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Distribution dynamics of alternative productivity measures: An empirical analysis

Gabriel Brondino[a], Facund Fora-Alcalde[b,c,*], Miguel Ángel Casaú-Guirao[d]

[a] Department of Economic and Social Sciences, Università Cattolica del Sacro Cuore, Piacenza, Italy
[b] Department of Economics and Economic History, Autonomous University of Barcelona, Barcelona, Spain
[c] Department of Applied Economics, University of the Balearic Islands, Palma, Spain
[d] Department of Economic Structure and Development Economics, Autonomous University of Madrid, Madrid, Spain

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ABSTRACT

This paper revisits the productivity convergence debate from the perspective of Structural Economic Dynamics. Building on a novel indicator of total labour productivity, we provide a comprehensive analysis of productivity convergence across 61 economies over the period 1995–2019. Instead of using regression methods, we make use of the distribution dynamics approach which captures the full evolution of productivity distributions over time. Our results reveal contrasting patterns of convergence depending on the measure chosen. While total factor productivity suggests reduced dispersion and a tendency toward homogeneity, apparent labour productivity and our measure indicate persistent polarisation, with countries clustering into high- and low-productivity groups.

1. Introduction

The evolution of productivity across countries, and whether it has exhibited convergence or divergence, remains a topic of ongoing debate. Central to this discussion is the definition of productivity itself, which depends on the inputs and outputs considered in its measurement. Empirical research has produced diverse conclusions, often influenced by the specific productivity measures used.

Scholars within the neoclassical tradition define productivity using income-based indicators, with real value-added per hour worked and total factor productivity (TFP) being the most commonly used measures. Advocates of this approach argue that diminishing returns to capital accumulation, coupled with the relative ease of imitation compared to innovation, drive an inevitable convergence of lower-income countries toward higher-income counterparts (Baumol, 1994).

The *Structural Economic Dynamics* (SED) approach offers an alternative perspective, defining productivity in physical terms. Its key indicator, Total Labour Productivity (TLP), measures the labour content embodied in a unit of final consumption goods. Unlike income-based measures, TLP provides a purely technological metric that captures the sectoral interdependencies within production processes (Santini and Araujo, 2024). Empirical studies utilising TLP have often concluded that productivity convergence across countries is not inevitable (e.g., Elmslie and Milberg, 1996; Wirkierman, 2022).

However, much of the existing TLP literature operates within a domestic framework. When an open economy is considered, changes in the supply of inputs through outsourcing and offshoring can affect productivity independently of technical change. These dynamics are often unaccounted for or difficult to disentangle in conventional productivity metrics (see Brondino et al., 2024). Drawing on this latter approach, this paper emphasises that provisioning practices can result in labour-saving processes (and consequent productivity increases) without a systematic relationship to technical progress but rather through imports. To this end, we propose an empirical indicator of TLP that translates imports into domestic labour equivalents. Inspired by Pasinetti's (1981) notion that the labour content of an imported machine is determined by the goods exchanged (exported) for its acquisition, this indicator enables differentiation between labour savings driven by technical progress and those arising from external provisioning practices. Thus, this approach allows for an analysis of productivity convergence between countries in a context of open economies.

Convergence has traditionally been examined through beta and sigma convergence However, such methods have well-documented limitations, including sensitivity to the sample composition or the difficulties to capture the formation of convergence clubs. In contrast, DDA examines the entire distribution of productivity levels across countries,

* Corresponding author.
E-mail addresses: gabriel.brondino@unicatt.it (G. Brondino), facund.fora@uab.cat (F. Fora-Alcalde), miguel.casau@uam.es (M.Á. Casaú-Guirao).

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capturing transitions in relative positions over time and overcoming the shortcomings of regression methods. Due to these advantages, this study adopts the DDA framework to investigate productivity convergence.

The originality of our contribution is threefold. First, the development of a new empirical indicator of labour productivity that takes into account the role of imports. Second, its application to convergence, in comparison with alternative productivity measures, to a sample of 61 economies. Third, the detailed analysis of convergence patterns thanks to the DDA methodology. Our main results show that there is a clear pattern of polarisation when we account for a technical measure of productivity. Furthermore, such pattern contrast with the convergence depicted by TFP, an income-based measure. Thus, the elected measure reflects different dimensions of productivity.

The remainder of this article is structured as follows. Section 2 reviews the literature on productivity convergence. Section 3 outlines the methodology. Section 4 compares the proposed productivity indicator with conventional measures and presents the results of the convergence analysis. Finally, Section 5 concludes with the study's main findings and implications.

2. The productivity convergence debate

Productivity convergence refers to both the reduction in the dispersion of productivity levels between countries and the catch-up process of less productive economies toward more advanced ones (Baumol, 1994). Over the past decades, the productivity convergence hypothesis between countries has been a highly widespread strand of research within economic growth theory. We suggest that the diversity of results relies on differences in the theoretical foundations of convergence, the empirical indicator used to measure productivity and the methodological choice in the way of capturing the convergence patterns.

2.1. Convergence theories: Support and critique

On the first place, studies rooted in the neoclassical tradition argue that convergence is based on two fundamental explanations: the theory of common forces and the contagion theory (Baumol, 1994). The theory of common forces posits that economies are influenced by shared factors that push them toward a common steady state. According to this view, convergence arises from diminishing returns to capital accumulation. As marginal returns on capital decline, developing countries, characterised by lower capital intensity, experience higher returns on capital investment relative to developed countries. In a context where technology diffuses freely across borders, this disparity incentivises capital reallocation from wealthier to poorer economies. If countries share similar saving rates, technological capabilities, and rates of technical progress, these diminishing returns drive all economies toward a shared steady state, leading to an inevitable convergence process (Barro, 1991).

However, the inevitability of this process is contingent upon the assumption of uniform economic fundamentals (savings ratios, technology levels, rate of technical progress) across countries. Endogenous growth theory extends this analysis by incorporating human and intangible capital, which do not exhibit diminishing returns. This expanded definition of capital can counterbalance the declining marginal returns of physical capital, reshaping convergence patterns (Lucas, 1988; Romer, 1990). Thus, while diminishing returns remain central to neoclassical convergence theory, the inclusion of human and intangible capital complicates its application, highlighting conditions under which convergence may fail to materialise (Bernard and Durlauf, 1996).

The contagion theory, by contrast, does not rely on uniform technological capabilities or saving rates. In particular, it is based on the so-called "advantage of backwardness" (Gerschenkron, 1962) related to the faster and cheaper absorption of technological innovations rather than their creation. Knowledge spillovers, facilitated by absorptive capacity—the ability to internalise external knowledge—enhance productivity in countries and sectors behind the technological frontier. As a result, these economies may experience accelerated growth driven by the diffusion of technological innovations (Aghion and Jaravel, 2015). In the same way, international trade and foreign direct investment (FDI) further reinforce this process, enabling the transfer of research-intensive imports and technological know-how from advanced economies (Wolff, 2013).[1]

Nevertheless, some studies call into question the advantage of backwardness, highlighting that the diffusion and absorption of technology and knowledge depend on a country's initial economic conditions and its degree of integration into the global economy (Ottaviano and Puga, 1998). Countries with a competitive edge in certain industries tend to widen their advantage over time, creating a self-reinforcing cycle of divergence. Consequently, trade and time can exacerbate initial productivity gaps rather than narrowing them, undermining the contagion theory's premise (Krugman, 1981).

There is a substantial body of work that critique the neoclassical notion of convergence. For example, Latin American structuralism and Dependency theory offer important perspectives that challenge the neoclassical framework. These approaches argue that convergence is improbable—or even impossible—within a global economy marked by asymmetric interdependence between central and peripheral economies (Prebish, 1949; Amin, 1976).[2] Central economies benefit from technological progress through mechanisms that retain productivity gains internally, often reflected in rising wages. Peripheral economies, by contrast, remain dependent on central economies, limiting their technological progress and ability to retain productivity gains domestically. This dependency perpetuates unequal productivity and wage evolution, undermining the convergence process (Fisher, 2015).

Related to this, *Structural Economic Dynamics* (SED) approach criticises the neoclassical analysis of convergence, highlighting the dualism between economies explained by the divergent evolution among sectors. Specifically, these studies point out that the development process occurs unevenly across sectors (Pasinetti and Spaventa, 1960). Productive sectors are interrelated, with structural tensions conditioning productive linkages and interdependencies, such as certain rigidities or bottlenecks. Such structural interdependencies and tensions give rise to processes of development and underdevelopment, as structural dynamics are not only disproportionate across sectors but also across countries (Spaventa, 1959; 1960).

