	Barbados	0.0221	Nicaragua	-0.0111
Canada	0.0434	Papua New G.	0.0207	Honduras	-0.0114
Singapore	0.0431	Mexico	0.0197	Ireland	-0.0581
Uganda	0.0428	Philippines	0.0180		
Switzerland	0.0415	Norway	0.0179		

Source: Author's own estimation

There exists, however, a difficulty here since the implied a_i^* value is not positive for three countries; these are El Salvador, India, and Sierra Leone. These countries are the ones for which the simple AR(1) model of relative TFPs is not rich enough to imply $a_i^* > 0$ as a plausible outcome. But looking at the experiences of these three countries more closely reveals that the case of India is markedly differ from the cases of El Salvador and Sierra Leone. The latter two suffer not only from a low innovation parameter implying $1 + g - \gamma_i > 0$; they also record a negative value for the imitation parameter η_i. The Indian economy, on the other hand, has a large innovation parameter, but its imitation parameter is very close to zero. Dropping these three countries is the only theoretically justifiable option for the unrestricted model, and proceeding accordingly results in the steady-state distribution whose density estimate is pictured in Figure 6. Once again, the Gaussian kernel smoother is used with the optimal bandwidth, the support of the distribution is assumed to include strictly positive real numbers, and the x-axis has a logarithmic scale for better readability of the figure. Contrasting the 1960 distribution with the implied steady-state, we observe a single-peaked distribution with a larger variance but with a similarly skewed shape.

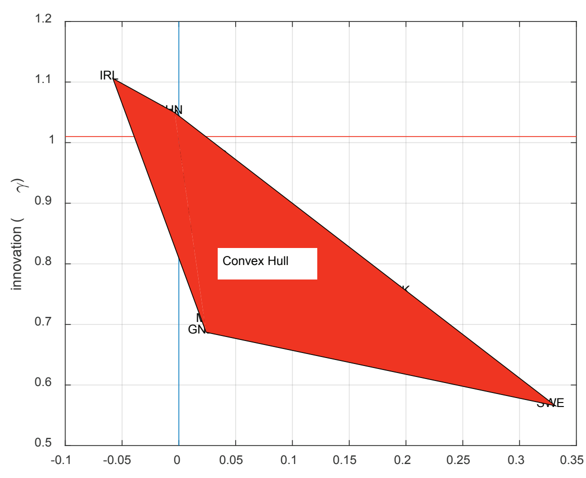
Figure 6: Density Estimates of Relative TFP: 1960 to the steady-state



Relative TFP ($a_{i,t}$)

Source: UNIDO and Author's own estimation

Figure 7: The Convex Hull (Unrestricted Model)



Source: Author's own estimation

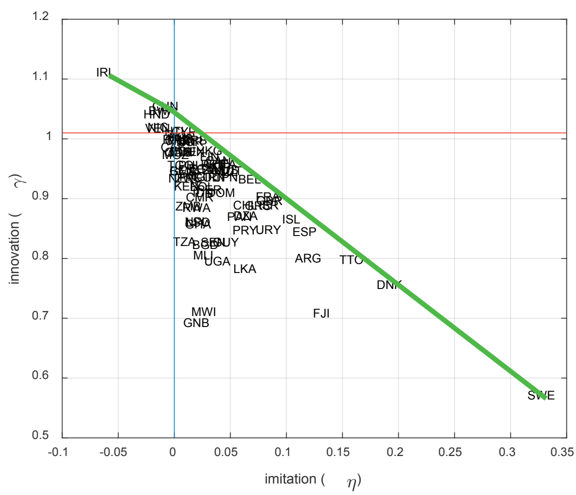
6.1.3. The Distance to the Growth Frontier

While the existing literature on productivity levels and growth rates and their variation across countries focuses on *the distance to frontier* defined as in

$$\bar{A}_t - A_{i,t} \qquad (9)$$

our exploratory analysis on innovation and imitation parameters naturally leads us to a genuinely new frontier concept, i.e., *the growth frontier*.

