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Measuring total labour productivity in the open economy: A proposal

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Abstract:
In the classical approach, one of the main measures of productivity is the so-called 'total labour productivity' (TLP), which can be computed as the reciprocal of the vertically integrated labour required to produce one unit of net output. In closed economies, this index changes exclusively due to technical progress. However, in open economies, where intermediate imports are required for the production of national output, changes in TLP may reflect changes in sourcing practices, which do not necessarily represent technical progress but rather the reorganization of production chains. To account for these new sources of productivity, Pasinetti proposed considering the quantity of domestic labour embedded in exports that is employed to finance imports. Building on this idea, this paper develops an 'adjusted' measure of TLP that corrects the effect of imports on productivity and studies its properties. We compare this measure to other indices related to TLP and highlight its relevance for empirical analysis.

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Productivity is a ratio between outputs and inputs, but which products and inputs should be considered is a debated issue. The discussion depends on the research question and the adopted theoretical framework. Within the classical approach, labour productivity stands as the most relevant measure of productivity, and there are various alternative ways for measuring it. The so-called total labour productivity is a good option when the analysis is linked to the quantitative dimension of technological change. It measures the net production of a sector that a unit of *integrated* labour, that is, direct and indirect, generates. A special feature is that it considers all necessary work, including that of other activities directly or indirectly linked to the sector. In this theoretical framework, labour saving is the ultimate manifestation of technological progress.

This type of measure pairs well with input-output analysis, as its calculation requires information on inter-industry relationships. When the unit of analysis is a country with an economy open to international trade, some additional difficulties arise. Offshoring, outsourcing – in short, the cross-border lengthening of production chains – involves using imported inputs and capital goods, that is, foreign resources. In this scenario, both globalisation and technological change are sources of domestic labour savings.

Several alternative ways of measuring productivity arise, depending on how imported inputs are treated. Firstly, they can be treated as nonreproducible resources (equating them to labour), and domestic labour productivity can be calculated without distinguishing alternative sources of labour savings. Secondly, imported inputs can be treated as if they were produced domestically, and a notional labour productivity can be calculated. Thirdly, in the case of having information on inter-industry relationships between countries (as in the multi-regional input-output framework), global labour productivity can be computed, considering the domestic and foreign labour necessary for final production. Each measure captures one aspect of the labour savings process and leaves out another.

This paper explores the construction of a productivity measure based on a suggestion made by Pasinetti in his book *Structural Change and Economic Growth*. The suggestion is to consider the domestic labour necessary to produce exports that allow the purchase of imported inputs required in production. We elaborate on this idea for the case of a small economy with balanced trade. Additionally, we develop a simple numerical example to compare how alternative measures of total labour productivity respond to an increase in offshoring and highlight the characteristics of the proposed measure.

The structure of the article is as follows. The section after this introduction offers some preliminary observations on productivity measurement. Section 2 focuses on measuring productivity in the classical approach through the quantity system. Section 3 discusses the various alternatives available for measuring productivity when countries trade with each other. These alternatives are derived from an extensive review of specialised literature. In the fifth section, we develop an alternative measure inspired by Pasinetti's idea, while in the following section we present a numerical example to compare all measures of productivity and highlight the salient features of our proposal. The last section concludes and proposes future lines of research.

1. Preliminary remarks

Virtually all economists agree that productivity is a ratio between outputs and inputs. However, which outputs and inputs should be considered is usually a matter of controversy, and this usually depends on the research question and the economic theory.

The research could focus on studying the evolution of the units of a final product created in a given sector or group of sectors by one hour of work. This would be a purely physical measure of productivity. Changes in this index through time would reflect shifts in the technical capabilities of this specific sector or group of sectors.

If, instead, the research is aimed at studying the evolution of the purchasing power created by an input flow (say, one hour of work), one could measure how much output of sector *i*, or of a basket of outputs can be commanded by one hour of work in sector *k*. Since we are talking about purchasing power, relative prices are also required in this measurement. Furthermore, price variations will affect this measurement too. If the purpose is to study physical changes in productivity, this is not acceptable.