In fact, the dynamics of technological diffusion through sectoral interrelations depend on the stage of economic development in which the economy is situated (Cardinale, 2019). The growth process of countries that were the first to experience strong economic growth through technical progress is distinct from those that began growing later. In the first case, countries have been the makers of technical progress and have not skipped any steps in technical evolution. This leads to a gradual technological development process at the domestic level throughout the entire productive structure (Andreoni and Chang, 2019). The second group of countries introduces modern industries with new production methods and their demand leaps to some of the more advanced products produced by more developed countries at a still very early stage of the system's development. In this case, technological diffusion takes place through the importation of technology from more advanced economies. This can result in a dual productive structure, where advanced sectors with high growth rates and high productivity coexist with traditional sectors with low productivity levels (Spaventa, 1960). Thus, late development is subject to a process of cumulative divergence both within and between countries (Andreoni, 2015). Consequently, divergent trajectories between advanced and developing economies in terms

[1] Similarly, in chapter XI of Pasinetti (1981), international trade is considered the main source of international learning. However, it is important to note that Pasinetti did not adhere to an automatic notion of convergence.

[2] For an analysis of alternative core-periphery conceptualisations, see Kvangraven (2023).

of productivity can be explained by whether the source of technical change has occurred domestically or has been imported from abroad.

Ultimately, these critiques suggest that productivity convergence is far from inevitable. Instead, it is contingent on the interplay between sectoral dynamics, the origin of technical progress, and structural asymmetries within the global economy. Divergence remains a plausible outcome when technological diffusion and productivity gains reinforce existing disparities, challenging the foundational premises of neoclassical convergence theories.

2.2. Methodologies for measuring convergence: From averages to distributions

Methodologically, convergence has been typically analysed using beta- and sigma-convergence indicators. Beta-convergence is derived from regressing economic growth over a given period against the initial level of income per capita—along with other relevant variables, if conditional convergence is being assessed. A negative coefficient for the initial income level suggests that less developed economies are growing faster than more developed ones, indicating they are "catching up".

Despite its widespread use, beta-convergence has important limitations. Most notably, the results of these regressions describe the behaviour of a "representative economy", which may obscure the evolution of countries' dispersion within the group. For example, beta-convergence could be present in a sample where a few low-income countries experience rapid growth, driving the overall result, while other poorer nations stagnate or even decline, increasing the overall variance of the sample (Quah, 1993a, 1997; Magrini, 2007).

To address this issue, traditional analysis complements beta-convergence with sigma-convergence indicators, which measure the dispersion of the sample, typically using the standard deviation or, less commonly, inequality indicators such as Gini or Atkinson coefficients. Regardless of the specific measure used, though, sigma-convergence, by its nature, provides a single summary statistic that aggregates diverse economic phenomena, potentially masking important structural shifts. For instance, while overall income dispersion may decrease, this could be driven by the emergence of distinct "convergence clubs"—clusters of countries that converge within their group but not with the rest of the sample. In this scenario, intermediate countries might disappear, leading to polarisation or stratification, even as sigma-convergence suggests that dispersion is declining.

To avoid these limitations, several scholars have proposed to use the DDA, which consists of analysing the entire distribution of income levels across countries, rather than focusing on average growth rates or single dispersion indicators like beta- and sigma-convergence. Therefore, the DDA shifts attention from individual regression outcomes or summary statistics toward understanding how the entire distribution of income evolves over time.

The key strength of this method lies in its capacity to capture changes in the full spectrum of income possibilities, thus bringing to the fore transitions across different relative positions and allowing for the identification of more complex patterns such as polarisation, stratification, or the formation of "convergence clubs". This approach highlights not only whether convergence occurs but also how the process unfolds across the entire spectrum of income or productivity levels, offering deeper insights into the dynamics of global economic development.

2.3. Measuring productivity: Income-based vs. output-based indicators

Most empirical analyses on convergence rely on income-based productivity measures (see e.g., Barro (2015) or Wolff (2013)) such as real value-added per hour worked or TFP. These measures are grounded in the neoclassical theory of distribution, which conceptualises production as a linear process from inputs (factors of production) to outputs (consumption goods). Within this framework, value added serves as the preferred measure for output. It is calculated subtracting the cost of means of productions from the gross output and is equal to the primary factors (wages and profits). Thus, capital is conceived as a primary factor of production that is itself not subject to technical change (Pasinetti, 1959; see also Garbellini and Wirkierman, 2023).

Only under the neoclassical assumption of general equilibrium,[3] where factor prices directly correspond to physical (marginal) productivity, can TFP meaningfully represent technological change (ten Raa, 2004). Instead, as Wirkierman (2022) highlights, value-added-based measures of technical progress reflect income distribution between workers (wages) and capitalists (profits), thus capturing changes in income distribution rather than physical productivity changes. A value-added indicator like TFP captures a reduction in real costs (Wirkierman, 2024). Therefore, TFP convergence can be interpreted as convergence in the functional distribution of income between countries but not necessarily as convergence in their technology (Elmslie and Milberg, 1996).

Even when real value added per hour worked is used as the productivity indicator (henceforth, apparent labour productivity—ALP—), it is impossible to distinguish between a volume and a price dimension, because the operating surplus component within value added is calculated as a residual magnitude (Meade, 2010; Wirkierman, 2022).

The SED approach offers an alternative way to measure productivity, drawing from the classical tradition in which production is conceived as a circular process. This perspective uses the concept of subsystems, smaller components of the economic system that encompass all the inputs required to produce a net output consisting of a single final commodity. Pasinetti (1973) operationalises the notion of subsystems through the concept of the vertically integrated sector, building on the classical framework rooted in Sraffa's (1960) work. A vertically integrated sector succinctly represents a subsystem, comprising two key elements: the vertically integrated labour coefficient, which measures the total (direct and indirect) labour required to produce one unit of the final commodity, and the vertically integrated unit of productive capacity, which accounts for the productive resources needed for its reproduction.

The reciprocal of the vertically integrated labour coefficient corresponds to the so-called TLP, which expresses the amount of net output produced by one unit of vertically integrated labour. The TLP indicator has two properties: (i) it is a measure that reflects the technical conditions of production, disregarding institutional factors like income distribution (Wirkierman, 2022); (ii) it focuses on final goods, capturing sectoral interdependencies and accounting for the full range of inputs in the production process (Gupta and Steedman, 1971).

Several studies have utilised this indicator for convergence analysis. Milberg and Elmslie (1992) compared productivity measures across five economies from 1959 to 1975, finding direct productivity (gross output per unit of direct labour) convergence, which contrasted with divergence observed when using TLP. Later, Elmslie and Milberg (1996) applied TLP to compare Japan's productivity convergence with Portugal's divergence during the same period, attributing Portugal's stagnation to its specialisation in low-productivity-growth sectors and historical constraints that hindered technological advancement.

Dietzenbacher et al. (2000) examined TLP convergence among six developed economies from 1975 to 1985, using structural decomposition analysis to identify the determinants of TLP evolution. Their findings demonstrate the existence of convergence and highlight the importance of input reorganisation and changes in trade structure in counteracting productivity growth. More recently, Rial et al. (2024) applied the subsystem approach to analyse the productivity convergence

[3] That is, to assume (i) that production processes can be properly described by homogenous, linear and convex functions; (ii) that the economy works with only one capital good or, equivalently, that capital intensity is equal across all branches of production; and (iii) that factors' shares don't change during the period under analysis (Ten Raa & Mohnen, 2002).

in EU countries during 1995–2017. Their results show that Mediterranean economies failed to converge, while Central and Eastern European countries showed substantial progress.

Finally, Wirkierman (2022) extended the analysis to disaggregated productivity convergence in six advanced economies, employing TLP at the vertically hyper-integrated level (Pasinetti, 1988), thus including inputs required for subsystem reproduction and expansion. Results showed convergence in high-tech sectors between 1995 and 2007, followed by a reversal during 2007–2015 in dynamic sectors such as ICT and the automotive industry.

From this perspective, all studies have used the TLP indicator within a domestic framework. However, when considering that economies are open, labour-saving processes may be due to productivity increases or shifts from domestic to imported inputs. This distinction is very relevant with the intensification of outsourcing, offshoring, and production fragmentation. In this sense, countries specialise in specific stages of production. Recent studies on global value chains (GVCs) highlight how international productive fragmentation influences productivity dynamics. Participation in GVCs and trade in intermediate inputs play a crucial role in technology diffusion and productivity advances as they facilitate knowledge transfer enhancing productivity (Timmer et al., 2014). However, other studies also highlight the risk of some countries becoming trapped in low-value-added activities (Baldwin and Ito, 2021). Thus, any domestic productivity measure should take into account the international interdependencies and role of reorganisation of inputs.