Figure 8: The Growth Frontier (Unrestricted Model)



Source: Author's own estimation

The above distance is simply the size of the scope of imitation for country i. Therefore, this frontier concept does not give us any information about how fast or slow country *i* can grow. As defined in (4), the growth rate $g_{i,t}$ of country i depends both on η_i and on γ_i. The concept of the growth frontier takes these two effects into consideration. Countries with highest TFP growth performances form well-shaped line segments with negative slopes on the (η, γ) plane as clearly seen in the northeast portion of Figure 5. The line segments that define the boundary of the convex hull of the set of (η, γ) pairs on that portion of the figure also define *the growth frontier*.

Formally, define $S \subset \mathbf{R}^2$ as the set of (η, γ) pairs for 85 countries in the unrestricted model. Then, the convex hull of S can easily be found as depicted in Figure 7. The four countries define S since they have highest or lowest η and/or γ or their location is closest and/or farthest to the origin. These countries are Ireland, China, Sweden, and Guinea-Bissau. The first three countries clearly define the growth frontier pictured in Figure 8.

The growth frontier indicates the location of an infinite number of hypothetical countries that perform best in the growth of relative TFP for any level of η (or any level of γ). No country, *according to the estimation results*, would do any better than the growth frontier.

Table 3: Distance to Growth Frontier in the Unrestricted Model

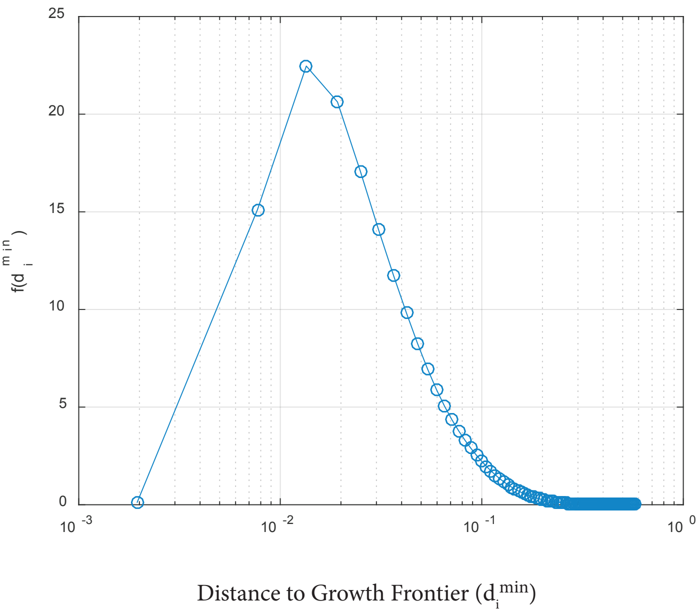
Country	d_i^{min}	Country	d_i^{min}	Country	d_i^{min}
Denmark	0.0061	Mexico	0.0246	Papua New G.	0.0472
Botswana	0.0070	Pakistan	0.0251	Peru	0.0480
Belgium	0.0086	South Africa	0.0256	Gambia	0.0492
Trin. & Tob.	0.0105	Costa Rica	0.0258	Benin	0.0498
Hong Kong	0.0105	Nicaragua	0.0262	Bolivia	0.0500
Italy	0.0112	Greece	0.0271	Zimbabwe	0.0517
Cyprus	0.0112	Mexico	0.0246	Panama	0.0519
Barbados	0.0117	Pakistan	0.0251	Indonesia	0.0561
France	0.0122	South Africa	0.0256	Niger	0.0577
Canada	0.0134	Costa Rica	0.0258	Paraguay	0.0605
United King.	0.0138	Nicaragua	0.0262	Kenya	0.0616
Honduras	0.0146	Greece	0.0271	Cameroon	0.0617
Austria	0.0147	Venezuela	0.0274	Rwanda	0.0740
Norway	0.0161	Ecuador	0.0303	Zambia	0.0792
Iceland	0.0166	Iran	0.0323	Fiji	0.0838
South Korea	0.0170	Guatemala	0.0330	Guyana	0.0852
Finland	0.0173	Egypt	0.0334	Lesotho	0.0868
Mauritius	0.0173	Jamaica	0.0337	Nepal	0.0880
Switzerland	0.0176	Cen. Afr. Rep.	0.0346	Ghana	0.0885
Spain	0.0176	Congo	0.0346	Senegal	0.0951
New Zealand	0.0186	Chile	0.0358	Sri Lanka	0.0975
Haiti	0.0187	Colombia	0.0380	Bangladesh	0.1026
Singapore	0.0197	Philippines	0.0390	Uganda	0.1096
Israel	0.0198	Mozambique	0.0390	Mali	0.1152
Malaysia	0.0202	Argentina	0.0402	Tanzania	0.1158
Portugal	0.0214	Dom. Rep.	0.0418	Malawi	0.1682
Tunisia	0.0216	Uruguay	0.0427	Guinea-Bissau	0.1838
Japan	0.0236	Togo	0.0453		
Thailand	0.0245	Algeria	0.0465		

