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Productivity Convergence and Divergence in Latin America, 1970-2014

CHRISTOS KOLLIAS
Department of Economics, University of Thessaly

PANAYIOTIS TZEREMES
Department of Accounting and Finance, University of Thessaly

NICKOLAOS G. TZEREMES
Department of Economics, University of Thessaly[*]

The paper examines Latin American countries' productivity growth levels and their convergence patterns through nonparametric frontier approaches. Utilizing a sample of 17 Latin American countries for the period 1970-2014 it estimates various productivity indexes alongside their main components. Moreover, a convergence analysis is conducted estimating relative productivity convergence paths. The results suggest that over the period examined, countries' productivity growth levels have contracted. We provide evidence that the implementation of the structural reforms of the 1990s do not appear to have driven Latin American countries to higher productivity levels. Moreover, the results do not render support to the productivity convergence hypothesis. On the other hand, some support was found for countries' technological change levels, identifying three convergence clubs.

Keywords: Productivity convergence; Latin American countries; Nonparametric analysis

JEL Classifications: O40; O47; O54

1 Introduction

A theme that continues to attract attention in the economics literature is that of convergence. Convergence theory is closely related and associated with theories of social change and modernization (Barro, 2015). In brief, it advocates that as countries develop, they will tend to

[*] Department of Economics, University of Thessaly, 28th October street, 78, 38333, Volos, Greece. Corresponding author's email: bus9nt@econ.uth.gr. We would like to thank the Co-Editor Professor Thanasis Stengos and the anonymous reviewers for their useful comments on an earlier version of our manuscript. The usual disclaimer applies.

progressively move towards a condition of similarity. Thus, progressively they will exhibit akin characteristics and attributes in many and varied spheres including income per-capita, labor productivity, organizational structures. The predominant strand of the growing convergence literature focuses on income levels (*inter alia*: Lee, 2019; Barrios *et al*. 2019; King and Ramlogan-Dobson, 2016; Tsanana and Katrakilidis, 2014). In broad terms, as De la Fuente (2000) notes, the process of convergence in income levels implies that in a given group of countries, such as the Latin American ones examined here, income differentials progressively will be reduced when the poorer economies of the group grow faster than their richer neighbors. Hence, as a result, income levels will gradually converge. As pointed out by Islam (2003) the convergence (or the absence of it) hypothesis is strongly linked to the validity issue of alternative growth theories (*inter alia*: De la Fuente, 1997, 2000; Mazumdar, 2003; Inklaar and Timmer, 2009; Martino, 2015). It was initiated by the studies of Solow (1956) and Swan (1956). These seminal contributions were further supported by the works of Barro (1991) and Barro and Sala-i-Martin (1992). Since then, the accumulated theoretical and empirical literature on convergence is rather large and steadily growing, fueling an ongoing discourse. As already noted, the convergence hypothesis has been tested empirically on many and varied themes including convergence in terms of productivity (*inter alia*: Inklaar and Timmer, 2009; Margaritis *et al*. 2007; Sondermann, 2014; Kollias and Messis, 2020). The present paper draws from this productivity convergence literature to examine the presence of convergence (or for that matter divergence) in terms of productivity using a sample of seventeen Latin American countries[1]. In the section that follows we begin with a brief literature review of the convergence studies for Latin America. Section three describes the data used and the methodology employed. In section four, the findings are presented and discussed and section five concludes the paper.

2 Convergence in Latin America: an Epigrammatic Literature Review

The literature on Latin American development is rich and growing. In it, a cohort of factors that affect growth performance on a regional or country level are examined (*inter alia*: Edwards, 2009; Batista, 2004; Reyes and Sawyer, 2011; Cupples, 2013; Ranis and Stewart, 2001; Casacuberta *et al*. 2011; Tzeremes, 2019). A strand of this large body of literature focuses on the issue of income convergence between Latin American countries. Recent examples include King and Ramlogan-Dobson (2016), Ayala *et al*. (2012, 2013), Barrios *et al*. (2019). In a similar vein, convergence patterns of Latin America countries' growth factors, have also been comprehensively analyzed using different methodological approaches. Easterly *et al*. (1997) evaluated the structural reforms of Latin America countries during the 1990s. The results

[1]The sample consists of the following countries: Argentina, Belize, Bolivia, Brazil, Chile, Colombia, Ecuador, El Salvador, Guatemala, Honduras, Mexico, Nicaragua, Panama, Paraguay, Peru, Uruguay, Venezuela

indicate the existence of growth convergence alongside with an average of 2% growth during the examined period. On the other hand, Taylor (1998) using a five year-period for 1970 to 1989 applies a structural growth regression model examines the growth determinants between Latin America and Asia-Pacific. The results suggest that Latin America's adopted policies had a negative effect on countries' growth rates which was driven by a low investment path. Similarly, Devlin and Ffrench-Davis (1999) analyzed the reforms implemented in Latin America during 1990s giving emphasis on the agreements of regional integration. Their findings reveal policy implementation obstacles that arose during the regional integration process, which in turn affected negatively countries' growth performance. Dobson and Ramlogan (2002a) provide evidence of unconditional *b*-convergence among the Latin America countries between 1960 and 1990. However, during the mid-1980s the results do not support the convergence hypothesis. Similar findings are also reported by Dobson and Ramlogan (2002b). During the 1970s there was convergence among Latin American countries, but for the 1990s convergence cannot be empirically supported. In contrast, over the period of 1983-1993, Ramirez and Nazmi (2003) report findings in favour of conditional convergence among Latin American countries. Evidence of stochastic convergence between nineteen Latin American countries is also reported by Galvao and Reis Gomes (2007) over the period 1951 to 1999. On the other hand, the findings of Astorga *et al*. (2005) and Astorga (2010) indicate that convergence occurs among the largest Latin American countries and not with the smaller economies. Barrios *et al*. (2019) identify four groups of Latin American countries each one converging towards its own steady-state path. King and Ramlogan-Dobson (2016) report findings that point to the presence of two such clubs. Astorga *et al*. (2011) examined the productivity levels of the six largest Latin American countries over the period 1900-2000. Their findings suggest that total factor productivity has decreased over the last three decades. The decrease of TFP of Latin American countries after 1970s is also confirmed by the study of Ferreira *et al*. (2013).

The contribution of the paper is based in the utilization of nonparametric frontier approaches for investigating productivity-convergence phenomena in Latin America (*inter alia*: Margaritis *et al*. 2007; Badunenko *et al*. 2008; Castillo *et al*. 2011). Using the sample of the seventeen Latin American countries over the period 1970-2014 the paper applies four different productivity decompositions (Färe *et al*. 1994; Ray and Desli 1997; Simar and Wilson 1998) in order to measure countries' productivity levels. Since we cover a period under which countries have been engaged on different macro-economic reform programmes, the adopted nonparametric framework allows to model productivity without imposing any specific functional form on estimated countries' production function (Margaritis *et al*. 2007).

Given the fact that convergence is a key factor of market integration and economic growth (Bianco *et al*., 1997; Cabral and Castellanos-Sosa, 2019), Phillips and Sul's (2007, 2009) convergence approach is adopted in order to identify any productivity convergence paths. In addition, we utilize Quah's (1996a, 1996b) methodological approach in order to examine the distributional dynamics of countries' productivity levels. Both methodological frameworks allow us to test different convergence/divergence patterns of countries' productivity levels (and their components), alongside with the existence of possible productivity convergence clubs. To this end, in the next section, we proceed with the presentation of the data and methodology used.

3 Variable Description and Methodological Framework

3.1 Data description

As noted in the introduction, for the purposes of the analysis conducted herein, we use a sample of seventeen Latin American countries over the period 1970-2014. Specifically, in order to estimate countries' aggregate production process, we use as inputs total employment (in millions) and capital stock at current PPPs (in billions 2011US$). As output we use output-side real GDP at current PPPs (in billions 2011US$). All the data have been extracted from the latest Penn World Tables (PWT version 9.0). According to Feenstra *et al.* (2015) the latest PWT version improves some methodological issues of the previous releases while the reference year in the PWT 9.0 has been changed from 2005 to 2011. Table 1 presents the descriptive statistics of the variables used in our analysis.

3.2 Methodological framework

3.2.1 Estimation of output distance functions

Let countries' production process to be defined by a set of input $\boldsymbol{x} \in \mathbb{R}_{+}^{\boldsymbol{p}}$ and output $\boldsymbol{y} \in \mathbb{R}_{+}^{\boldsymbol{q}}$ vectors. In addition, by assuming convexity and strong disposability of inputs and outputs. Therefore, the production possibility set at time t can be presented as:

$$\Psi^{t} = \{(\boldsymbol{x}, \boldsymbol{y}) | \boldsymbol{x} \text{ can produce } \boldsymbol{y} \text{ at time t}\} \quad (1)$$

For the purpose of our analysis we need to define output distance functions for current and mixed periods, which will enable us to construct the productivity and their decomposed components. Following Simar and Wilson (1998) we can define a set Φ^{t} as the convex cone which is spanned by Ψ^{t} such as $\Psi^{t} \subseteq \Phi^{t}$. If however the technology is assumed to be expressed by constant returns to scale (CRS) everywhere, then $\Psi^{t} = \Phi^{t}$. However, if it is assumed to be expressed by variable returns to scale (VRS) then $\Psi^{t} \subset \Phi^{t}$. In that, respect the Shephard (1970) output distance functions for the input-output vectors of countries i at current period t for the future period t_{k} and the case of mixed periods, can be defined as follows:

Table 1: Descriptive statistics of the variables over the period 1970-2014.