Addressing these gaps, this paper makes several contributions. First, we will use a productivity measure that builds on this framework while also accounting for the role of intermediate imports. This indicator aligns with and expands upon GVC insights shedding light on the productivity spillovers of the export sectors and on the imported requirements in domestic production. Furthermore, we will include 61 countries in the sample, in contrast to other studies mentioned above, who focus on a few advanced countries, a particular region (Europe) or selected case studies. Third, we will explore an alternative method for measuring convergence, the DDA analysis, allowing us to include the distribution of the productivity over time.

3. An adjusted total labour productivity indicator

This section introduces an input-output model of a national economy engaged in international trade and characterised by single-product industries and circulating capital. It then described the computation of TLP, as well as the adjustments that this measure requires when domestic production processes incorporate inputs imported from abroad.

The national input-output system at basic prices can be described by the set of matrices and vectors presented in the following table:

	Industries	Final demand	Output
Domestic industries	$\boldsymbol{Z}_{(n\times n)}$	$\boldsymbol{F}_{(n\times k)}$	$\boldsymbol{x}_{(n\times 1)}$
Imports	$\boldsymbol{M}^{z}{}_{(n\cdot r\times n)}$	$\boldsymbol{M}^{f}{}_{(n\cdot r\times k)}$	$\boldsymbol{m}_{(n\cdot r\times 1)}$
Gross value added	$\boldsymbol{g}^{T}{}_{(1\times n)}$		
Gross output	$\boldsymbol{x}^{T}{}_{(1\times n)}$		

Where $\boldsymbol{Z}$ is the matrix of intermediates consumption (n stands for the number of sectors); $\boldsymbol{x}$ is the vector of gross outputs; $\boldsymbol{F}$ is the matrix of final demands (k represents the type of demand: private, public, investment, foreign – exports –); $\boldsymbol{v}$ is the vector of value-added levels.

$\boldsymbol{M}$, at its turn, represents the matrix of imports for intermediate (superscript z) and final consumption (superscript f). Since we derive the system from a global input-output model, the dimensions of these matrices are different from the usual representation. If c stands for the number of regions included in the model, and $r = c - 1$, then $\boldsymbol{M}^{z}$ has a dimension of $nr \times n$. It is a block matrix, where the sub-matrices represent the imports from different countries.

$$\boldsymbol{M}^{Z} = \begin{bmatrix} \boldsymbol{M}_1^{z} \\ \vdots \\ \boldsymbol{M}_r^{z} \end{bmatrix} \tag{1}$$

The expenditure system, then, may be represented in compact form as follows:

$$\boldsymbol{x} = \boldsymbol{Z}\boldsymbol{1}_n + \boldsymbol{F}\boldsymbol{1}_k \tag{2}$$

Where $\boldsymbol{1}$ represents an all-ones vector, with the subscript indicating the dimension of the vector.

Also, let us define $\boldsymbol{A}^{d} = \boldsymbol{Z}(\widehat{\boldsymbol{x}})^{-1}$ as the matrix of domestic inputs coefficients and rewrite the expenditure system as follows:

$$\boldsymbol{x} = \boldsymbol{A}^{d}\boldsymbol{x} + \boldsymbol{f} \tag{3}$$

With $\boldsymbol{f}$ representing the vector of final demands. If this vector is taken as given, it is possible to find the vector of gross outputs that satisfy the equality:

$$\boldsymbol{x} = \left(\boldsymbol{I} - \boldsymbol{A}^{d}\right)^{-1}\boldsymbol{f} \tag{4}$$

Now, let $\boldsymbol{a}_l$ denote the vector of employment coefficients, where each component a_{lj} is defined as $a_{lj} = l_j/x_j$; with l_j representing the level of employment in industry j, and x_j the total output of industry j. Then, the aggregate level of employment in the economy can be expressed as:

$$L = \boldsymbol{a}_l^{T}\boldsymbol{x} \tag{5}$$

Furthermore, let $\boldsymbol{f}_i$ be a vector in which all components are zero except for the i th position, which holds the value of the final demand specific to industry i:

$$\boldsymbol{f}_i = \boldsymbol{e}_i f_i \tag{6}$$

Here, $\boldsymbol{e}_i$ is a vector with all zeros except for a 1 in the i th position.

Then, for each level of net output f_i we can compute the gross outputs and domestic labour required for its production:

$$\boldsymbol{x}^{(i)} = \left(\boldsymbol{I} - \boldsymbol{A}^{d}\right)^{-1}\boldsymbol{f}_i \tag{7}$$

$$L^{(i)} = \boldsymbol{a}_l^{T}\left(\boldsymbol{I} - \boldsymbol{A}^{d}\right)^{-1}\boldsymbol{f}_i \tag{8}$$

The term $\boldsymbol{a}_l^{T}\left(\boldsymbol{I} - \boldsymbol{A}^{d}\right)^{-1} \equiv \boldsymbol{v}^{T}$ is known as the vector of vertically integrated labour coefficients. Each coefficient v_i succinctly expresses the domestic labour directly and indirectly required to produce one unit of net output in sector i. Therefore:

$$\frac{f_i}{L^{(i)}} = \frac{f_i}{\boldsymbol{a}_l^{T}\left(\boldsymbol{I} - \boldsymbol{A}^{d}\right)^{-1}\boldsymbol{f}_i} = \frac{f_i}{\boldsymbol{a}_l^{T}\left(\boldsymbol{I} - \boldsymbol{A}^{d}\right)^{-1}\boldsymbol{e}_i f_i} = \frac{1}{\boldsymbol{a}_l^{T}\left(\boldsymbol{I} - \boldsymbol{A}^{d}\right)^{-1}\boldsymbol{e}_i} = \frac{1}{v_i} \tag{9}$$

Which is the reciprocal of the vertically integrated labour coefficient, traditionally referred as total labour productivity (TLP). Since we are concerned with the impact of the importation of inputs in productivity measurement, we call this measure domestic total labour productivity, to emphasise the location where the labour was performed.

Elsewhere, we have argued that the main drawback of this measure in the context of open economies is its inability to account for the source of labour saving (Brondino et al., 2024). Even without changes in production techniques, shifting sourcing practices may reduce the use of domestic labour, which, in this framework, would appear as an improvement in domestic productivity.

To address this issue, we have proposed an *adjusted* measure of labour productivity (ATLP), inspired by a passage in Pasinetti's 1981 work, which states:

> "If a certain set of machinery is imported into a country because, for example, it cannot be made in the country itself, it must be paid for by using the proceeds coming from other goods which are exported. This means that the amount of embodied labour which the imported

machinery represents for the importing country is given by the amount of labour required in the importing country to produce those commodities which are given in exchange, and not by the amount of labour which has actually been embodied in the machinery, in the country of origin" (Pasinetti, 1981, p. 185).

Thus, the proposed measure seeks to translate the vertically integrated unit of imports into a quantity of domestic labour. The first step to accomplish this task is to define an exporting basket. Let $\boldsymbol{f}_X$ be the vector of exports, $1_n^T\boldsymbol{f}_X = \epsilon$ is the total value of exports, The total labour content for producing one dollar's worth of exports is:

$$L^* = \boldsymbol{v}^T\boldsymbol{f}_X / \epsilon \tag{10}$$

Imports are also required in the production of one dollar's worth of exports:

$$\sigma^* = 1_{r \cdot n}^T \boldsymbol{A}^m \left(\boldsymbol{I} - \boldsymbol{A}^d\right)^{-1}\boldsymbol{f}_X \Big/ \epsilon \tag{11}$$

Here, $\boldsymbol{A}^m = \boldsymbol{M}^Z(\widehat{\boldsymbol{x}})^{-1}$. This measure is similar to the so-called "import content of exports" (Hummels et al. 2001).

To obtain σ^* dollars of exports $L^*\sigma^*$ units of labour and $(\sigma^*)^2$ dollars of imports are required. This leads to a circular logic whereby an infinite sum of labour obtained:

$$L^* + L^*\sigma^* + L^*(\sigma^*)^2 + \ldots \tag{12}$$

Since $0 \leq \sigma^* < 1$, the series is convergent to:

$$\frac{L^*}{1-\sigma^*} \tag{13}$$

This is the total labour required to produce one dollar's worth of exports.