Another key issue of controversy arises in the conceptualisation of production adopted. In the neoclassical theory, production is conceived as a "one-way avenue that leads from 'factors of production' to 'consumption goods'". Solow's (1957) is one of the canonical models used for analysing economic growth and technical progress. A key tool within this model is the aggregate production function.[1] It represents alternative ways of efficiently producing a consumption good Q with capital C and labour L and may be written in the following way:

$$Q = A \cdot F(C, L)$$

A is a parameter that reflects the state of technical knowledge. F fulfils all the desired properties, the most relevant being that it is homogeneous of degree one. Given this property, it is possible to restate the production function as follows:

$$q = A \cdot F(c, 1) = A \cdot f(c)$$

where q is the output per labour unit, and c is the capital-labour ratio. As can be seen, q is a measure of productivity, and its *immediate* determinants in this framework are A and c. The change in the former is termed “total factor productivity” growth (and reflects shifts or jumps in the production function). In contrast, the change in the latter is called “capital deepening” (and reflects movements along the production function). Growth accounting exercises focus on assessing which determinant is more relevant in each case. Theoretically, total factor productivity is the key determinant for sustained long-run productivity growth because the productivity gains from capital deepening (from each worker being employed with more capital) are eventually exhausted due to diminishing returns (another property of the production function).

Despite its widespread use, the neoclassical production function has been attacked on so many fronts that reviewing all the criticisms (and their rejoinders) would require a multi-volume collection. One of the main problems is whether total factor productivity effectively captures technical progress. Value added is the preferred measure for output in empirical analyses. Nevertheless, value added represents income distributed to both workers, in the form of wages, and capitalists, in the form of profits. Therefore, estimating total factor productivity growth using value-added data ultimately reflects changes in income distribution (Shaikh, 1974), which may not necessarily correlate with physical changes in productivity.[2]

2. The classical approach

In the classical framework, production is conceived as a circular process. In the simplest setting, the production of commodities involves the use of other commodities and labour. Labour is the sole nonproduced factor and, therefore, is the critical input for measuring productivity.[3] Production is carried out through an extensive division of labour and marked specialisation (Pasinetti, 1993). These two components are key determinants of labour productivity. As the separation of tasks performed by each worker expands, and workers specialise in their respective tasks, their higher productivity spills over and improves overall efficiency. Furthermore,

[1] Despite its well-known problems, it is still extensively employed in the literature. In fact, Pasinetti (2000) was astonished that aggregate production functions made a comeback in the literature in the 1980s, as if there had never been any issues around their use.

[2] Naturally, changes in income distribution could be due to technical progress – say, given stable factor shares, real wages increase because output per worker has risen – but it would be misleading to assert that this constitutes the only source of changes in income distribution in the long term.

[3] A crucial difference between this approach and the neoclassical one is that, in the latter, the treatment of factors is symmetrical. We could have just as well worked with “capital’ productivity by transforming the production function into $v = Af(l)$, where v is output per unit of capital and l is the labour-capital ratio.

productivity may be referenced to a single commodity without losing sight of this interdependency. Several tasks and activities contribute to the production of a finished product.

The above is made possible through the method of subsystems. Following Sraffa (1960, Appendix C), it is possible to subdivide the economic system into many parts, each consisting of one kind of commodity (belonging to the net output). Each part forms a "smaller self-replacing system" (ibid.), encompassing the direct and indirect input and labour requirements to produce the commodity. Pasinetti (1973) shows how to derive them analytically and terms them "vertically integrated sectors". Furthermore, Pasinetti (1988) extended this definition to consider the expansion of the productive capacity, i.e. *growing* subsystems.

2.1. The device of vertical integration

We will work with a simple setting of single-output industries and circulating capital. The technical methods of production are represented by:[4]

- A square matrix $\mathbf{A} = [a_{ij}]$, $i, j = 1, 2, \dots n - 1$, all $a_{ij} \geq 0$, where a_{ij} denotes the quantity of commodity i used as an input for producing one unit of commodity j.
- A vector $\mathbf{a}_n = [a_{nj}]$, $j = 1, 2, \dots n - 1$, all $a_{nj} \geq 0$, where a_{nj} denotes the amount of labour units (hours, persons engaged, etc.) required for producing one unit of commodity j.

Additionally, let vector $\mathbf{q} = [q_i]$ denote the vector of gross outputs, and vector $\mathbf{y} = [y_i]$ represent the vector of net outputs. With these definitions, the physical economic system is represented as follows:

$$(\mathbf{I} - \mathbf{A})\mathbf{q} = \mathbf{y} \quad (1)$$

$$\mathbf{A}\mathbf{q} = \mathbf{s} \quad (2)$$

$$\mathbf{a}_n^{\mathrm{T}}\mathbf{q} = L \quad (3)$$

where L is the total amount of labour units required by the economic system and $\mathbf{s}$ is the vector of intermediate consumption.