Country	Country	Statistic	Labor	Capital Stock	GDP
ARG	Argentina	mean	12.33	859520.70	361713.01
		Std	3.01	683238.87	253570.42
BLZ	Belize	mean	0.07	1662.02	1219.65
		Std	0.03	1399.04	707.65
BOL	Bolivia	mean	2.88	39045.84	22812.80
		Std	1.04	29854.95	14912.93
BRA	Brazil	mean	70.18	3924439.24	1257379.08
		Std	20.65	3537967.06	783575.48
CHL	Chile	mean	4.64	355559.25	148968.91
		Std	1.55	308349.95	94539.40
COL	Colombia	mean	13.94	773414.30	273822.66
		Std	5.53	414684.59	129949.67
ECU	Ecuador	mean	3.59	187725.70	68197.75
		Std	1.43	159095.90	41272.66
SLV	El Salvador	mean	1.80	23232.19	12910.98
		Std	0.49	30495.30	13576.04
GTM	Guatemala	mean	2.93	91116.06	47834.55
		Std	1.16	83359.51	27859.97
HND	Honduras	mean	1.77	43165.74	17766.76
		Std	0.80	35207.03	8939.63
MEX	Mexico	mean	30.88	2549712.14	1050096.78
		Std	11.87	1525412.96	421384.08
NIC	Nicaragua	mean	1.34	50608.70	17990.72
		Std	0.60	18350.09	3769.28
PAN	Panama	mean	0.90	50771.41	26126.40
		Std	0.41	47290.44	19303.85
PRY	Paraguay	mean	1.74	47252.33	20634.19
		Std	3.41	40888.96	13201.92
PER	Peru	mean	8.47	288406.98	124840.63
		Std	3.41	255266.18	82688.80
URY	Uruguay	mean	1.32	100637.49	33160.07
		Std	0.22	58676.73	11978.20
VEN	Venezuela	mean	7.07	777954.71	218429.48
		Std	2.85	560057.84	123497.44

$$\Delta^t(\boldsymbol{x}_i^t\boldsymbol{y}_i^t) \equiv \inf\{\vartheta > 0 | (\boldsymbol{x}_i^t, \boldsymbol{y}_i^t/\vartheta) \in \Psi^t\} \quad (2)$$

$$\Delta^{t_k}(\boldsymbol{x}_i^{t_k}, \boldsymbol{y}_i^{t_k}) \equiv \inf\{\vartheta > 0 | (\boldsymbol{x}_i^{t_k}, \boldsymbol{y}_i^{t_k}/\vartheta) \in \Psi^{t_k}\} \quad (3)$$

$$\Delta^{t_k}(\boldsymbol{x}_i^t, \boldsymbol{y}_i^t) \equiv \inf\{\vartheta > 0 | (\boldsymbol{x}_i^t, \boldsymbol{y}_i^t/\vartheta) \in \Psi^{t_k}\} \quad (4)$$

$$\Delta^t(\boldsymbol{x}_i^{t_k}, \boldsymbol{y}_i^{t_k}) \equiv \inf\{\vartheta > 0 | (\boldsymbol{x}_i^{t_k}, \boldsymbol{y}_i^{t_k}/\vartheta) \in \Psi^t\} \quad (5)$$

$$D^t(\boldsymbol{x}_i^t, \boldsymbol{y}_i^t) \equiv \inf\{\vartheta > 0 | (\boldsymbol{x}_i^t, \boldsymbol{y}_i^t/\vartheta) \in \Phi^t\} \quad (6)$$

$$D^{t_k}(\boldsymbol{x}_i^{t_k}, \boldsymbol{y}_i^{t_k}) \equiv \inf\{\vartheta > 0 | (\boldsymbol{x}_i^{t_k}, \boldsymbol{y}_i^{t_k}/\vartheta) \in \Phi^{t_k}\} \quad (7)$$

$$D^{t_k}(\boldsymbol{x}_i^t, \boldsymbol{y}_i^t) \equiv \inf\{\vartheta > 0 | (\boldsymbol{x}_i^t, \boldsymbol{y}_i^t/\vartheta) \in \Phi^{t_k}\} \quad (8)$$

$$D^t(\boldsymbol{x}_i^{t_k}, \boldsymbol{y}_i^{t_k}) \equiv \inf\{\vartheta > 0 | (\boldsymbol{x}_i^{t_k}, \boldsymbol{y}_i^{t_k}/\vartheta) \in \Phi^t\} \quad (9)$$

Distance functions under the assumption of VRS are defined by the expressions (2) to (5), whereas, expressions (6) to (9) define the distance functions under the CRS assumption. The estimators for the distance functions described previously can then be estimated by:

$$\hat{\Delta}_n^t(\boldsymbol{x}_i^t, \boldsymbol{y}_i^t) = \max\{\vartheta | \vartheta \boldsymbol{y}_i^t \leq \boldsymbol{\xi}\boldsymbol{Y}_i^t, \boldsymbol{x}_i^t \geq \boldsymbol{\xi}\boldsymbol{X}_i^t, \boldsymbol{i\xi} = 1, \boldsymbol{\xi} \in \mathbb{R}_+^n\} \quad (10)$$

$$\hat{\Delta}_n^{t_k}(\boldsymbol{x}_i^{t_k}, \boldsymbol{y}_i^{t_k}) = \max\{\vartheta | \vartheta \boldsymbol{y}_i^{t_k} \leq \boldsymbol{\xi}\boldsymbol{Y}_i^{t_k}, \boldsymbol{x}_i^{t_k} \geq \boldsymbol{\xi}\boldsymbol{X}_i^{t_k}, \boldsymbol{i\xi} = 1, \boldsymbol{\xi} \in \mathbb{R}_+^n\} \quad (11)$$

$$\hat{\Delta}_n^{t_k}(\boldsymbol{x}_i^t, \boldsymbol{y}_i^t) = \max\{\vartheta | \vartheta \boldsymbol{y}_i^t \leq \boldsymbol{\xi}\boldsymbol{Y}_i^{t_k}, \boldsymbol{x}_i^t \geq \boldsymbol{\xi}\boldsymbol{X}_i^{t_k}, \boldsymbol{i\xi} = 1, \boldsymbol{\xi} \in \mathbb{R}_+^n\} \quad (12)$$

$$\hat{\Delta}_n^t(\boldsymbol{x}_i^{t_k}, \boldsymbol{y}_i^{t_k}) = \max\{\vartheta | \vartheta \boldsymbol{y}_i^{t_k} \leq \boldsymbol{\xi}\boldsymbol{Y}_i^t, \boldsymbol{x}_i^{t_k} \geq \boldsymbol{\xi}\boldsymbol{X}_i^t, \boldsymbol{i\xi} = 1, \boldsymbol{\xi} \in \mathbb{R}_+^n\} \quad (13)$$

$$\widehat{D}_n^t(\boldsymbol{x}_i^t, \boldsymbol{y}_i^t) = \max\{\vartheta | \vartheta \boldsymbol{y}_i^t \leq \boldsymbol{\xi}\boldsymbol{Y}_i^t, \boldsymbol{x}_i^t \geq \boldsymbol{\xi}\boldsymbol{X}_i^t, \boldsymbol{\xi} \in \mathbb{R}_+^n\} \quad (14)$$

$$\widehat{D}_n^{t_k}(\boldsymbol{x}_i^{t_k}, \boldsymbol{y}_i^{t_k}) = \max\{\vartheta | \vartheta \boldsymbol{y}_i^{t_k} \leq \boldsymbol{\xi}\boldsymbol{Y}_i^{t_k}, \boldsymbol{x}_i^{t_k} \geq \boldsymbol{\xi}\boldsymbol{X}_i^{t_k}, \boldsymbol{\xi} \in \mathbb{R}_+^n\} \quad (15)$$

$$\widehat{D}_n^{t_k}(\boldsymbol{x}_i^t, \boldsymbol{y}_i^t) = \max\{\vartheta | \vartheta \boldsymbol{y}_i^t \leq \boldsymbol{\xi}\boldsymbol{Y}_i^{t_k}, \boldsymbol{x}_i^t \geq \boldsymbol{\xi}\boldsymbol{X}_i^{t_k}, \boldsymbol{\xi} \in \mathbb{R}_+^n\} \quad (16)$$

$$\widehat{D}_n^t(\boldsymbol{x}_i^{t_k}, \boldsymbol{y}_i^{t_k}) = \max\{\vartheta | \vartheta \boldsymbol{y}_i^{t_k} \leq \boldsymbol{\xi}\boldsymbol{Y}_i^t, \boldsymbol{x}_i^{t_k} \geq \boldsymbol{\xi}\boldsymbol{X}_i^t, \boldsymbol{\xi} \in \mathbb{R}_+^n\} \quad (17)$$

In equations (10) to (17), $\boldsymbol{Y}^t = [\boldsymbol{y}_i^t, \dots, \boldsymbol{y}_n^t]$, $\boldsymbol{Y}^{t_k} = [\boldsymbol{y}_i^{t_k}, \dots, \boldsymbol{y}_n^{t_k}]$, $\boldsymbol{X}^t = [\boldsymbol{x}_i^t, \dots, \boldsymbol{x}_n^t]$, $\boldsymbol{X}^{t_k} = [\boldsymbol{x}_i^{t_k}, \dots, \boldsymbol{x}_n^{t_k}]$.