If we further define the value of imports required to produce one unit of commodity i as a final output as:

$$\sigma^{(i)} = 1_{r \cdot n}^T \boldsymbol{A}^m \left(\boldsymbol{I} - \boldsymbol{A}^d\right)^{-1}\boldsymbol{f}_i \tag{14}$$

Then the total labour required for this production is:

$$v_i^a = v_i + \frac{L^*}{1-\sigma^*}\sigma^{(i)} \tag{15}$$

The reciprocal of this term is our adjusted measure of total labour productivity, which is an index that captures the amount of net product generated in a specific industry per unit of domestic, direct and indirect labour, when we take into account that importing inputs requires the use of such labour in quantities determined by international relative prices.[4]

4. Empirical results

4.1. Data collection and processing

Our calculations for ALP and ATLP are based on the 2024 Inter-Country Input-Output (ICIO) tables, kindly provided by the OECD staff, where one can find information for 45 sectors and 77 countries plus the rest of the world (ROW) for the period ranging from 1995 to 2020.

Since the data is available in current and in previous-year US dollars, we have deflated them and obtained matrices at constant prices of the base year. When prices are needed, as is the case when computing the labour required to import production inputs, we have divided the original data in current prices for the corresponding values in constant prices.

Also from the OECD, we use the Trade in Employment (TiM) database, which offers information on thousands of people employed in each of the 45 sectors considered, in 61 countries,[5] for the period between 1995 and 2020. Given that the ICIO tables contain data for more countries than those covered in the TiM database, the data of these countries has been added to ROW, as if we did not have disaggregated information for them.

With regards to the employment figures for this ROW "region", they have been calculated by assuming that it has the average direct labour productivity of the non-OECD-nor-BRICS countries of which we had information.[6] If this assumption is close to reality, the direct labour coefficients of the rest of world can be approximated by dividing the gross output figures of this region by that average direct labour productivity of the non-OECD-nor-BRICS countries.

On the other hand, due to data limitations, the TFP measures used in this analysis are derived from version 10.01 of the Penn World Table (Feenstra et al., 2015). This dataset provides information on TFP levels at current purchasing power parities (PPP) with the U.S. set as the benchmark (USA=1), as well as TFP at constant national prices (2017=1), for the period 1950–2019. These data are given in aggregate national terms. For this reason, although our calculations of ALP and ATLP were performed at the industry level, they have been aggregated into national figures[7] and the coming analysis is performed at the national level.

To assess TFP growth, we utilised the TFP indicator at constant national prices. For TFP levels, we combined both indices to estimate yearly national TFP relative to the U.S. benchmark in 2017. Specifically, we constructed an internationally comparable indicator of domestic TFP by multiplying the TFP data at constant national prices (2017=1) by the TFP level at current PPP (USA=1) for the year 2017.

All countries for which the ICIO and TiM databases offer information are also considered in the Penn World Table, with only one exception: Vietnam. The latter database has no information for the TFP of this country, forcing us to remove it from the data from the OECD with which ATLP and ALP have been calculated.

4.2. Features of ATLP and comparison with other indices

The trends of the three productivity indicators under consideration, with 1995=1 set as the benchmark, are reported in Fig. 1. They show significant differences in growth dynamics across regions and between indicators, aligning with the theoretical distinctions highlighted earlier.

ATLP and ALP have very similar trends, although the former exhibits higher growth rates, particularly in developing countries. TFP growth, on the other hand, is notably weaker across most regions, and even negative in some cases, such as those of Mediterranean and Middle East economies. This divergence underscores the limitations of TFP in fully capturing technical progress, as it ignores developments in the production of capital goods (Pasinetti, 1959).

Looking at ATLP and ALP, BRICS, Eastern European, ROW and Asian countries show the highest growth rates of productivity; Western offshoots, Western Europe, Middle East and Latin American countries exhibit a slightly lower performance; and Mediterranean countries show a quite remarkably poorer performance. Instead, when TFP is considered, Eastern European, BRICS and Asian economies have outperformed the rest of regions considered, while Western Offshoots, Western Europe

[4] See Appendix I for details on the relationship between prices and physical data in the ATLP.

[5] See Appendix II for the list of countries used as well as their codes and groupings used in the graphs.

[6] The alternatives of treating "ROW" as exogenous or aligning its labour requirements with those of the BRICS seemed to us less appropriate because, in the first case, we would miss the effect of an important number of countries of the world, and, in the second, we would treat these countries as having the very particular features of nations such as China, India or Brazil.

[7] Aggregate national figures for ALP and ATLP are averages of sectoral productivity weighted by the share of the direct (and indirect) employment of that industry in the whole labour force employed.

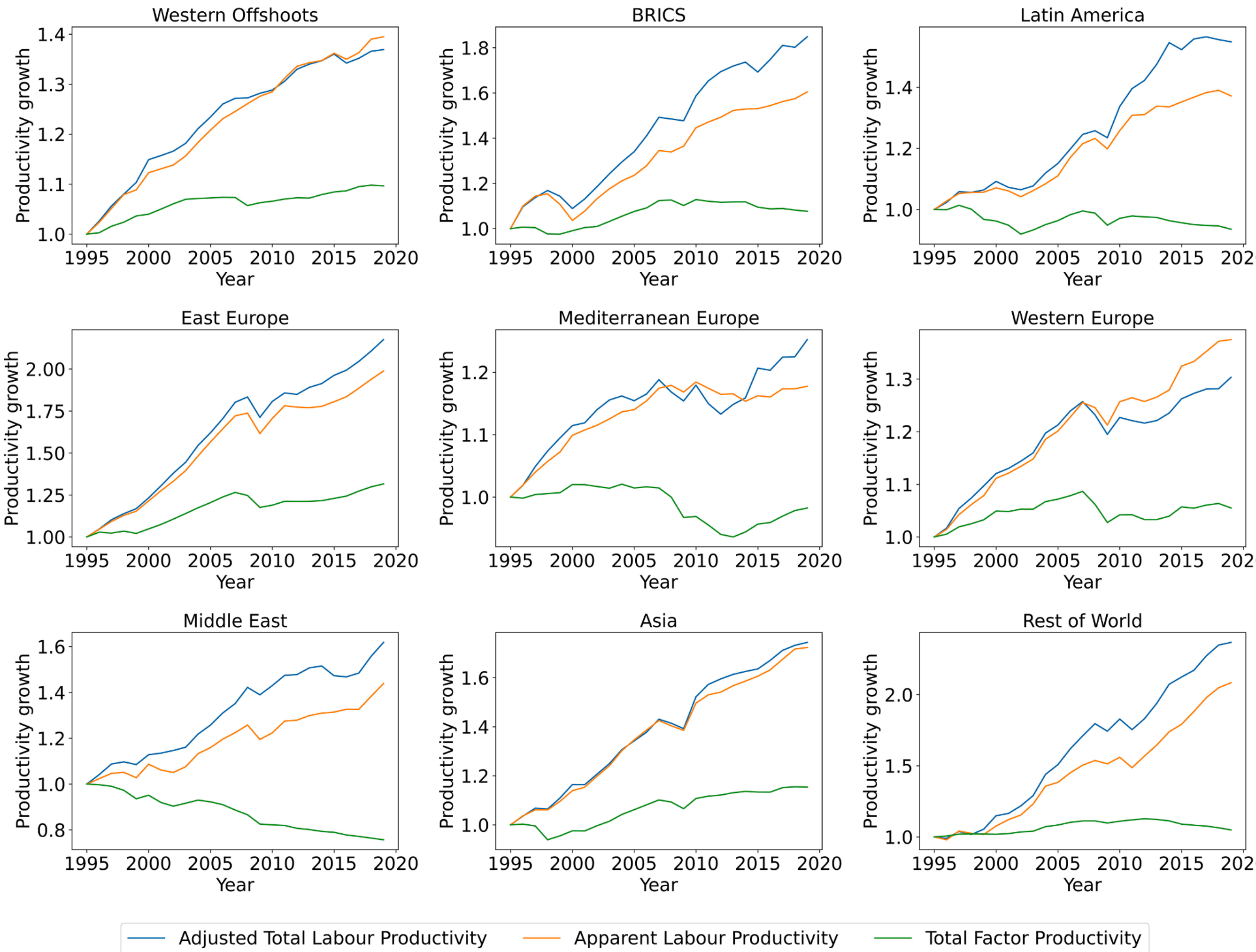

Fig. 1. Productivity growth in different regions (Index 1995=1).
Source: ICIO OECD Database and Penn World Table. Own calculations.

and ROW have shown a somewhat slower growth but still positive. Mediterranean, Middle Eastern and Latin American economies, on the other hand, all show negative growth rates of their TFP.