Source: Author's own estimation

The shortest distance to the growth frontier from the point (η_i, γ_i), denoted by $d_i^{min} > 0$, is a metric that measures how poorly country i performs in relative TFP growth. This distance is quite easily calculated since the information on the boundary points of the convex hull allows us to calculate the slopes and intercepts of all of the line segments that define the growth frontier.

Table 3 presents the calculated shortest distances to the growth frontier for the unrestricted model. Denmark, Botswana, and Belgium are the top-three countries located closest to the growth frontier, and the largest distance is recorded for Guinea-Bissau. The ratio of Guinea-Bissau's distance to that of Denmark is roughly equal to 30.

Figure 9: The Density Estimate of the Distance (Unrestricted Model)



Source: Author's own estimation

The final piece of evidence from the unrestricted model is the global distribution of the distance measure pictured in Figure 9. As in the previous density figures, the Gaussian kernel smoother is used with the optimal bandwidth, the support of the distribution is assumed to include strictly positive real numbers, and the x-axis has a logarithmic scale for better readability. The distribution is a skewed one such that a smaller number of countries are located away from the growth frontier.

6.2. The Restricted Model

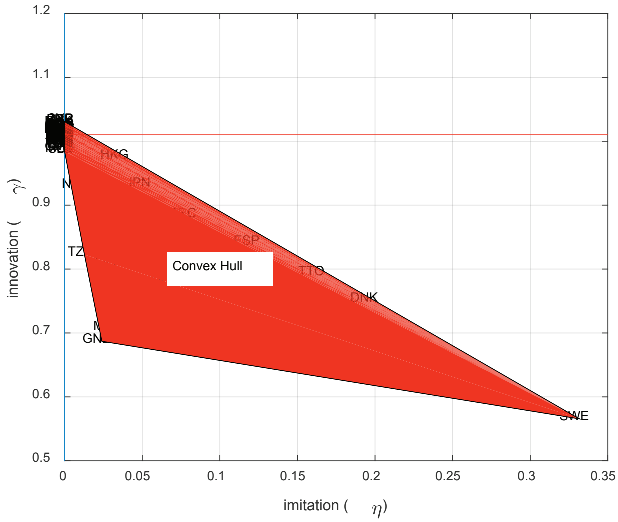
As mentioned above, a restricted model is estimated for countries for which the unrestricted model has returned η_i estimates that are either negative or statistically insignificant at 5% level of significance. Naturally, the restriction is $\eta_i = 0$ and the estimated AR(1) model in this case reads

$$a_{i,t+1} = \beta_{1,i} a_{i,t} + \xi_{i,t} \qquad (10)$$

where $\beta_{1,i}$ identifies γ_i given the frontier growth rate g as before.