3.2.2 Productivity indexes and main decompositions

Based on the works by Caves *et al*. (1982) and Färe *et al*. (1994) we can define the Malmquist Productivity Index (MPI) as[2]:

$$M(\boldsymbol{x}_i^t, \boldsymbol{y}_i^t, \boldsymbol{x}_i^{t_k}, \boldsymbol{y}_i^{t_k}) = \underbrace{\left[\frac{\widehat{D}_n^{t_k}(\boldsymbol{x}_i^{t_k}, \boldsymbol{y}_i^{t_k})}{\widehat{D}_n^{t}(\boldsymbol{x}_i^{t}, \boldsymbol{y}_i^{t})}\right]}_{TE\Delta_{CRS}} \times \underbrace{\left\{\left[\frac{\widehat{D}_n^{t}(\boldsymbol{x}_i^{t_k}, \boldsymbol{y}_i^{t_k})}{\widehat{D}_n^{t_k}(\boldsymbol{x}_i^{t_k}, \boldsymbol{y}_i^{t_k})} \times \frac{\widehat{D}_n^{t}(\boldsymbol{x}_i^{t}, \boldsymbol{y}_i^{t})}{\widehat{D}_n^{t_k}(\boldsymbol{x}_i^{t}, \boldsymbol{y}_i^{t})}\right]\right\}^{1/2}}_{T\Delta_{CRS}} \tag{18}$$

The first part ($TE\Delta_{CRS}$) in equation (18) describes efficiency changes (technological catch-up), whereas, the second part ($T\Delta_{CRS}$) describes technological changes among the two examined periods. Similarly, by following Färe *et al*. (1994) equation (19) presents a different decomposition. Specifically, under the VRS assumption countries' efficiency change is presented by $TE\Delta_{VRS}$, whereas, $SE\Delta$ captures the scale efficiency component. In addition, $T\Delta_{CRS}$ captures countries' technological changes levels:

$$\begin{aligned} M(\boldsymbol{x}_i^t, \boldsymbol{y}_i^t, \boldsymbol{x}_i^{t_k}, \boldsymbol{y}_i^{t_k}) &= \underbrace{\left[\frac{\hat{\Delta}_n^{t_k}(\boldsymbol{x}_i^{t_k}, \boldsymbol{y}_i^{t_k})}{\hat{\Delta}_n^{t}(\boldsymbol{x}_i^{t}, \boldsymbol{y}_i^{t})}\right]}_{TE\Delta_{VRS}} \times \underbrace{\left\{\frac{[\widehat{D}_n^{t_k}(\boldsymbol{x}_i^{t_k}, \boldsymbol{y}_i^{t_k}) / \hat{\Delta}_n^{t_k}(\boldsymbol{x}_i^{t_k}, \boldsymbol{y}_i^{t_k})]}{[\widehat{D}_n^{t}(\boldsymbol{x}_i^{t}, \boldsymbol{y}_i^{t}) / \hat{\Delta}_n^{t}(\boldsymbol{x}_i^{t}, \boldsymbol{y}_i^{t})]}\right\}}_{SE\Delta} \\ &\times \underbrace{\left\{\left[\frac{\widehat{D}_n^{t}(\boldsymbol{x}_i^{t_k}, \boldsymbol{y}_i^{t_k})}{\widehat{D}_n^{t_k}(\boldsymbol{x}_i^{t_k}, \boldsymbol{y}_i^{t_k})} \times \frac{\widehat{D}_n^{t}(\boldsymbol{x}_i^{t}, \boldsymbol{y}_i^{t})}{\widehat{D}_n^{t_k}(\boldsymbol{x}_i^{t}, \boldsymbol{y}_i^{t})}\right]\right\}^{1/2}}_{T\Delta_{CRS}} \end{aligned} \tag{19}$$

Later in a different decomposition, Ray and Desli (1997) merged the $SE\Delta$ and the $T\Delta_{CRS}$ factor and presented an alternative decomposition (equation 20).[3] As can been observed the alternative decomposed MPI measures catch-up effects and technological change effects under the VRS assumption, whereas, introduces a new 'scale change factor' ($S\Delta$), which is the geometric mean of scale efficiencies ratios having as benchmark the two examined periods.

[2] For other approaches on the estimation of productivity growth see the studies by Empora and Mamuneas (2011), Polemis and Stengos (2015) and Kalaiitzidakis *et al*., (2018).

[3] For a detail analysis of the advantages and disadvantages of the main Malmquist productivity decompositions see Lovell (2003).

$$M(\boldsymbol{x}_i^t, \boldsymbol{y}_i^t, \boldsymbol{x}_i^{t_k}, \boldsymbol{y}_i^{t_k}) = \underbrace{\left[\frac{\hat{\Delta}_n^{t_k}(\boldsymbol{x}_i^{t_k}, \boldsymbol{y}_i^{t_k})}{\hat{\Delta}_n^{t}(\boldsymbol{x}_i^{t}, \boldsymbol{y}_i^{t})}\right]}_{TE\Delta_{VRS}} \times \underbrace{\left[\frac{\hat{\Delta}_n^{t}(\boldsymbol{x}_i^{t_k}, \boldsymbol{y}_i^{t_k})}{\hat{\Delta}_n^{t_k}(\boldsymbol{x}_i^{t_k}, \boldsymbol{y}_i^{t_k})} \times \frac{\hat{\Delta}_n^{t}(\boldsymbol{x}_i^{t}, \boldsymbol{y}_i^{t})}{\hat{\Delta}_n^{t_k}(\boldsymbol{x}_i^{t}, \boldsymbol{y}_i^{t})}\right]^{\frac{1}{2}}}_{T\Delta_{VRS}} \times \underbrace{\left\{\left[\frac{\hat{D}_n^{t}(\boldsymbol{x}_i^{t_k}, \boldsymbol{y}_i^{t_k})/\hat{\Delta}_n^{t}(\boldsymbol{x}_i^{t_k}, \boldsymbol{y}_i^{t_k})}{\hat{D}_n^{t}(\boldsymbol{x}_i^{t}, \boldsymbol{y}_i^{t})/\hat{\Delta}_n^{t}(\boldsymbol{x}_i^{t}, \boldsymbol{y}_i^{t})}\right] \times \left[\frac{\hat{D}_n^{t_k}(\boldsymbol{x}_i^{t_k}, \boldsymbol{y}_i^{t_k})/\hat{\Delta}_n^{t_k}(\boldsymbol{x}_i^{t_k}, \boldsymbol{y}_i^{t_k})}{\hat{D}_n^{t_k}(\boldsymbol{x}_i^{t}, \boldsymbol{y}_i^{t})/\hat{\Delta}_n^{t_k}(\boldsymbol{x}_i^{t}, \boldsymbol{y}_i^{t})}\right]\right\}^{1/2}}_{S\Delta}. \tag{20}$$

However, Simar and Wilson (1998) suggest that if the $S\Delta \neq 1$ we are not able to identify if the productivity change is caused due to the change of the technology or from the movements away or towards the frontier, or even from a combination of the two phenomena. Simar and Wilson (1998) provide an alternative productivity decomposition (equation 21). It is clearly that this productivity index consists four different components. The $TE\Delta_{VRS}$ is the same as in the decomposition of Färe et al. (1994) and Ray and Desli (1997) and measures the technological catch-up over the two periods under the assumption of VRS. Similarly $SE\Delta$ measures the scale efficiency as in the decomposition of Färe *et al*. (1994) and $T\Delta_{VRS}$ is the technological change factor under the assumption of VRS which is identical to the one presented in Ray and Desli (1997):