At its turn, Fig. 2 offers one scatter plot for each productivity indicator, relating the initial productivity level in the year 1995, normalised for the inter-country mean, with the compound average growth rate (CAGR) of each country.

In all three indicators, countries in the lower positions of relative productivity have, on average, experienced higher rates of growth between 1995 and 2019. However, for ATLP and ALP, these countries are China, India and the Eastern European countries in general, while in TFP, they are the Eastern European and non-BRICS Asian countries.

Moreover, for the first two indices, the possibility of beta convergence breaks apart once one analyses what happens in the countries positioned immediately after those at the lowest positions: countries initially with productivity levels above the 50 % of the world average have not generally grown more than those that had productivity levels beyond 100 % or 200 % of the world average. This is not the case for TFP, where the negative relationship between initial productivity level and its growth rate is a general trend of the sample.

To conclude this general overview, we present Fig. 3, where countries are arranged along the x-axis in ascending order based on their normalised productivity levels in 1995. The blue dots represent each country's normalised productivity value in the base year, providing a baseline for comparison. Red dots, in turn, indicate the normalised productivity levels for each country in 2019, offering a visual depiction of the changes in relative productivity over the observed period.

The results reinforce our previous conclusions. Countries placed at extreme positions in the distribution of both ATLP and ALP have got closer to the world average productivity, but these movements have been very weak, and relative positions have barely changed. However, with regards to TFP measures, countries at the lowest initial position have acquired levels of relative productivity comparable to those at which the countries at the highest initial positions have moved during the period under consideration. For this reason, when looking at TFP, we can see an important process of convergence which, moreover, has implied important shifts in relative positions.

5. Convergence analysis

Within the DDA there are several tools to assess convergence. One of them is the visual inspection of the cross-section distribution of the variable under consideration over time, normalised to its yearly average. More precisely, kernel density estimation (KDE) allows for the computation of probability density functions (PDFs) with which to build distribution density plots for different years (see Magrini, 2007, for details).

Fig. 4 reports the PDFs for the years 1995, 2007, and 2019, calculated three distinct productivity indicators.

ATLP and ALP measures present a bimodal distribution, suggesting the existence of convergence clubs when productivity is evaluated with

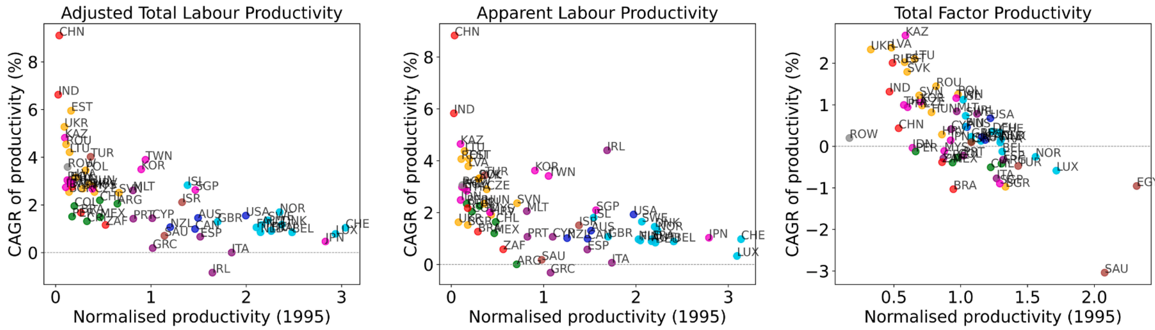

Fig. 2. Relation between productivity growth rates and initial productivity.
Source: ICIO OECD Database and Penn World Table. Own calculations.

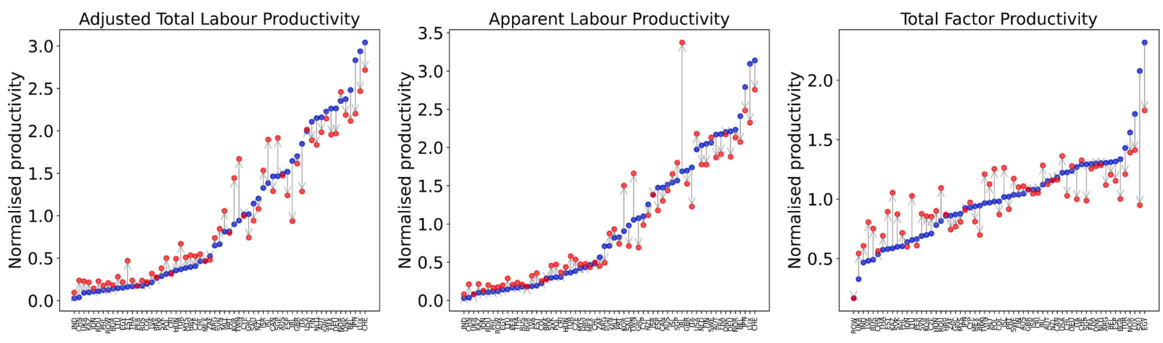

Fig. 3. Evolution of normalised productivity.
Source: ICIO OECD Database and Penn World Table. Own calculations.

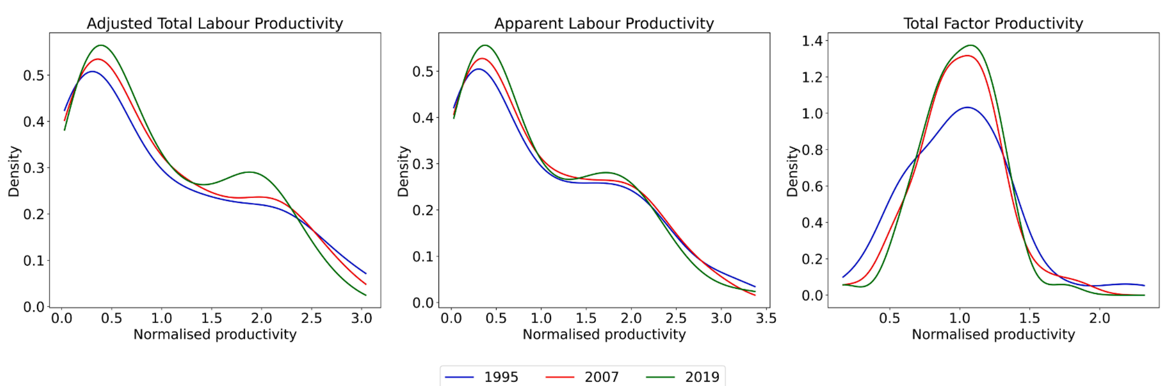

Fig. 4. Probability density functions of normalised productivity.
Source: ICIO OECD Database and Penn World Table. Own calculations.

either of these indicators. Moreover, in the period under consideration, each peak of the PDFs of both measures has tightened, indicating that intermediate positions have vanished to join one of these clubs.

These results are consistent with findings in the existing literature. For instance, Ceccobelli et al. (2012) analysed several yearly probability density functions for a sample of 14 OECD countries and observed that, similar to the results of Margaritis et al. (2007) and López-Pueyo and Mancebón-Torrubia (2009), the distribution of apparent labour productivity tends to adopt a bimodal shape. Furthermore, most papers using the DDA to assess convergence of income per head across world regions also find polarisation (see, for example, Quah, 1993a, 1993b, 1997 for early contributions, or Canova, 2004, for a more recent one).

Meanwhile, the PDF of TFP presents a normal distribution which, moreover, tends to concentrate around 1 as time goes by, indicating a reduction in the standard deviation of the sample and suggesting that there are no convergence clubs, with all countries showing a trend toward greater similarity in their TFP levels.

While no recent studies assessing TFP convergence across different world areas by means of the DDA have been found, Akram and Rath (2019: 97) use unit root tests to assess convergence between 44 developing economies and 29 OECD countries and conclude that there is “evidence of TFP convergence for developing countries”. At their turn, Miller and Upadhyay (2002: 282) analyse beta- and sigma-convergence indicators and “discover stronger evidence of convergence for total factor productivity than for real GDP per worker”, which is again coherent with our findings.

However, as is well-known, TFP growth captures changes in income distribution among real wages and the rate of return on fixed capital (Wirkierman, 2022). For this reason, TFP convergence could be based on distributional trends, but not technical change (Elmslie and Milberg, 1996: 161). Thus, the difference between TFP indicator and ATLP implies that the apparent income distribution convergence may occur independently of any convergence in techniques.[8]

The latter notwithstanding, the analysis of PDFs is still very aggregate and does not tell us how countries move across the distribution with the passage of time. To explore this "intra-distribution mobility", Quah (1993b) proposed to categorise data in groups, in such a way to make it possible to build a transition matrix that tells us the probability of transitioning to each category depending on the category of departure.