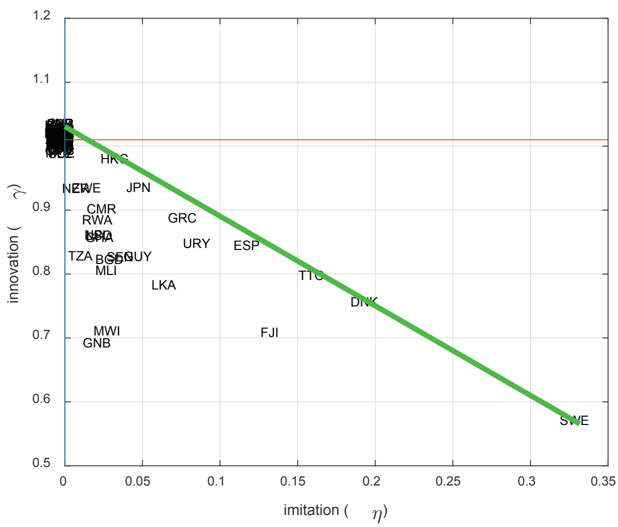
Results reported below merge the two sets of estimates in the following way: If η_i is restricted to be equal to 0 for country i, then the point estimates of (η_i, γ_i) for this country originate from the restricted model. Otherwise, if η_i is positive and statistically significant at 5% level of significance, then (η_i, γ_i) estimates for this country are the ones estimated via unrestricted model and reported in Subsection 6.1.

Figure 10: The Convex Hull (Restricted Model)



Source: Author's own estimation

Figure 11: The Growth Frontier (Restricted Model)



Source: Author's own estimation

Table 4: Innovation Parameters in the Restricted Model

Country	γ_i	Country	γ_i	Country	γ_i
Cyprus	1.0306	United King.	1.0099	Gambia	0.9878
Barbados	1.0292	Canada	1.0086	Mozambique	0.9846
Ireland	1.0290	Peru	1.0079	Sierra Leone	0.9839
China	1.0269	Algeria	1.0076	Hong Kong	0.9746
Botswana	1.0265	Ecuador	1.0076	Japan	0.9304
South Korea	1.0235	Guatemala	1.0074	Zimbabwe	0.9287
Singapore	1.0228	Panama	1.0073	Niger	0.9283
Congo	1.0219	Indonesia	1.0072	Cameroon	0.8969
Mauritius	1.0211	South Africa	1.0070	Greece	0.8829
Thailand	1.0205	Mexico	1.0067	Rwanda	0.8792
Haiti	1.0188	Iran	1.0054	Nepal	0.8553
Portugal	1.0185	Argentina	1.0050	Lesotho	0.8553
Tunisia	1.0178	Paraguay	1.0048	Ghana	0.8520
Italy	1.0177	Bolivia	1.0045	Uruguay	0.8423
Finland	1.0174	Philippines	1.0045	Spain	0.8397
India	1.0172	Switzerland	1.0038	Tanzania	0.8225
Norway	1.0164	Jamaica	1.0022	Guyana	0.8220
Austria	1.0161	New Zealand	1.0020	Senegal	0.8217
Belgium	1.0158	Zambia	1.0020	Bangladesh	0.8178
Malaysia	1.0157	Costa Rica	1.0011	Mali	0.8000
Pakistan	1.0149	Uganda	1.0004	Trin. & Tob.	0.7925
Dom. Rep.	1.0148	Honduras	0.9990	Sri Lanka	0.7771
Israel	1.0146	Benin	0.9977	Denmark	0.7506
Kenya	1.0143	El Salvador	0.9974	Malawi	0.7055
Egypt	1.0133	Venezuela	0.9965	Fiji	0.7033
France	1.0133	Papua New G.	0.9958	Guinea-Bissau	0.6870
Chile	1.0133	Togo	0.9929	Sweden	0.5656
Iceland	1.0123	Nicaragua	0.9908		
Colombia	1.0104	Cen. Afr. Rep.	0.9888		

Source: Author's own estimation

Tables 4 and 5 list the point estimates of γ_i and η_i, respectively. Given these estimates, the convex hull S and the line segment that defines the growth frontier are pictured respectively in Figures 10 and 11.

The frontier is now defined by only aline segment, and this is the one that connects Cyprus and Sweden. Sweden is still the country that has the largest level of imitation parameter that is equal to $\eta_{SWE} = 0.3317$, but Cyprus now dominates Ireland in recording the largest level of innovation parameter of $\gamma_{CYP} = 1.0306$. Once again, all the other countries are located at some distance to the growth frontier.