$$M(\boldsymbol{x}_i^t, \boldsymbol{y}_i^t, \boldsymbol{x}_i^{t_k}, \boldsymbol{y}_i^{t_k}) = \underbrace{\left[\frac{\hat{\Delta}_n^{t_k}(\boldsymbol{x}_i^{t_k}, \boldsymbol{y}_i^{t_k})}{\hat{\Delta}_n^{t}(\boldsymbol{x}_i^{t}, \boldsymbol{y}_i^{t})}\right]}_{TE\Delta_{VRS}} \times \underbrace{\left\{\frac{[\hat{D}_n^{t_k}(\boldsymbol{x}_i^{t_k}, \boldsymbol{y}_i^{t_k})/\hat{\Delta}_n^{t_k}(\boldsymbol{x}_i^{t_k}, \boldsymbol{y}_i^{t_k})]}{[\hat{D}_n^{t}(\boldsymbol{x}_i^{t}, \boldsymbol{y}_i^{t})/\hat{\Delta}_n^{t}(\boldsymbol{x}_i^{t}, \boldsymbol{y}_i^{t})]}\right\}}_{SE\Delta} \times \underbrace{\left[\frac{\hat{\Delta}_n^{t}(\boldsymbol{x}_i^{t_k}, \boldsymbol{y}_i^{t_k})}{\hat{\Delta}_n^{t_k}(\boldsymbol{x}_i^{t_k}, \boldsymbol{y}_i^{t_k})} \times \frac{\hat{\Delta}_n^{t}(\boldsymbol{x}_i^{t}, \boldsymbol{y}_i^{t})}{\hat{\Delta}_n^{t_k}(\boldsymbol{x}_i^{t}, \boldsymbol{y}_i^{t})}\right]^{\frac{1}{2}}}_{T\Delta_{VRS}} \times \underbrace{\left\{\left[\frac{\hat{D}_n^{t}(\boldsymbol{x}_i^{t_k}, \boldsymbol{y}_i^{t_k})/\hat{\Delta}_n^{t}(\boldsymbol{x}_i^{t_k}, \boldsymbol{y}_i^{t_k})}{\hat{D}_n^{t_k}(\boldsymbol{x}_i^{t_k}, \boldsymbol{y}_i^{t_k})/\hat{\Delta}_n^{t_k}(\boldsymbol{x}_i^{t_k}, \boldsymbol{y}_i^{t_k})}\right] \times \left[\frac{\hat{D}_n^{t}(\boldsymbol{x}_i^{t}, \boldsymbol{y}_i^{t})/\hat{\Delta}_n^{t}(\boldsymbol{x}_i^{t}, \boldsymbol{y}_i^{t})}{\hat{D}_n^{t_k}(\boldsymbol{x}_i^{t}, \boldsymbol{y}_i^{t})/\hat{\Delta}_n^{t_k}(\boldsymbol{x}_i^{t}, \boldsymbol{y}_i^{t})}\right]\right\}^{1/2}}_{SBT\Delta} \tag{21}$$

According to Simar and Wilson (1998, p.10) the last factor ($SBT\Delta$) measures the changes in scale of the technology under the two examined periods.[4] It must be noted that $SBT\Delta$ accounts for those changes that are attributed to changes in the shape of the technology. Therefore if $SBT\Delta > 1$ indicates an increasing curvature of the technology implying that a VRS assumption is more appropriate, whereas, when $SBT\Delta < 1$ indicates a flattening of the technology implying that a CRS assumption is more appropriate when measuring productivity levels among two periods.

[4] According to Lovell (2003, p.456) the SBTΔ factor can be interpreted as the scale bias of technical change.

3.2.3 Club convergence

As a further step we follow the relative literature (Camarero *et al*., 2013, 2014; Chen *et al*., 2018), which performs an efficiency estimation on a first stage and a convergence estimation of the obtained efficiencies in a second stage. Specifically, we apply the Phillips and Sul's (2007) approach to check the convergence-divergence patterns of countries' productivity levels and its components. The two methodological approaches are well integrated since Phillips and Sul's (2007) is less restricted by strong assumptions relied to trend and to the stochastic stationarity of the sample. Moreover, the estimations conducted under their convergence approach is in relative terms, which is also aligned with the nonparametric productivity methodology described in the previous section[5].

Firstly, we apply a time–varying factor of the estimated MPI and its components series m_{it}, defined as:

$$m_{it} = \gamma_{it}\mu_t \tag{22}$$

In equation (22) γ_{it} represents the time-varying idiosyncratic factor capturing potential deviations of state i from a path defined by μ_t, which is a single component. In that respect we can assume that countries' 'N'-groups can converge in the future to a steady state when $\lim_{\varphi\to\infty} \gamma_{it+\varphi} = \gamma$ for all $i = 1,2,\dots,,N$. Phillips and Sul (2007) describe how the transition path can be measured in average terms as:

$$h_{it} = \frac{m_{it}}{\left[\frac{1}{N\sum_{j=1}^{N} m_{jt}}\right]} = \frac{\gamma_{it}}{\left[\frac{1}{N\sum_{j=1}^{N} \gamma_{jt}}\right]} \tag{23}$$

Moreover, it is assumed that:

$$\gamma_{it} = \gamma_i + \sigma_{it}\xi_{it}, \tag{24}$$

where $\sigma_{it} = \frac{\sigma_i}{[L(t)t^{\alpha}]}$, $\sigma_i > 0, t \geq 0$ and $L(t) = log(t)$. Then the convergence hypothesis can be defined as:

$$H_0: \gamma_{it} = \gamma, \alpha \geq 0, \tag{25}$$

and the alternative hypothesis (non-convergence) as:

[5] For different approaches on convergence measurement see the studies by Wells and Stengos (2010), Stengos and Yazgan (2014), Stengos *et al.* (2017, 2018) and Beylunioğlu *et al.* (2018, 2020).

$$H_1: \gamma_{it} \neq \gamma, \alpha < 0. \tag{26}$$

In order to test the null hypothesis Phillips and Sul (2007) propose to estimate the following regression:

$$log(H_1/H_t) - 2logL(t) = \hat{c} + blogt + \hat{u}_t. \tag{27}$$

A we can see from equation (27) $b = 2\breve{\alpha}$ and the null hypothesis can be estimated as one sided test of $b \geq 0$ against $b < 0$. As a result, by calculating an one-sided test, we can reject the null –hypothesis if the critical *t-value* is less than -1.65. This test can be applied to different country clubs. Finally, we apply a four-step algorithm developed by Phillips and Sul (2007) which enable us to identify different productivity clubs among the countries.

4 Empirical Findings

We begin by analyzing countries' productivity levels between 1970 and 2014. The results are presented in Table 2. Looking the mean productivity values it is evident that countries' productivity levels among these two years are 0.7856. When the estimated value of $M(x_i^t, y_i^t, x_i^{t_k}, y_i^{t_k})$ is below 1 it indicates that countries productivity levels has descended between 1970 and 2014. In fact it appears that only Colombia and Ecuador have $M(x_i^t, y_i^t, x_i^{t_k}, y_i^{t_k})$ values greater than 1 indicating an increase on their productivity levels over the two periods.[6] The countries with the lowest productivity levels are: Nicaragua, Paraguay, Belize, Honduras and Peru. When examine countries' catching up levels $(TE\Delta_{CRS})$ and $(TE\Delta_{VRS})$ it is evident that on average terms countries' have efficiency change values greater than one, which signifies their ability to move towards the estimated technological frontier over the two examined periods. It is also evident that when the technologies exhibit variable returns to scale, 11 out of 17 countries have estimated pure efficiency values greater than one. This in turn suggests that when we account for an increasing curvature of the estimated technology more countries have higher pure efficiency change values. Furthermore, Table 2 presents the results of the estimated technological (technical) change under the CRS $(T\Delta_{CRS})$ and VRS $(T\Delta_{VRS})$ assumption. Technical change signifies the movements of the frontier (i.e. the shift of the technology) under the CRS or the VRS assumption. Values greater than one indicate an improvement, values equal to one suggest no improvement, whereas, values less than one suggest that there is no technological improvement between the two periods. It appears that both under the assumption of CRS and VRS the majority of countries have a technological

[6] It must be noted that Argentina has a $M(\boldsymbol{x}_i^t, \boldsymbol{y}_i^t, \boldsymbol{x}_i^{t_k}, \boldsymbol{y}_i^{t_k})$ value of 0.9939. However, we cannot assume if the estimation is statistical significant from unity.

change measure less than 1, indicating a shortage of technological improvement among the two periods.[7] From the other hand $SE\Delta$ measures the scale efficiency change over the two periods. A scale efficient country is deemed when values are above 1, with values less than one indicating scale inefficient countries. The overall findings suggest that on average terms the Latin American countries are not operating on scale efficient sizes among the two periods. It appears that only Argentina, Bolivia, Brazil, Guatemala and Panama are scale efficient. Ray and Desli (1997) in their productivity decomposition presented the scale change factor $S\Delta$ which is a geometric mean of two $SE\Delta$ ratios measured in respect to the two examined periods. Again it is reported that on average terms $S\Delta$ values are below one, suggesting that Latin American countries are scale inefficient over the two examined periods. Similarly, the estimated countries values of $SBT\Delta$ are below one, suggesting that a scale bias on technical change occurs resulting to a flattening of the technology (Simar and Wilson 1998). This is evident in our case since on average terms countries' $SBT\Delta$ are below one (i.e. 0.888) signifying the existence of CRS technology among the two periods. Finally, we can conclude that during the two periods the productivity levels of Latin American countries was driven by their ability to catch-up to the technological frontier.

Table 2 presented countries' productivity levels over a large period of time (i.e. 1970 and 2014). However, even though the results provide us with a concrete view among the two periods; the analysis wasn't able to provide us with evidence of the effect of different policy adjustments and reforms adopted on countries' productivity levels over the several decades. For this reason we re-run our analysis by using the two years of every decade estimating therefore countries' productivity measures in a ten-year basis. Table 3 presents countries' average productivity estimates (alongside with their components) under the assumption of CRS technology for the periods: 1970-1980, 1980-1990, 1990-2000, 2000-2010 and 2010-2014.[8] The results suggest that countries' productivity was deteriorated only during the period 1980-1990 and 2010-2014.[9] For all the other examined periods we observe an increase on countries' productivity levels. It is evident that during the post-reform period (i.e. during the 1990s), country productivity levels have been increased.