Formally, let $S = \{s_1, s_2, \ldots, s_m\}$ represent m distinct states or groups, such that each interval s_k covers a specific range of normalised values (e.g., low, medium and high income relative to the mean). Then, each country's normalised productivity value can be assigned to a state s_k so that we get $G_t = \left\{g_{1,t}, g_{2,t}, \ldots, g_{m,t}\right\}$, where $g_{k,t}$ tells us the amount of countries placed in state k at time t.

Taking all this into account, it is possible to define:

$$G_{t+q} = M \cdot G_t \tag{16}$$

Where M is the so-called transition matrix that "maps one distribution into another" (Quah, 1993b). It can be easily calculated when we know G_t and G_{t+q} and, thus, we only need to look at the number of transitions across each pair of categories and divide it by the total amount of observations found in the initial category.

For the present analysis, let us set $q = 1$ and define $s_1 = [0,\ 0.5)$, $s_2 = [0.5,\ 0.75)$, $s_3 = [0.75,\ 1)$, $s_4 = [1,\ 1.25)$ and $s_5 = [1.25,\ \infty)$.[9] Then, we can calculate the one-year transition matrix of our three datasets by looking at the frequency with which observations move from one state to another between consecutive years. For our three productivity indicators, this process yields the following results:

Fig. 5

In these transition matrices, rows indicate the state of the base period and columns indicate the state in the end period. For example, with regards to ATLP, we can see that 2 % of the countries that began in state 1 in the base year finished in state 2 in the final period, while 10 % of the countries that began in state 2 ended up at state 1.

Therefore, the high values in all three main diagonals tell us that countries tend to remain from year to year in the same category. However, ATLP's and ALP's least mobile groups are found at the extremes; and, if one looks at the immediate off-diagonal elements, it is also clear that countries occupying central positions in the distribution of ATLP and ALP tend to move towards the extremes. This suggests that ATLP and ALP exhibit a polarisation pattern, where countries in the middle of the distribution are less stable and more likely to shift towards either the highest or lowest productivity categories. This is coherent with the literature of SED on cumulative divergence, where initial structural conditions play a significant role in determining economic trajectories (Spaventa, 1959; 1960). That is, structural bottlenecks and uneven development force economies toward either high or low productivity poles. These patterns challenge the neoclassical expectation of inevitable convergence driven by diminishing returns and spillover effects (Baumol, 1994).[10]

Conversely, in the case of TFP, it is the countries at the extremes that move towards the centre. That is, the TFP indicates a sort of convergence pattern, where countries at the extremes (either very low or very high TFP) tend to migrate towards intermediate categories. In this sense, the differences in relation to the other measures support the idea that TFP convergence reflects shifts in functional income distribution rather than convergence in labour-saving techniques.

This is further confirmed by the ergodic distribution, shown in Fig. 6, that describes the long-run, steady-state distribution of each productivity index, if the transitions across categories took place recursively until no relevant shifts across them could be registered (see Quah, 1993a for details).

For ATLP and ALP, the ergodic distribution confirms the tendency for countries in the central range of productivity to drift towards either higher or lower productivity states over time, reinforcing the pattern of polarisation. Conversely, the TFP index shows a different dynamic, with countries initially at high or low productivity levels demonstrating a higher probability of moving toward central positions. This suggests a convergence trend in TFP, where extreme TFP level states become less persistent over time, leading to a more balanced distribution across TFP levels.

However, using time-invariant states to define S has limitations in capturing changes in rank positions within the distribution. Specifically, it does not account for whether individual countries ascend or descend relative to others, as the focus remains solely on shifts between predefined categories and, once a country has entered or left a certain category, it is not possible to how it is positioned relative to other countries. For this reason, to understand how countries move up or down in comparison to others within the sample, it may be more informative to use discrete categories defined by time-varying quantiles.

In this case, to get informative results, we set $q = 10$ and compute the transitions with time-varying states as defined by each year's quintiles.[11] The results are offered in Fig. 7.

The matrices of transitions across quintiles for ten years periods, show high persistence in relation with the ordering between countries, especially at the extremes. For ATLP and ALP the results emphasise lower mobility between quintiles, mainly in relation to central categories, than for TFP. On the contrary, in the TFP matrix, although there is persistence particularly with the countries at the extremes, in the central categories there is greater mobility. That is, there are continuous changes in the central part of the ranking of countries in the TFP, while the extremes are immobilised.

[8] By techniques we refer the specific methods of production. That is, the quantity of units of productive capacity and the units of vertically integrated labour in order to produce one unit of final commodity.

[9] The researcher must choose which values are assigned to t and q. With regards to the former, it is a common practice to select as many ts as q allows, in such a way that, given the transition time under consideration, q, we will get more than one observation and, thus, increase the robustness of our results. For example, if we were interested in 5 years transitions in the period 1995-2020, we would analyse all five-year transitions beginning in 1995, 1996 and so on, up to the transition from 2015 to 2020.This implies that the bigger q is, the lower the number of observations we will obtain. For this reason, it is usual to set $q = 1$, the exceptions being, as we will shortly see, those cases where yearly changes are so small that q needs to be bigger if we want to obtain informative results.Besides that, another choice that the researcher must make is related to the definition of the states contained in S. One option is to set them at the points the researcher considers appropriate, which is the approach followed by Quah (1993b) and the first for which we offer results. Another option is to define them according to quintiles, as explained below.

[10] For the neoclassical expectation to be true, we should observe greater mobility towards the centre. This would happen if right off-diagonal elements of the first two rows and left off-diagonal elements of the last two rows showed greater values.

[11] As we have already seen, yearly transitions tell us almost nothing because the off-diagonal elements are almost nil, and it requires several years for their impact to be felt. When using time invariant categories, this was resolved by looking at the ergodic distribution. However, when using time-varying quantiles, the share of countries leaving one category is necessarily the same that is entering it; for this reason, the ergodic distribution will be equal to the initial one, defined by quantiles.When categories are defined as time-varying quantiles, then, it is preferrable to look at transitions between time periods that are long enough to see general trends of intra-distribution dynamics. To do so, we can either raise the M obtained for the newly defined S to the power of the q that we consider appropriate, or we can compute M from the q-years transitions that can be found in our dataset. Here, we offer the results of the second method because it is a more direct estimation method, but they are not significantly different from those obtained with the first one.

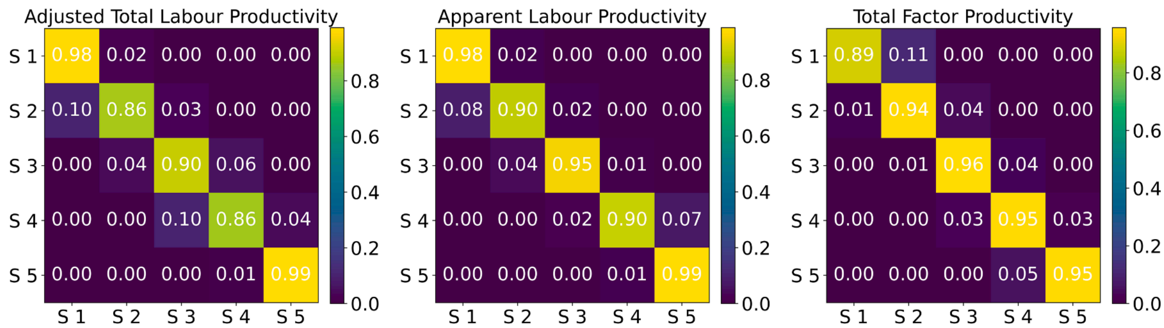

Fig. 5. Yearly transition matrices with time invariant states.
Source: ICIO OECD Database and Penn World Table. Own calculations.

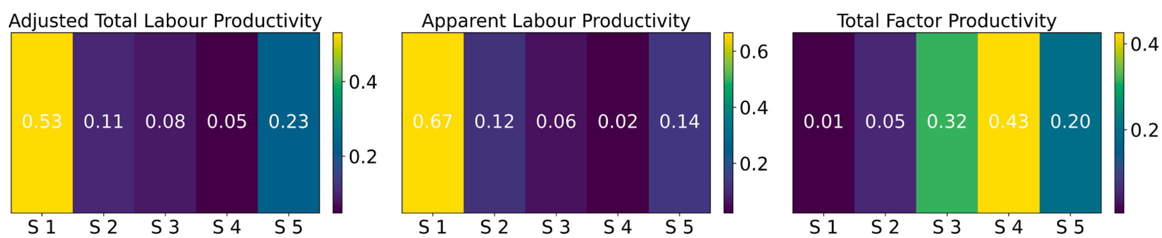

Fig. 6. Ergodic distribution.
Source: ICIO OECD Database and Penn World Table. Own calculations.