For a given net output vector (final demand), this system of equations represents an "open Leontief system" (Pasinetti, 1977, p. 61). The solution is:

$$\mathbf{q} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{y}$$

Substituting this solution in equations (2) and (3) gives:

$$\mathbf{A}(\mathbf{I} - \mathbf{A})^{-1}\mathbf{y} = \mathbf{s}$$

$$\mathbf{a}_n^{\mathrm{T}}(\mathbf{I} - \mathbf{A})^{-1}\mathbf{y} = L$$

The columns of matrix $\mathbf{H} \coloneqq \mathbf{A}(\mathbf{I} - \mathbf{A})^{-1}$ represent the vertically integrated units of productive capacities. On the other hand, vector $\mathbf{v}^{\mathrm{T}} = \mathbf{a}_n^{\mathrm{T}}(\mathbf{I} - \mathbf{A})^{-1}$ contains the vertically integrated labour coefficients.

A vertically integrated sector may be represented as follows (Pasinetti, 1990):

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[4] We will adopt the usual notation, whereby a boldface capital letter represents a matrix; a boldface lowercase letter represents a vector; all vectors are columns except when transposed, represented by the letter T.

$[y_i, \quad \mathbf{h}_i y_i, \quad v_i y_i]$

where $\mathbf{h}_i$ denotes the i-th column of matrix $\mathbf{H}$. Dividing all terms by y_i gives:

$[1, \quad \mathbf{h}_i, \quad v_i]$

Commodities entering vector $\mathbf{h}_i$ are measured in their specific physical unit (such as kWh, litres, and numbers). It is possible to treat $\mathbf{h}_i$ as a composite commodity and refer to it as a physical unit of vertically integrated productive capacity, k_i. In equilibrium, one unit of vertically integrated productive capacity is required to produce one unit of final output; thus, at unitary activity levels, $k_i = 1$. Hence, we may write:

$[1, \quad 1, \quad v_i]$

To deliver one unit of final output, one unit of vertically integrated productive capacity and v_i units of vertically integrated labour are required.[5] The reciprocal of the latter is the so-called "total labour productivity". It gives the quantity of net output produced by one unit of vertically integrated labour. Two crucial properties of this index stand out:

- It can be derived by looking exclusively at the quantity system. In other words, it can be known for given technical conditions of production. Therefore, any changes in the index reflect solely technical progress.
- As anticipated, it captures all the relevant interindustry relations working in the background that influence the production of net outputs. Any improvement (e.g., a more efficient use of labour or reproducible inputs) in upstream or downstream activities is reflected in the productivity of finished products. Consider, for example, technical progress in the cotton textile sector during the Industrial Revolution. The sector's success was due to technical innovations in spinning and weaving. Furthermore, the crucial breakthrough was using steam engines as the power source. Other technical innovations came from the bleaching, dyeing and printing processes. These innovations also spilt over to other related sectors (see Findlay and O'Rourke, 2007, pp. 318-320).

From these properties there follows a remarkable insight. When v_i diminishes, it is possible to assert that "somewhere in the economic system there has been a saving of labour requirements" (Pasinetti, 1981, p. 207).[6] The foremost implication is that "technical progress is, in the end, labour-saving" (ibid.). In the classical framework, saving labour is the "ultimate meaning of technical progress" (ibid.).[7] Recalling the previous example of the cotton textile sector,

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[5] "[T]he remarkable feature of the concept of a vertically integrated sector is that, complex though it may be (behind the scenes, so to speak) in its composition, it is simply reduced to two ones and to a further single number representing a physical quantity of labour" (Pasinetti, 1990, p. 236).

[6] Pasinetti draws this conclusion from analysing the dynamics of unit prices at the integrated level. If the price of a commodity decreases over time for a given rate of profit, it indicates technical progress in its production. When the rate of profit is set at its 'natural' level, the unit price of a commodity equals its vertically hyper-integrated labour coefficient, which includes both direct and indirect labour, as well as the hyper-indirect labour necessary to expand productive capacity. In this scenario, it can be unambiguously established that the reduction of this coefficient over time is associated with technical progress in the production of the commodity. The effects of technical progress on the productive structure may vary, depending on whether it occurs in the production of consumption goods or capital goods. For instance, technical progress may encompass physical-capital-using techniques or physical-capital-saving cum direct-labour-using techniques. See Pasinetti (1981, p. 213) for a detailed classification of technical progress.