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[7] It can be also observed in the estimation of technological change under the VRS assumption we encounter estimation problems with infeasibility (inf). According to Grosskopf (2003, p.461) this is common when calculating mixed period under the VRS assumption.

[8] Since the PWT v.9 database provides data up to 2014, the productivity measurement of the last to year period in our analysis covers only the years 2010 and 2014.

[9] Our findings for $SBT\Delta$ values are below unity suggesting a flattering of the technology. This finding therefore provides support that the estimated technology exhibits CRS (Simar and Wilson 1998). The analytical results are available upon request.

Table 2: Countries' productivity levels and its components between 1970-2014

Country Code	$M(\boldsymbol{x}_i^t, \boldsymbol{y}_i^t, \boldsymbol{x}_i^{t_k}, \boldsymbol{y}_i^{t_k})$	$TE\Delta_{CRS}$	$T\Delta_{CRS}$	$TE\Delta_{VRS}$	$SE\Delta$	$T\Delta_{VRS}$	$S\Delta$	$SBT\Delta$
ARG	0.9939	1.2496	0.7954	1.0000	1.2496	1.0726	0.9267	0.7416
BLZ	0.5703	1.0000	0.5703	1.0000	1.0000	*inf*	*inf*	*inf*
BOL	0.9680	1.9225	0.5035	1.8678	1.0293	0.5522	0.9385	0.9118
BRA	0.8564	1.0605	0.8075	1.0000	1.0605	2.2148	0.3867	0.3646
CHL	0.9225	1.0000	0.9225	1.0000	1.0000	0.8955	1.0301	1.0301
COL	1.3187	1.5007	0.8787	1.5140	0.9912	1.2047	0.7230	0.7294
ECU	1.1121	1.3097	0.8491	1.3204	0.9919	0.8265	1.0190	1.0273
SLV	0.4927	0.9005	0.5471	1.0000	0.9005	*inf*	*inf*	*inf*
GTM	0.6083	0.9822	0.6194	0.9384	1.0466	0.6272	1.0335	0.9875
HND	0.5143	0.9070	0.5670	0.9400	0.9649	0.5653	0.9679	1.0031
MEX	0.8801	0.7879	1.1170	1.0000	0.7879	1.9895	0.4424	0.5614
NIC	0.3951	0.5666	0.6973	0.6424	0.8820	0.6389	0.9625	1.0914
PAN	0.9265	1.0805	0.8575	1.0471	1.0319	0.8658	1.0220	0.9904
PRY	0.4406	0.7915	0.5567	0.8694	0.9104	*inf*	*inf*	*inf*
PER	0.5505	0.8844	0.6225	0.8942	0.9890	0.6605	0.9321	0.9424
URY	0.9381	0.9769	0.9603	1.0167	0.9608	0.9068	1.0175	1.0590
VEN	0.8671	0.7838	1.1063	0.7907	0.9913	1.1148	0.9837	0.9923
Mean	*0.7856*	*1.0414*	*0.7634*	*1.0495*	*0.9875*	*1.0097*	*0.8847*	*0.8880*
Std	*0.2638*	*0.3159*	*0.1964*	*0.2837*	*0.0960*	*0.5081*	*0.2144*	*0.2122*
Min	*0.3951*	*0.5666*	*0.5035*	*0.6424*	*0.7879*	*0.5522*	*0.3867*	*0.3646*
Max	*1.3187*	*1.9225*	*1.1170*	*1.8678*	*1.2496*	*2.2148*	*1.0335*	*1.0914*

This finding finds support by the study of Easterly et al. (1997), suggesting an overall growth of 2% during the post-reform period. Similarly, the reported deterioration of countries' productivity levels between 1980-1990 finds also support from the evidence provided by Taylor (1998), signifying that distortion policies had a negative effect during the specified period. Moreover, Table 3 suggests that between 2010 and 2014 countries' productivity levels are estimated below unity, suggesting a slight regress of productivity. Following the remarks raised by Simar and Wilson (1998) we have further adopted the productivity estimates under the assumption of CRS since the estimated SBTΔ values are below unity.[10]

[10] In addition it must be highlighted that Malmquist and Hicks–Moorsteen productivity indexes coincide under the assumption of CRS and the assumption of homotheticity (Färe *et al.* 1996, 2021; Peyrache 2014, Mizobuchi 2017). However, as has been suggested by Margaritis et al. (2007) our estimations cover a long period with macro-economic reforms, which affects movements of the production frontier

Table 3: Ten-year average statistics of Latin American countries' productivity levels and their components

Measure	Statistic	1970-	1980-	1990-	2000-	2010-
$M(x_i^t, y_i^t, x_i^{t_k}, y_i^{t_k})$	*Mean*	1.2460	0.9718	1.2709	1.5464	0.9945
	Std	0.2646	0.2125	0.4011	0.4416	0.0683
$TE\Delta_{CRS}$	*Mean*	0.9261	1.1976	0.9513	1.2650	0.9926
	Std	0.1892	0.2606	0.2906	0.3549	0.0631
$T\Delta_{CRS}$	*Mean*	1.3434	0.8115	1.3333	1.2210	1.0028
	Std	0.0685	0.0367	0.0320	0.0638	0.0453

Moreover, for the purpose of the convergence analysis we re-calculate countries' productivity levels using the Färe *et al*. (1994) decomposition assuming CRS.[11] Moreover, and in order to increase our observed estimations we re-calculate countries' $M(x_i^t, y_i^t, x_i^{t_k}, y_i^{t_k})$, $TE\Delta_{CRS}$ and $T\Delta_{CRS}$ indexes in a year by year basis (i.e. 1970-1971,1971-1972, 1972-1973,…,2013-2014). Then as has been described in the methodological section we apply the Phillips and Sul's (2007, 2009) approach in order to identify converge clubs among countries' estimated productivity levels and their components.[12] Table 4 presents the results of the convergence analysis. As can be observed for $M(x_i^t, y_i^t, x_i^{t_k}, y_i^{t_k})$ we obtain $\mathrm{t_b} = -30.307 < -1.65$ indicating that we reject H_0. This finding suggests that countries' productivity levels over the examined periods do not convergence. When we follow the same procedure for the estimations of countries' catching-up levels, again we reject H_0 since $\mathrm{t_b} = -2.324 < -1.65$. Our empirical evidence suggest that countries' catching-up levels do not convergence over the examined periods. In contrast to our previous findings when we examine if countries' technological change levels $T\Delta_{CRS}$ converge, we find that $\mathrm{t_b} = -1.177 > -1.65$ signifying that we cannot reject H_0. As a result the empirical evidence highlight that over the examined periods a convergence of countries' technological levels exists. However, it must be noted that the speed of adjustment is negative (-0.1407) suggesting a weak transitional divergence. This is also signified by the negative value of the estimated coefficient (-0.2814) suggesting a negative speed of adjustment. In order to analyze further this phenomenon we follow the procedure by Phillips and Sul (2009) and we estimate the potential convergence clubs for countries' productivity levels and their

over time both in input and output direction. As a result Hicks-neutral technical change does not describe countries' technology in a realistic manner.

[11] Apart that the CRS assumption is the most common assumption when analyzing economic phenomena, Shiu and Zelenyuk (2011, p.26) emphasize that under the CRS assumption all countries are compared evenly to the same cone. Finally, they suggest that the CRS assumption is more appropriate in cases we apply aggregated the data.

[12] For the estimation of the Phillips and Sul's (2007, 2009) approach we use the R-codes provided by Schnurbus *et al*. (2017).

components. Table 4 presents our findings for the estimated $M(x_i^t, y_i^t, x_i^{t_k}, y_i^{t_k})$ suggesting the existence of one club (Club 1) consisting by nine countries (COL, ECU, PER, VEN, ARG, BLZ, CHL, SLV and PAN). However, the analysis suggests the existence of another 3 clubs, but in all three cases we reject the null hypothesis. Similar findings we observe for the estimated $TE\Delta_{CRS}$ values suggesting the convergence among nine countries (MEX, NIC, GTM, BLZ, URY, BOL, ECU, PAN and VEN) forming one club (Club 1). In addition for the case of $T\Delta_{CRS}$ our findings signify the existence of two convergence clubs (Club 1 and Club 2), one formed by sixteen countries (ARG, BOL, BRA, COL, ECU, SLV, HND, NIC, PRY, PER, URY, VEN, BLZ, CHL, GTM and PAN), whereas, the second "club" is formed only by Mexico (MEX). The overall results signify that over the examined periods the convergence on countries' technological change does not guarantee an overall convergence on their productivity levels. Regardless our 'partial' convergence findings, our study contradicts with the previous studies (Dobson and Ramlogan 2002a, 2002b; Ramirez and Nazmi 2003; Astorga *et al*. 2005; Astorga 2010) which provide evidence that in different periods countries' income growth levels converge. However, our overall findings support Saravia *et al*. (2014) suggesting that non-convergence in Latin American countries is attributed to different countries' non-uniform productivity levels.