Table 5: Imitation Parameters in the Restricted Model

Country	η_i	Country	η_i	Country	η_i
Sweden	0.3317	Benin	0.0000	Kenya	0.0000
Denmark	0.1961	Bolivia	0.0000	South Korea	0.0000
Trin. & Tob.	0.1617	Botswana	0.0000	Malaysia	0.0000
Fiji	0.1343	Canada	0.0000	Mauritius	0.0000
Spain	0.1203	Cen. Afr. Rep.	0.0000	Mexico	0.0000
Uruguay	0.0880	Chile	0.0000	Mozambique	0.0000
Greece	0.0789	China	0.0000	New Zealand	0.0000
Sri Lanka	0.0666	Colombia	0.0000	Nicaragua	0.0000
Guyana	0.0503	Congo	0.0000	Norway	0.0000
Japan	0.0503	Costa Rica	0.0000	Pakistan	0.0000
Senegal	0.0386	Cyprus	0.0000	Panama	0.0000
Hong Kong	0.0355	Dom. Rep.	0.0000	Papua New G.	0.0000
Bangladesh	0.0321	Ecuador	0.0000	Paraguay	0.0000
Malawi	0.0301	Egypt	0.0000	Peru	0.0000
Mali	0.0291	El Salvador	0.0000	Philippines	0.0000
Cameroon	0.0270	Finland	0.0000	Portugal	0.0000
Ghana	0.0255	France	0.0000	Sierra Leone	0.0000
Lesotho	0.0254	Gambia	0.0000	Singapore	0.0000
Rwanda	0.0244	Guatemala	0.0000	South Africa	0.0000
Guinea-Bissau	0.0240	Haiti	0.0000	Switzerland	0.0000
Nepal	0.0239	Honduras	0.0000	Thailand	0.0000
Zimbabwe	0.0172	Iceland	0.0000	Togo	0.0000
Tanzania	0.0128	India	0.0000	Tunisia	0.0000
Niger	0.0102	Indonesia	0.0000	Uganda	0.0000
Algeria	0.0000	Iran	0.0000	United King.	0.0000
Argentina	0.0000	Ireland	0.0000	Venezuela	0.0000
Austria	0.0000	Israel	0.0000	Zambia	0.0000
Barbados	0.0000	Italy	0.0000		
Belgium	0.0000	Jamaica	0.0000		

Source: Author's own estimation

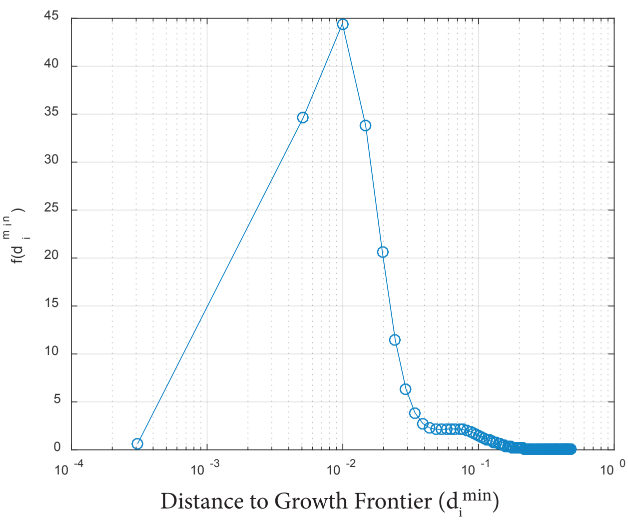
Table 6: Distance to Growth Frontier in the Restricted Model

Country	d_i^{min}	Country	d_i^{min}	Country	d_i^{min}
Barbados	0.0008	Chile	0.0101	El Salvador	0.0193
Ireland	0.0010	Iceland	0.0106	Venezuela	0.0198
China	0.0022	Colombia	0.0118	Papua New G.	0.0203
Botswana	0.0024	United King.	0.0121	Greece	0.0216
Denmark	0.0029	Canada	0.0128	Togo	0.0219
Hong Kong	0.0036	Spain	0.0129	Nicaragua	0.0231
South Korea	0.0041	Peru	0.0132	Cen. Afr. Rep.	0.0243
Singapore	0.0046	Algeria	0.0134	Gambia	0.0249