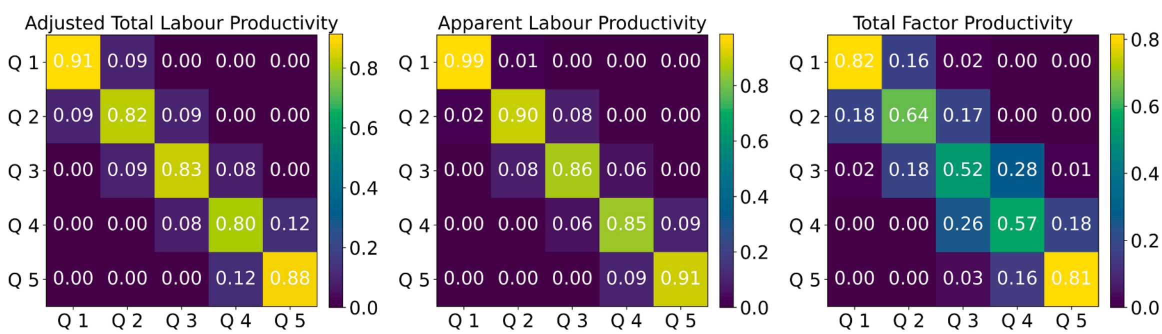

Fig. 7. Ten-year transition matrices with time-varying states.
Source: ICIO OECD Database and Penn World Table. Own calculations.

Discrepancies in the country ranking show the divergent evolution of the information reflected in each productivity measure. As Wirkierman (2022) argues, TFP's higher mobility is related to the higher dynamism in terms of the capacity to reduce production costs in real terms of countries in the middle part of the ranking. However, this mobility is not reflected in terms of technological catch-up of these countries, in which the ATLP shows high persistence positions in technological development. Furthermore, ALP shows lower mobility in the ranking than ATLP. These mismatches between ATLP and ALP are related to the unit of analysis. Beyond the critiques to the physical interpretation of the income-side measure of real value added (see Meade, 2010), ALP represents the labour productivity performance at the industry level (i.e., it does not take into account the productivity of the inputs used). In this sense, when a systemic measure is used such as ATLP, the higher mobility in the central part of the distribution of the ranking might be related to the inputs and the productive interdependencies involving the industries.

All this notwithstanding, it must be acknowledged that the values contained in transition matrices are always affected by the discretisation used in the definition of S and, thus, if other discretisation were used, different results might appear (Chung, 1960; Bulli, 2001). For this reason, Quah (1997) introduced the visual inspection of stochastic kernels as a way to complement the DDA to convergence analysis (see Magrini, 2007, for details).

Compared to the previous transition matrix, the stochastic kernel can be understood as a transition matrix "with a continuum of rows and columns" (Quah, 1997: 36), which shows how the relative productivities of countries in year t evolve to those in year $t+q$. Therefore, the analysis of the stochastic kernel itself can be illustrative of the movements of countries across different relative positions.

Following the literature, we plot it in a 3D graph and in an equivalent contour plot where the vertical axis shows the density, while the other two axes show, respectively, the values of the variable under consideration at time t and the values of the variable under consideration at time $t+q$. Therefore, the lower the movements across relative positions, the more concentrated the density will be around the diagonal, where each position at time t is preserved at time $t+q$. Instead, if all countries converged towards the mean, density would be concentrated in parallel to the axis of observations at time t and corresponding to value 1 in the axis of observations at time $t+q$.

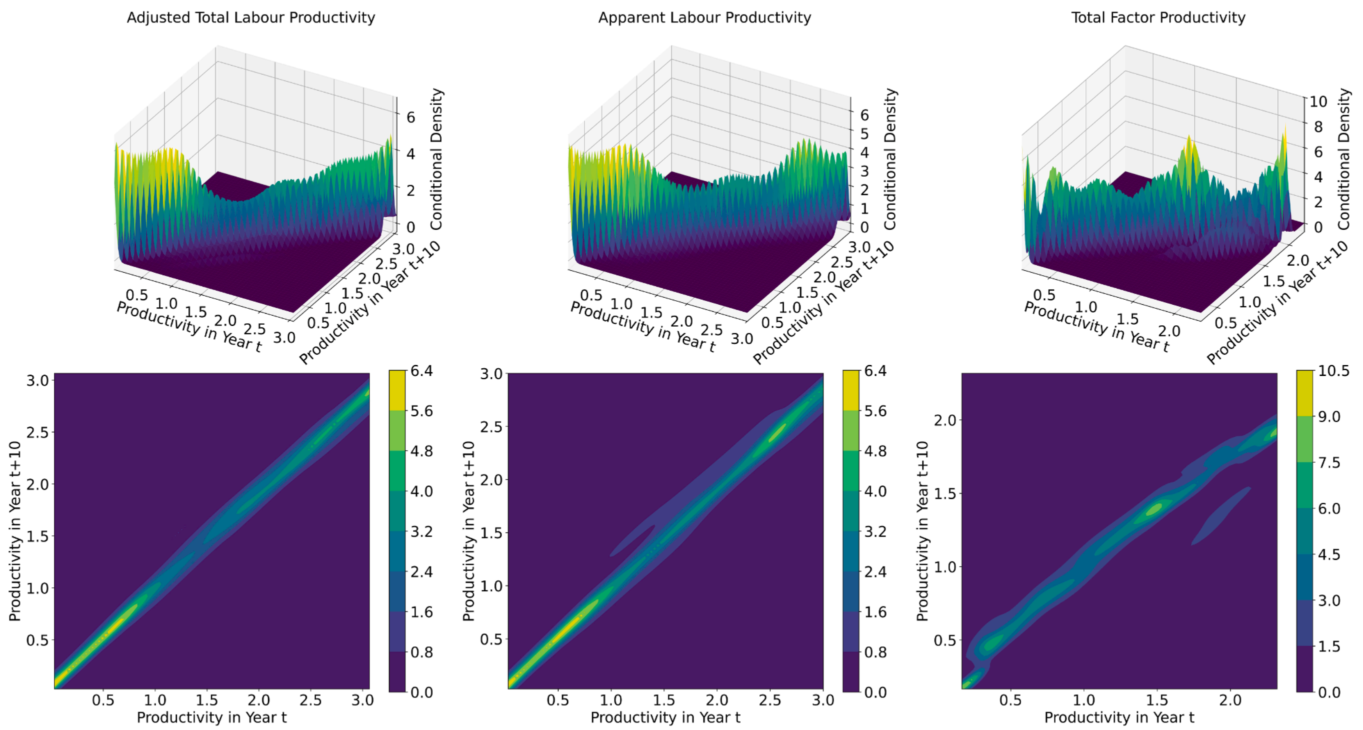

Fig. 8. Stochastic kernels for ten-years transitions.
Source: ICIO OECD Database and Penn World Table. Own calculations.

Setting $q = 10$ we compute the stochastic kernel and obtain the results shown in Fig. 8.[12]

The conclusions that can be drawn from these figures reinforce what has already been said in the analysis of previous results: there is high persistence for all indicators, especially at extreme positions. However, mobility is higher for TFP, in general, and a considerable share of countries beginning in extreme positions end up closer to the average after 10 years.

6. Concluding remarks

Following a suggestion by Pasinetti, this paper has proposed an empirical measure of productivity, that accounts for the role of imports, and which we have called adjusted total labour productivity. This measure has been used to assess convergence in a sample of 61 economies and the rest of the world, following the Distribution Dynamics Approach. The findings were then compared against those derived from more conventional productivity indicators, namely apparent labour productivity and total factor productivity.

The findings reveal significant differences in the trajectories of these indicators, shedding light on distinct dimensions of productivity dynamics reflected by the empirical measure chosen. On the one hand, TFP evolution depicts a tendency toward reduced dispersion over time, indicating a more homogeneous productivity pattern, and with higher mobility of countries at the extremes showing a tendency to converge toward intermediate positions. On the other hand, ALP and ATLP suggest the presence of convergence clubs. These clubs reflect the polarisation of countries into high- and low-productivity groups. Transition matrix analysis reveals limited mobility, particularly at the extremes, further confirming the polarisation dynamic.