In addition Figure 1 presents the relative transition paths separately for all the clubs for their productivity $M(x_i^t, y_i^t, x_i^{t_k}, y_i^{t_k})$, technical efficiency change $TE\Delta_{CRS}$ and technical change $T\Delta_{CRS}$ levels. It is evident in all cases that the reported Club 1 (blue color) and Club 2 (red color) have closely related transition paths over the examined period regardless the examined measure. However, our findings suggest that during the 1990s the transition paths of convergence within and among the two Clubs (i.e. Club 1 and Club 2) and across the different measures appear to have an asymmetric shape. This finding supports the findings by Dobson and Ramlogan (2002b) suggesting that during 1990s. A similar behavior can be also observed on the first half of 1970s. This can be attributed due to the fact that during 1970s growth inequalities were enhanced among the Latin American countries (Dobson and Ramlogan 2002a).

Table 4: Test statistics of convergence

Convergence Clubs			
Category	log t	t-stat	Decision
$M(x_i^t, y_i^t, x_i^{t_k}, y_i^{t_k})$	-2.201	-30.307*	No
$TE\Delta_{CRS}$	-0.063	-2.324*	No
$T\Delta_{CRS}$	-0.281	-1.177	Yes

Note: the critical value is −1.65, "*" shows rejection.

Convergence Clubs for $M\left(x_i^t, y_i^t, x_i^{t_k}, y_i^{t_k}\right)$

Category	log t	t-stat	New club	Final classification	log t	t-stat
Club 1 [COL, ECU, PER, VEN]	0.270	0.548	1+2	Club 1	0.311	1.564
Club 2 [ARG, BLZ, CHL, SLV, PAN]	0.784	4.153				
Club 3 [HND, URY]	-2.311	-1.050	3	Club 2	-1.174	-7.097*
Club 4 [BRA, NIC, PRY]	-0.527	-0.474	4	Club 3	-2.298	-13.094*
Club 5 [BOL, MEX]	4.329	12.244	5	Club 4	-1.156	-7.085*
Divergent Group 6 [GTM]	-1.182	-2.930*	6	-	-	-

Note: the critical value is −1.65, "*" shows rejection.

Convergence Clubs for $TE\Delta_{CRS}$

Category	log t	t-stat	New club	Final classification	log t	t-stat
Club 1 [MEX, NIC, GTM, BLZ, URY, BOL, ECU, PAN, VEN]	6.960	31.667	1+2	Club 1	6.240	25.715
Club 2 [BRA, SLV, HND, PRY, PER]	1.468	8.531				
Club 3 [ARG, CHL]	-3.111	-1.606	3	Club 2	-4.795	-6.343*
Divergent Group 4 [COL]	-4.733	-4.974*	-	-	-	-

Note: the critical value is −1.65, "*" shows rejection.

Convergence Clubs for $T\Delta_{CRS}$

Category	log t	t-stat	New club	Final classification	log t	t-stat
Club 1 [ARG, BOL, BRA, COL, ECU, SLV, HND, NIC, PRY, PER, URY, VEN]	2.714	4.978	1+2	Club 1	0.787	3.028
Club 2 [BLZ, CHL, GTM, PAN]	-0.680	-0.776				
Club 3 [MEX]	0.555	0.637	3	Club 2	-0.680	-0.776

Finally, as robustness check regarding the previous convergence analysis, we follow several other studies (Massoumi *et al*., 2007, Magrini, *et al*., 2015; Kounetas *et al*., 2021) performing a distribution dynamic analysis examining the distributional dynamics of countries' productivity levels and their comments. Specifically, we adopt the methodology by Quah (996a, 1996b) utilizing a probability model of transitions for countries' $M\left(x_i^t, y_i^t, x_i^{t_k}, y_i^{t_k}\right)$, $TE\Delta_{CRS}$ and $T\Delta_{CRS}$ distributions.

Figure 1: Transition paths of the convergence clubs

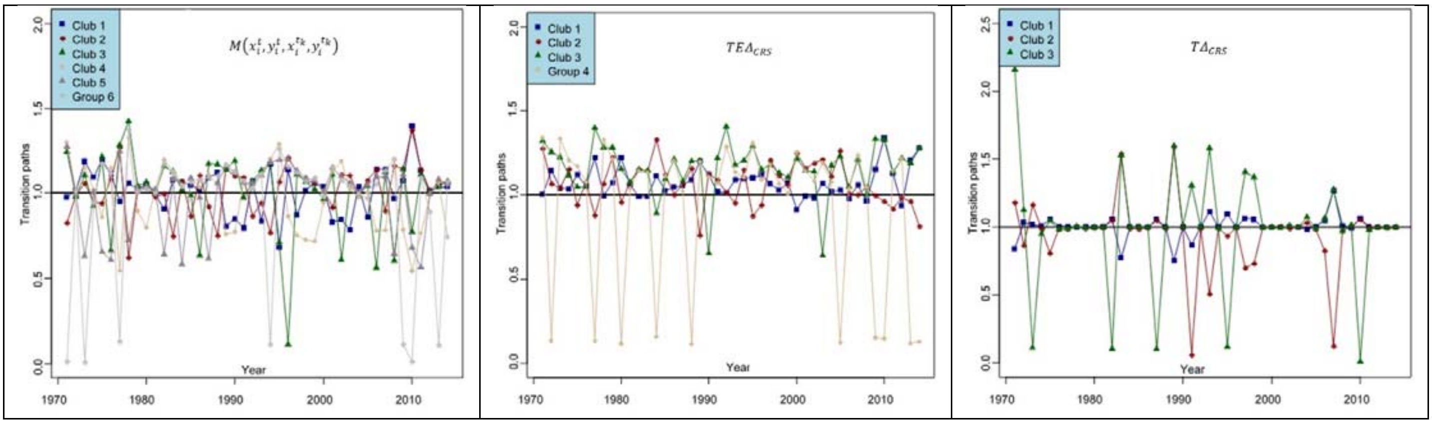


Figure 2 presents our findings of the analysis. We estimate the stochastic kernels of the productivity and the components by estimating the density function of the distribution for the estimates for the period 2013-2014 conditioned on the estimates obtained for the period 1970-1971. The findings of our analysis verify the previous findings obtained utilizing Phillips and Sul's (2009) methodological framework. It is evident that for the case of $T\Delta_{CRS}$ we can trace two separate "groups" (two peaks).