[7] See also the so-called "law of decreasing labour content' (Farjoun and Machover, 1985; Flaschel et al., 2013).

Chapman (1972, p. 20) reported that the number of operative hours to process 100 pounds (around 45 kilograms) of cotton was over 50,000 for Indian hand spinners in the eighteenth century. In England, it was cut to 2,000 in 1780 with the introduction of Crompton's mule, and it decreased to 300 by 1795 with the help of power-assisted mules.

3. International economic relations

Technological progress and institutional change in the last quarter of the twentieth century reduced natural and artificial trade barriers, increasing the type and number of commodities countries could exchange. Baldwin (2016) has called this process "globalisation's second unbundling".

Multinational firms began sourcing inputs that came from offshore locations and that were produced by other firms and began relocating several stages of production abroad to minimise costs and increase market share. Trade in intermediate inputs surged. From the standpoint of national economies, the trade patterns became more complex than the traditional import-export of finished goods.

This process has certainly affected the domestic conditions of production. When a country's economy is open to international trade, the import of capital goods and intermediate inputs plays a relevant role in domestic production. The production of net outputs no longer requires only domestic resources but also foreign ones.[8]

Let us return to the initial model to adapt it to the case of an open economy. The major change is that matrix $\mathbf{A}$ is split into two: a matrix of domestic input coefficients $\mathbf{A}^d$ and a matrix of imported input coefficients $\mathbf{A}^m$ ($\mathbf{A} \equiv \mathbf{A}^d + \mathbf{A}^m$).

The physical economic system is now written as follows:

$$\left(\mathbf{I} - \mathbf{A}^d\right)\mathbf{q} = \mathbf{y} \tag{4}$$

$$\mathbf{A}^d\mathbf{q} = \mathbf{s}^d \tag{5}$$

$$\mathbf{A}^m\mathbf{q} = \mathbf{s}^m \tag{6}$$

$$\mathbf{a}_n^{\mathrm{T}}\mathbf{q} = L \tag{7}$$

In this scenario, labour-saving is no longer strictly associated with technological progress. It is also possible to reduce the labour content of a vertically integrated sector by substituting domestic inputs for imported inputs without changing the method of production.

To see this, let us first define matrix $\mathbf{D} = \left[d_{ij}\right]$, where $d_{ij} = a_{ij}^d / a_{ij}$ is the share of input *i* that is sourced domestically in the production of commodity *j*. Matrix $\mathbf{A}^d$ can be restated as $\mathbf{A}^d = \mathbf{D} \circ \mathbf{A}$, where $\circ$ denotes element-wise multiplication.[9]

The solution to equation (4) is $\mathbf{q} = \left(\mathbf{I} - \mathbf{A}^d\right)^{-1}\mathbf{y} = (\mathbf{I} - \mathbf{D} \circ \mathbf{A})^{-1}\mathbf{y}$. The vector of vertically integrated labour coefficients is now:

[8] This is not the only relevant feature of international economic relations. The possibility of learning, copying advanced techniques, etc., is also crucial.

[9] For example, given matrices $\mathbf{A} = \left[a_{ij}\right]$ and $\mathbf{B} = \left[b_{ij}\right]$, its element-wise product is matrix $\mathbf{A} \circ \mathbf{B} = \left[a_{ij} \cdot b_{ij}\right]$.

$$\mathbf{v}^{\mathrm{T}} = \mathbf{a}_n^{\mathrm{T}}(\mathbf{I} - \mathbf{D} \circ \mathbf{A})^{-1} \quad (8)$$

A decrease in any element of matrix **D**, related to lower domestic input consumption, leads to a fall in **v** and an increase in domestic productivity.[10] In other words, as production is increasingly relocated abroad, the domestic labour required per unit of net output decreases accordingly.

The previous result bears significance for the productivity measure and its interpretation. To the best of our knowledge, there are three approaches to measuring total labour productivity in an open economy. The first approach is to compute it using equation (8) above. We may call the measure domestic total labour productivity. In this case, imported inputs are regarded as nonproduced resources and are placed on an equal footing with domestic labour (Rampa, 1981). The main setback of this approach is that it is impossible to distinguish the source of labour saving; ultimately, one is constrained to embrace a broader concept of technological progress that also encompasses changes in sourcing practices.