Congo	0.0051	Ecuador	0.0134	Mozambique	0.0268
Mauritius	0.0055	Guatemala	0.0135	Sierra Leone	0.0272
Thailand	0.0059	Panama	0.0136	Uruguay	0.0377
Trin. & Tob.	0.0066	Indonesia	0.0136	Zimbabwe	0.0452
Haiti	0.0069	South Africa	0.0137	Niger	0.0511
Portugal	0.0071	Mexico	0.0139	Cameroon	0.0557
Tunisia	0.0075	Iran	0.0147	Rwanda	0.0680
Italy	0.0075	Argentina	0.0149	Guyana	0.0802
Finland	0.0077	Paraguay	0.0150	Fiji	0.0807
India	0.0078	Bolivia	0.0152	Lesotho	0.0811
Norway	0.0083	Philippines	0.0152	Nepal	0.0824
Austria	0.0084	Switzerland	0.0156	Ghana	0.0829
Belgium	0.0086	Jamaica	0.0165	Senegal	0.0899
Malaysia	0.0087	New Zealand	0.0166	Sri Lanka	0.0930
Pakistan	0.0091	Zambia	0.0167	Bangladesh	0.0974
Dom. Rep.	0.0092	Costa Rica	0.0171	Mali	0.1102
Israel	0.0093	Japan	0.0173	Tanzania	0.1104
Kenya	0.0095	Uganda	0.0175	Malawi	0.1643
Egypt	0.0100	Honduras	0.0184	Guinea-Bissau	0.1800
France	0.0101	Benin	0.0191		

Source: Author's own estimation

Figure 12: The Density Estimate of the Distance (Restricted Model)



Source: Author's own estimation

The shortest distance to this frontier for any country is calculated and reported in Table 6. Guinea-Bissau is once again the country with the largest distance to the growth frontier. The best-performers with minimum distances are Barbados, Ireland, China, Botswana, and Denmark.

7. Conclusion

This paper uses a simple theory and the relative TFP data for 85 countries for the 1960-2000 period to estimate the sources of economic growth, i.e., innovation and imitation. The theory has only two equations, one for the leader country and one for the others, and three structural parameters only. The data can very easily be mapped into the model equations for a unique identification of structural parameters.

Countries exhibit a diverse pattern of relative TFP growth. Some are successful in achieving growth, and others fail. But both the success stories and the failures have different levels of innovation and imitation parameters. Thus, some fastest-growing economies have low levels of innovation parameters but imitate frontier technologies at rates faster than others. Some others exhibit the opposite pattern, being very good at innovation but have a lower level of imitation parameter. Further, a similar result also holds for the group of countries with weaker and weakest growth performances.

With innovation and imitation being substitute processes that create (relative) TFP growth, the group of countries that exhibit fastest relative TFP growth in the sample period is located away from the rest and defines the growth frontier. The distance from this frontier then becomes a metric that quantifies how poor the relative TFP growth performance is for a particular country.

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Appendix: Notes on estimations and corrections

Results reported in Tables 1 and 2 for the unrestricted model in (7) and in Tables 4 and 5 for the restricted model in (10) build upon the Newey-West correction for the serial correlation. For the unrestricted model, all of the 85 AR(1) slope estimates are statistically significant at the 1% significance level. For exactly 60 countries, the intercept parameter is not significant at the 5% significance level. For Ireland that exhibits very fast relative TFP growth, the intercept parameter is negative. For these 61 countries, the restricted model is estimated. All of the slope parameters for these 61 countries are statistically significant at the 1% significance level under the restriction $\eta_i = 0$. For the remaining 24 countries, the restricted model is not estimated. Clearly, the parameter estimates reported in Tables 4 and 5 for these 24 countries are from the unrestricted model. The entire set of estimation results is available upon request.