Figure 2: Distribution dynamics of the productivity measures and components

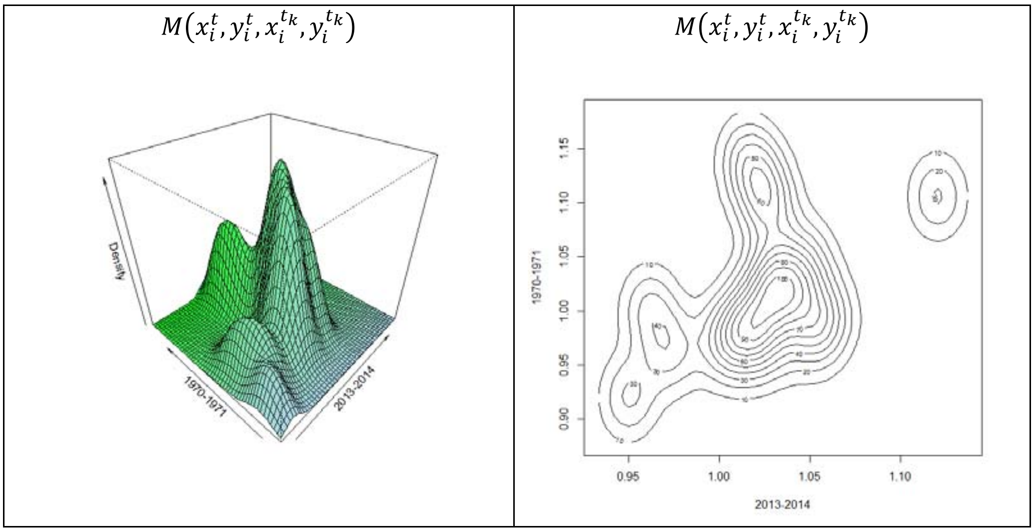
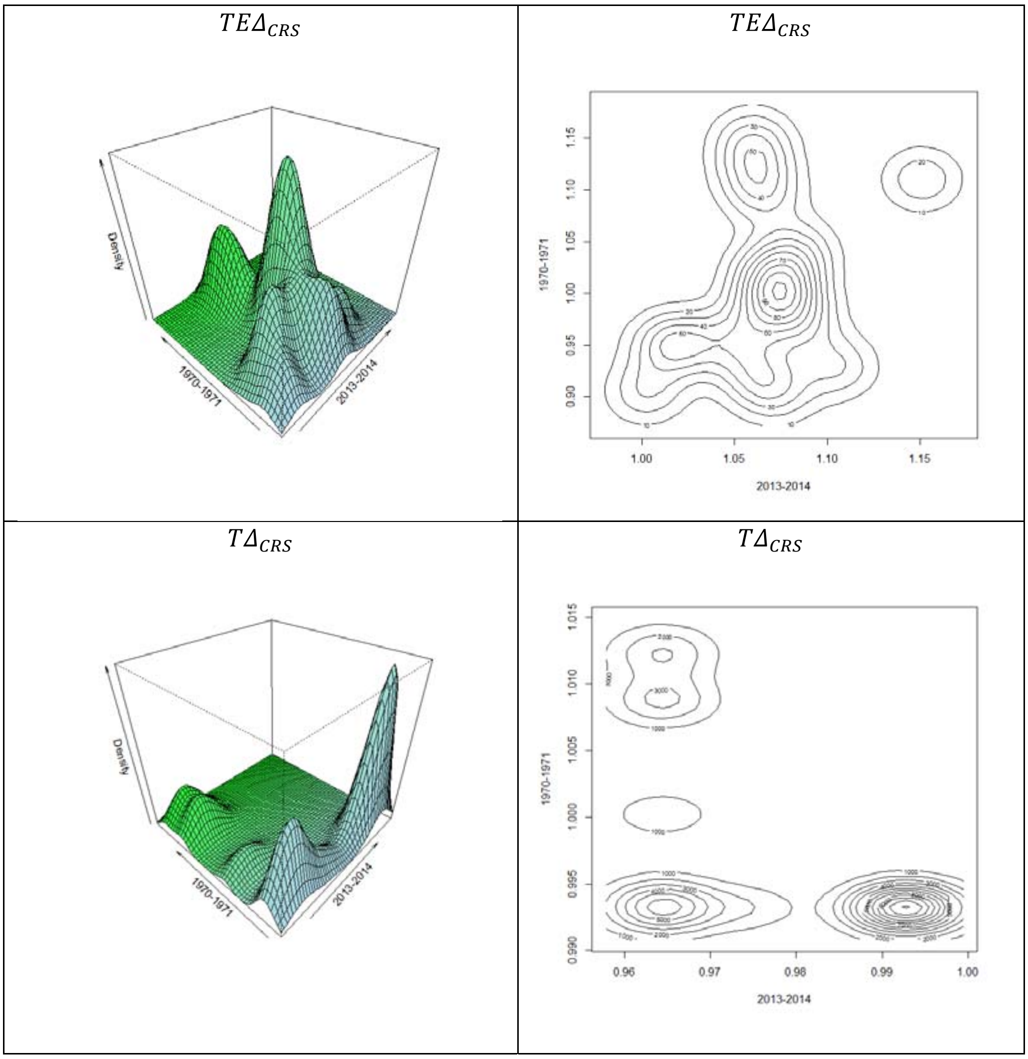


Figure 2 continued: Distribution dynamics of the productivity measures and components



5 Conclusions

By applying several decompositions of Malmquist productivity indexes as has been used in the relative literature (*inter alia*: Wei and Hao, 2011; Suyanto and Salim, 2010), we estimate the aggregate productivity levels of seventeen Latin American countries over the period 1970-2014. To the best of our knowledge, this is the first study that applies these productivity decompositions over a large time period in order to evaluate Latin American countries' productivity levels. For robustness check, we analyzed the productivity levels between 1970 and 2014 but also in a ten years window gap. The overall results of our analysis suggest that the majority of Latin American countries that form our sample here suffered from a contraction of their productivity levels over the period examined. Our findings are in line with the ones reported by previous studies (Taylor 1998; Devlin and Ffrench-Davis 1999; Katz 2000) suggesting that the structural reforms during 1990s did not materialize into higher growth rates, which in turn were reflected on countries' productivity levels (Astorga *et al*. 2011; Ferreira *et al*. 2013). Moreover, in the same spirit as in the studies by (Camarero *et al*. 2013, 2014), we apply the Phillips and Sul's (2007, 2009) approach for convergence estimation on the estimated productivity indexes. This methodology is more suitable with the adopted nonparametric productivity measurement, since it both approached do not impose any restrictive assumptions. Our empirical evidence seems to contradict some of the studies that report evidence of convergence among countries' income growth levels (Dobson and Ramlogan 2002b; Ramirez and Nazmi 2003; Astorga *et al*. 2005; Galvao and Reis Gomes 2007; Astorga 2010). Our findings do not render support to the hypothesis of productivity convergence. However, we have found convergence among countries' technological change levels and we identified three such convergence clubs. In addition we follow Kounetas *et al*., (2021) performing a distributional dynamic analysis, by assuming that productivity components follow a continuous-time stochastic process. Our findings verify the analysis conducted by using Phillips and Sul's (2007, 2009) methodological approach of convergence. Looking at both methodological frameworks of convergence analysis; we can conclude that the convergence patterns found among countries' technological change levels, are not able to initiate a potential productivity growth convergence. In addition, our findings indicate a distortion of the convergence patterns during the reform period (i.e. during the 1990s), followed by a weak transitional divergence with a negative speed of adjustment signifying asymmetric effects of policy implementations. It is evident that the weak productivity convergence it may be attributed to the absence of a proactive regional policies in Latin America. Such regional policies are needed in order to enhance regional development associations among the countries (Dobson and Ramlogan, 2002b). The convergence patterns in Latin America are among countries which are engaged on trade agreements. However, the long-term macroeconomic and institutional instability have been proven as the main drawback of productivity convergence among the regions. As has been highlighted by Astorga (2010) smaller countries in the region do not participate to any convergence process, whereas, the unstable macroeconomic environment in Latin America has been a barrier for growth and investment.

References

Astorga, P. (2010). A century of economic growth in Latin America. *Journal of Development Economics*, 92(2), 232-243.

Astorga, P., Bergés, A. R., & FitzGerald, V. (2005). The standard of living in Latin America during the twentieth century. *Economic History Review*, 58(4), 765-796.

Astorga, P., Berges, A. R., & Fitzgerald, V. (2011). Productivity growth in Latin America over the long run. *Review of Income and Wealth*, 57(2), 203-223.

Ayala, A., J. Cuñado & L. A. Gil-Alana (2012) Real convergence in Latin America: a fractionally integrated approach, *Applied Financial Economics*. 22(20), 1713-1717,

Ayala, A., J. Cunado & L. A. Gil-Alana (2013) Real convergence: empirical evidence for Latin America. *Applied Economics*, 45(22), 3220-3229

Badunenko, O., Henderson, D. J., & Zelenyuk, V. (2008). Technological change and transition: relative contributions to worldwide growth during the 1990s. *Oxford Bulletin of Economics and Statistics*, 70(4), 461-492.

Barrios, C. E. Flores & M. Á. Martínez (2019). Convergence clubs in Latin America, *Applied Economics Letters*, 26(1), 16-20

Barro R. (1991). Economic growth in a cross-section of countries. *Quarterly Journal of Economics*, 106, 407-443.

Barro, R. (2015). Convergence and modernization. *Economic Journal*, 125(585), 911-942.

Barro R. J. & Sala-i-Martin X. X. (1992). Convergence. *Journal of Political Economy*, 100(2): 223-251.

Batista, C. (2004). Latin American export specialization in resource-based products: implications for growth, *The Developing Economies*, 42(3): 337–70.

Beylunioğlu, F. C., Stengos, T., & Yazgan, M. E. (2018). Regime switching with structural breaks in output convergence. *Studies in Nonlinear Dynamics & Econometrics*, 22(3), 1-17.

Beylunioğlu, F. C., Yazgan, M. E., & Stengos, T. (2020). Detecting convergence clubs. *Macroeconomic Dynamics*, 24(3), 629-669.

Bianco, M., Gerali, A., & Massaro, R. (1997). Financial systems across "developed economies": convergence or path dependence?. *Research in Economics*, *51*(3), 303-331.

Cabral, R., & Castellanos-Sosa, F. A. (2019). Europe's income convergence and the latest global financial crisis. *Research in Economics*, https://doi.org/10.1016/j.rie.2019.01.003.

Camarero, M., Picazo-Tadeo, A. J., & Tamarit, C. (2013). Are the determinants of CO2 emissions converging among OECD countries? *Economics Letters*, 118(1), 159-162.

Camarero, M., Castillo-Giménez, J., Picazo-Tadeo, A. J., & Tamarit, C. (2014). Is eco-efficiency in greenhouse gas emissions converging among European Union countries?. *Empirical Economics*, 47(1), 143-168.

Casacuberta, C., G. Fachola and N. Gandelman (2011) Employment, capital and productivity dynamics: evidence from the manufacturing sector in Uruguay, *The Developing Economies* 49(3): 266–96

Castillo, L., D. S. Salem & J. L. Guasch (2011) Innovative and absorptive capacity of international knowledge: an empirical analysis of productivity sources in Latin American countries. *Latin American Business Review*, 12(4), 309-335.

Caves, D. W., Christensen, L. R., & Diewert, W. E. (1982). The economic theory of index numbers and the measurement of input, output, and productivity. *Econometrica*, 50(6), 1393-1414.

Chen, Z., Tzeremes, P., & Tzeremes, N. G. (2018). Convergence in the Chinese airline industry: A Malmquist productivity analysis. *Journal of Air Transport Management*, 73, 77-86.