This divergence underscores the role of real cost reduction and functional income distribution dynamics in shaping TFP convergence, rather than technological catch-up or changes in physical productivity reflected in ALP and ATLP. That is, convergence in cost-reduction capacity of economies is not correlated with labour-saving trends. Furthermore, even within labour productivity indicators, differences between ALP and ATLP, such as the greater mobility of the latter, stress the role of inputs in transferring technological advancement. This is because the former is a direct measure of productivity while the latter a systemic one, taking into account direct and indirect requirements of production.

Our productivity measure provides valuable insights to guide economic policy and promote convergence. Exporting sectors play a fundamental role, as productivity improvements tend to spill over into the rest of the economy. At the same time, a greater reliance on imported inputs in production requires additional resources to finance imports, which can, in turn, lead to a decline in productivity.[13] Finally, it is crucial to achieve broad-based productivity growth, supported by a common technological foundation across all sectors. While productivity gains may not be uniform, reducing excessive disparities can help sustain the standard productivity growth rate.

In closing, it is important to point out some limitations of the work and alternatives for moving forward. First, the analysis of aggregate data may be concealing some sector-specific dynamics. National averages include both traded and non-traded sectors, which is a cause for potential bias. Exploring convergence on a sectoral level could yield more granular insights into convergence patterns. For example, assess if convergence clubs are also present across sectors or identify which are

[12] As happened with the transition matrices that used moving quintiles, yearly transitions tell us almost nothing because the off-diagonal elements are almost nihil, and it requires several years for their impact to be felt. For this reason, we need to either use the convolution of the stochastic kernel, or compute it for a relatively bigger q, such as $q = 10$. Again, as we did for previous transition matrices, the results offered are those obtained following the second method, which are not significantly different to those obtained with the first.

[13] Examining equation (13), it is straightforward to observe that a higher σ^* increases the multiplier, thereby raising the labour content per unit of output across all sectors.

the specific activities creating these clubs. Second, the terms of trade affect our proposed measure of productivity (see Brondino et al., 2024, p. 184). Decomposing productivity growth to assess volume and price effects can highlight the role of changing terms of trade in productivity.[14]

CRediT authorship contribution statement

Gabriel Brondino: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Methodology, Formal analysis, Data curation, Conceptualization. **Facund Fora-Alcalde:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Methodology, Formal analysis, Data curation, Conceptualization. **Miguel Ángel Casaú-Guirao:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Methodology, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix I

A. Price-volume separation in the empirical national input-output framework

The key assumption for separating price and volume components is that basic prices are uniform for each output, both domestic and imported. Prices are assumed to be stable throughout the accounting period (year). The following table presents the price-volume decomposition of the components in the national input-output framework:

Nominal	Price-volume	Nominal	Price-volume
$\boldsymbol{x}$	$\widehat{\boldsymbol{p}}\boldsymbol{q}$	$\boldsymbol{a}_l^T$	$\boldsymbol{\alpha}^T\widehat{\boldsymbol{p}}^{-1}$
$\boldsymbol{f}_X$	$\widehat{\boldsymbol{p}}\boldsymbol{y}_X$	$\boldsymbol{A}^d$	$\widehat{\boldsymbol{p}}\boldsymbol{A}_q^d\widehat{\boldsymbol{p}}^{-1}$
$\boldsymbol{Z}$	$\widehat{\boldsymbol{p}}\boldsymbol{Z}_q$	$\boldsymbol{A}^m$	$\widehat{\boldsymbol{p}}_m\boldsymbol{A}_q^m\widehat{\boldsymbol{p}}^{-1}$
$\boldsymbol{M}^z$	$\widehat{\boldsymbol{p}}_m\boldsymbol{M}_q^z$		

From these definitions, we can derive further price-volume decompositions. For example, the vector of vertically integrated labour coefficients:

$$\boldsymbol{v}^T = \boldsymbol{a}_l^T\left(\boldsymbol{I}-\boldsymbol{A}^d\right)^{-1} = \boldsymbol{\alpha}^T\widehat{\boldsymbol{p}}^{-1}\left(\widehat{\boldsymbol{p}}\widehat{\boldsymbol{p}}^{-1}-\widehat{\boldsymbol{p}}\boldsymbol{A}_q^d\widehat{\boldsymbol{p}}^{-1}\right)^{-1} = \boldsymbol{\alpha}^T\widehat{\boldsymbol{p}}^{-1}\left[\widehat{\boldsymbol{p}}\left(\boldsymbol{I}-\boldsymbol{A}_q^d\right)\widehat{\boldsymbol{p}}^{-1}\right]^{-1} = \boldsymbol{\alpha}^T\left(\boldsymbol{I}-\boldsymbol{A}_q^d\right)^{-1}\widehat{\boldsymbol{p}}^{-1} = \boldsymbol{\nu}^T\widehat{\boldsymbol{p}}^{-1}$$

The vertically integrated matrix of import coefficients:

$$\boldsymbol{H}^m = \boldsymbol{A}^m\left(\boldsymbol{I}-\boldsymbol{A}^d\right)^{-1} = \widehat{\boldsymbol{p}}_m\boldsymbol{A}_q^m\widehat{\boldsymbol{p}}^{-1}\left[\widehat{\boldsymbol{p}}\left(\boldsymbol{I}-\boldsymbol{A}_q^d\right)\widehat{\boldsymbol{p}}^{-1}\right]^{-1} = \widehat{\boldsymbol{p}}_m\boldsymbol{A}_q^m\left(\boldsymbol{I}-\boldsymbol{A}_q^d\right)^{-1}\widehat{\boldsymbol{p}}^{-1} = \widehat{\boldsymbol{p}}_m\boldsymbol{H}_q^m\widehat{\boldsymbol{p}}^{-1}$$

The labour required per dollars' worth of exports:

$$v^* = \boldsymbol{\nu}^T\widehat{\boldsymbol{p}}^{-1}\widehat{\boldsymbol{p}}\boldsymbol{y}_X/\epsilon = \boldsymbol{\nu}^T\boldsymbol{y}_X/\epsilon$$

The imports required per dollars' worth of exports:

$$\sigma^* = 1_r^T\boldsymbol{H}^m\widehat{\boldsymbol{p}}\boldsymbol{y}_X\Big/\epsilon = 1_r^T\widehat{\boldsymbol{p}}_m\boldsymbol{H}_q^m\widehat{\boldsymbol{p}}^{-1}\widehat{\boldsymbol{p}}\boldsymbol{y}_X\Big/\epsilon = \boldsymbol{p}_m^T\boldsymbol{H}_q^m\boldsymbol{y}_X\Big/\epsilon$$

Hence, absolute values of our computed measure depend on basic prices. Since the variables are expressed in constant prices, their rates of change reflect variations solely in physical or real magnitudes.

The component:

$$\frac{v^*}{1-\sigma^*}\sigma_i^*$$

Can be computed at constant and current prices. The difference between both magnitudes reveals the effect of the terms of trade in labour productivity.

Appendix II

Group	Countries (and codes)
Western Offshoots	Australia (AUS), Canada (CAN), New Zealand (NZL), United States (USA)
BRICS	Brazil (BRA), China (CHN), India (IND), Russia (RUS), South Africa (ZAF)
Latin America	Argentina (ARG), Chile (CHL), Colombia (COL), Costa Rica (CRI), Mexico (MEX), Peru (PER)
East Europe	Bulgaria (BGR), Czechia (CZE), Estonia (EST), Croatia (HRV), Hungary (HUN), Lithuania (LTU), Latvia (LVA), Poland (POL), Romania (ROU), Slovakia (SVK), Slovenia (SVN), Ukraine (UKR)

(*continued on next page*)

[14] This issue has been partially addressed in Fora-Alcalde.

(*continued*)

Mediterranean Europe	Cyprus (CYP), Spain (ESP), Greece (GRC), Italy (ITA), Malta (MLT), Portugal (PRT)
Western Europe	Austria (AUT), Belgium (BEL), Switzerland (CHE), Germany (DEU), Denmark (DNK), Finland (FIN), France (FRA), United Kingdom (GBR), Ireland (IRL), Iceland (ISL), Luxembourg (LUX), Netherlands (NLD), Norway (NOR), Sweden (SWE)
Middle East	Egypt (EGY), Israel (ISR), Saudi Arabia (SAU), Turkey (TUR)
Asia	Indonesia (IDN), Japan (JPN), Kazakhstan (KAZ), South Korea (KOR), Malaysia (MYS), Philippines (PHL), Singapore (SGP), Thailand (THA), Taiwan (TWN)
ROW	Rest of the World (ROW)

Data availability

Data will be made available on request.

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