Cupples, J. (2013). *Latin American development*. New York: Routledge.

De la Fuente, A. (2000). Convergence across countries and regions: theory and empirics. *CEPR Discussion Paper* 2465.

De la Fuente, A. (1997) The empirics of growth and convergence: a selective review. *Journal of Economic Dynamics and Control* 21, 23–73.

Devlin, R., & Ffrench-Davis, R. (1999). Towards an evaluation of regional integration in Latin America in the 1990s. *World Economy*, 22(2), 261-290.

Dobson, S., & Ramlogan, C. (2002a). Economic growth and convergence in Latin America. *Journal of Development Studies*, 38(6), 83-104.

Dobson, S., & Ramlogan, C. (2002b). Convergence and divergence in Latin America, 1970-1998. *Applied Economics*, 34(4), 465-470.

Easterly, W., Loayza, N., & Montiel, P. (1997). Has Latin America's post-reform growth been disappointing?. *Journal of International Economics*, 43(3-4), 287-311.

Edwards, S. (2009) Forty years of Latin America’s economic development: from the alliance for progress to the Washington consensus. *NBER Working Paper No* 15190.

Empora, N., & Mamuneas, T. (2011). The effect of emissions on US state total factor productivity growth. *Review of Economic Analysis*, 3(2), 149-172.

Färe, R., Grosskopf, S., Norris, M., & Zhang, Z. (1994). Productivity growth, technical progress, and efficiency change in industrialized countries. *American Economic Review*, 84(1), 66-83.

Färe, R., Grosskopf, S., & Roos, P. (1996). On two definitions of productivity. *Economics Letters*, 53(3), 269-274.

Färe, R., Mizobuchi, H., & Zelenyuk, V. (2021). Hicks neutrality and homotheticity in technologies with multiple inputs and multiple outputs. *Omega*, 101, 102240.

Feenstra, R. C., Inklaar, R., & Timmer, M. P. (2015). The next generation of the Penn World Table. *American Economic Review*, 105(10), 3150-82.

Ferreira, P. C., Pessoa, S. D. A., & Veloso, F. A. (2013). On the evolution of total factor productivity in Latin America. *Economic Inquiry*, 51(1), 16-30.

Galvao Jr, A. F., & Reis Gomes, F. A. (2007). Convergence or divergence in Latin America? A time series analysis. *Applied Economics*, 39(11), 1353-1360.

Grosskopf, S. (2003). Some remarks on productivity and its decompositions. *Journal of Productivity Analysis*, 20(3), 459-474.

Islam, N. (2003). What have we learnt from the convergence debate? *Journal of Economic Surveys*, 17(3), 309-354.

Inklaar, R. & Timmer, M.P. (2009). Productivity convergence across industries and countries: the importance of theory-based measurement. *Macroeconomic Dynamics*, 13(S2), 218–240.

Kalaitzidakis, P., Mamuneas, T. P., & Stengos, T. (2018). Greenhouse emissions and productivity growth. *Journal of Risk and Financial Management*, 11(3), 1-14.

Kollias, C. and P. Messis (2020) Are future enlargement candidate countries converging with the EU? *Empirica* 47, 453–473.

Kounetas, K. E., Polemis, M. L., & Tzeremes, N. G. (2021). Measurement of eco-efficiency and convergence: Evidence from a non-parametric frontier analysis. *European Journal of Operational Research*, 291(1), 365-378.

King, A. and C. Ramlogan-Dobson (2016) Is there club convergence in Latin America? *Empirical Economics*, 51(3), 1011–1031

Lee, J-W. (2019) Convergence success and the middle-income trap, *Developing Economies* doi: 10.1111/deve.12214

Lovell, C. K. (2003). The decomposition of Malmquist productivity indexes. *Journal of Productivity Analysis*, 20(3), 437-458.

Margaritis, D., Färe, R., & Grosskopf, S. (2007). Productivity, convergence and policy: a study of OECD countries and industries. *Journal of Productivity Analysis*, *28*(1-2), 87-105.

Magrini, S., Gerolimetto, M., & Engin Duran, H. (2015). Regional convergence and aggregate business cycle in the United States. *Regional Studies*, 49(2), 251-272.

Maasoumi, E., Racine, J., & Stengos, T. (2007). Growth and convergence: A profile of distribution dynamics and mobility. *Journal of Econometrics*, 136(2), 483-508.

Mazumdar, K. (2003). Do standards of living converge? A cross-country study, *Social Indicators Research* 64, 29–50.

Mizobuchi, H. (2017). Productivity indexes under Hicks neutral technical change. *Journal of Productivity Analysis*, 48(1), 63-68.

Peyrache, A. (2014). Hicks-Moorsteen versus Malmquist: a connection by means of a radial productivity index. *Journal of Productivity Analysis*, 41(3), 435-442.

Phillips, P. C., & Sul, D. (2007). Transition modeling and econometric convergence tests. *Econometrica*, 75(6), 1771-1855.

Phillips, P. C., & Sul, D. (2009). Economic transition and growth. *Journal of Applied Econometrics*, 24(7), 1153-1185.

Polemis, M. L., & Stengos, T. (2015). Does market structure affect labour productivity and wages? Evidence from a smooth coefficient semiparametric panel model. *Economics Letters*, 137, 182-186.

Quah, D. T. (1996a). Twin peaks: growth and convergence in models of distribution dynamics. *Economic Journal*, 106(437), 1045-1055.

Quah, D. T. (1996b). Regional convergence clusters across Europe. *European Economic Review*, 40(3-5), 951-958.

Ramirez, M. D., & Nazmi, N. (2003). Public investment and economic growth in Latin America: An empirical test. *Review of Development Economics*, 7(1), 115-126.

Ranis, G. and F. Stewart (2001) Growth and human development: comparative Latin American experience, *The Developing Economies* 39(4): 333-365

Ray, S. C., & Desli, E. (1997). Productivity growth, technical progress, and efficiency change in industrialized countries: comment. *American Economic Review*, 87(5), 1033-1039.

Reyes, J. & C. Sawyer (2011) *Latin American Economic Development*. Routledge

Sala-i-Martin X. (1996). The classical approach to convergence analysis. *Economic Journal*, 106: 1019-1036.

Sala-i-Martin, X. (1994). Regional cohesion: evidence and theories of regional growth and convergence. *European Economic Review*, 40(6), 1325-1352.

Saravia, A., Machicado, C. G., & Rioja, F. (2014). Productivity, structural change and Latin American development. *Review of Development Economics*, 18(3), 610-624.

Schnurbus, J., Haupt, H., & Meier, V. (2017). Economic transition and growth: a replication. *Journal of Applied Econometrics*, 32(5), 1039-1042.

Shephard R.W. (1970).*Theory of cost and production functions*. Princeton: Princeton University Press.

Shiu, A., & Zelenyuk, V. (2011). *Production efficiency versus ownership: The case of China*. In Exploring research frontiers in contemporary statistics and econometrics, Physica-Verlag HD, pp. 23-44.

Simar, L., & Wilson, P. W. (1998). Productivity growth in industrialized countries, Papers 9810, Center for Operations Research and Econometrics [CORE], Université Catholique de Louvain (UCL), Louvain la Neuve, Belgium.

Solow, R. (1956). A contribution to the theory of economic growth. *The Quarterly Journal of Economics*, 70(1) 65-94.

Solow, R.M., (1957). Technical change and the aggregate production function. *Review of Economics and Statistics*, 39(3), 312-320.

Sondermann, D. (2014) Productivity in the euro area: any evidence of convergence? *Empirical Economics*, 47(3), 999–1027.

Stengos, T., & Yazgan, M. E. (2014). Persistence in convergence. *Macroeconomic Dynamics*, 18(4), 753-782.

Stengos, T., Yazgan, E., & Beylunioglu, F. C. (2017). Detecting capital market convergence clubs. *Studies in Nonlinear Dynamics & Econometrics*, 21(3), 1-14.

Stengos, T., Yazgan, M. E., & Özkan, H. (2018). Persistence in Convergence and Club Formation. *Bulletin of Economic Research*, 70(2), 119-138.

Suyanto and R. Salim (2010) Sources of productivity gains from FDI in Indonesia: is it efficiency improvement or technological progress? *The Developing Economies* 48(4), 450–72

Swan, T.W. (1956). Economic growth and capital accumulation. *Economic Record*, 32(2), 334-361.

Tsanana, E. and C. Katrakilidis (2014) Do Balkan economies catch up with EU? New evidence from panel unit root analysis, *Empirica*, 41:641–662

Taylor, A. M. (1998). On the costs of inward-looking development: price distortions, growth, and divergence in Latin America. *Journal of Economic History*, 58(1), 1-28.

Tzeremes, N. G. (2019). Technological change, technological catch-up and export orientation: evidence from Latin American Countries. *Journal of Productivity Analysis*, 52(1-3), 85-100.

Wei, Z. and R. Hao (2011) The role of human capital in China's total factor productivity growth: a cross-province analysis, *The Developing Economies* 49(1): 1–35.

Wells, G., & Stengos, T. (2010). Estimates of Technology and Convergence: Simulation Results. *Ekonomia*, 13(2-1), 97-108.