The second approach is constructing a table of *technical* coefficients by adding up the domestic and imported input coefficient matrices. In this case, the measure of productivity is *notional,* since it computes the total labour required under the assumption that all inputs are sourced domestically (Gupta and Steedman, 1971). However, changes in sourcing practices leave productivity unaffected.

The third and final approach is to work within a global input-output framework and consider all the labour requirements (domestic and foreign) of *global* vertically integrated sectors (Garbellini, 2014). Developing this measure requires some minor changes in our notation. Imagine that the world economy consists of two regions. Let $\mathbf{A}^{rs} = \left[a_{ij}^{rs}\right]$ be the matrix of interregional input coefficients, where a_{ij}^{rs} denotes the quantity of commodity i produced in country r used as an input for one unit of commodity j produced in country s. Thus, $\mathbf{A}^{rr}$ is the matrix of intraregional input coefficients. The complete matrix of input coefficients, also called the *global sourcing* matrix is:

$$\mathbf{\Lambda} = \begin{bmatrix} \mathbf{A}^{11} & \cdots & \mathbf{A}^{1p} \\ \vdots & \ddots & \vdots \\ \mathbf{A}^{p1} & \cdots & \mathbf{A}^{pp} \end{bmatrix} \quad (9)$$

Furthermore, let $\mathbf{a}_n^r$ denote the vector of direct labour coefficients of country r. We can stack the vectors of labour coefficients of each region to get the complete vector of labour coefficients:

$$\boldsymbol{\alpha}_n = \begin{bmatrix} \mathbf{a}_n^1 \\ \vdots \\ \mathbf{a}_n^p \end{bmatrix} \quad (10)$$

With these definitions, it is possible to compute the vector of vertically integrated labour coefficients as follows:

$$\mathbf{v}^{\mathrm{T}} = \boldsymbol{\alpha}_n^{\mathrm{T}}(\mathbf{I} - \mathbf{\Lambda})^{-1} \quad (11)$$

[10] A decrease in the share of domestic sourcing of at least one input, such that $\mathbf{D}' \leq \mathbf{D}$, implies that $(\mathbf{I} - \mathbf{D}' \circ \mathbf{A})^{-1} \leq (\mathbf{I} - \mathbf{D} \circ \mathbf{A})^{-1}$. It follows that **v** necessarily falls.

In this approach, it is preferable to talk of global vertically integrated sectors because each sector employs resources from all regions, and the notion of domestic and imported makes sense only if explicit reference to the production location is made. For example, automotive sectors are global because they require inputs from different countries, and, if we focus on the German automotive sector, we can distinguish domestic from foreign resources. Furthermore, it is also possible to distinguish the region in which technical progress occur.

3.1. Empirical analysis

Several scholars have offered an empirical analysis of total labour productivity with the help of input-output analysis. This is both an advantage and a curse. It is advantageous since it provides a straightforward empirical counterpart of the theoretical variables and a curse because it cannot be measured without input-output data, which is not always available.

An important strand of the literature has used the measure to account for technical progress in different contexts. Pioneer applications have focused on specific sectors. For example, Gossling and Dovring (1966) and later Gossling (1972) studied agriculture in the US, and Panethimitakis (1993) studied the Greek manufacturing sector. Moreover, there are several works on country case studies, such as Italy (Rampa, 1981; Rampa and Rampa, 1982; Garbellini and Wirkierman, 2010), the United States (Ochoa, 1986), Australia (Gowdy, 1992) and Spain (De Juan and Febrero, 2000).

Other studies apply this measure in a comparative way. In this sense, Elmslie and Milberg (1992) used total labour productivity to approximate the technological differences between seven OECD countries. Years later, Elmslie and Milberg (1996) tried to measure the cross-country convergence in labour productivity of Portugal and Japan at a vertically integrated level.[11]

Structural decomposition analysis[12] is applied in another group of studies in order to analyse the evolution of occupational structures, defining the “productivity effect” as the variation in the decomposition related to the vector of total labour requirements by industry. This tool has been used to study employment in Japan (Han, 1995), the growth of information workers in the United States (Wolff, 2006), the impacts of international trade on different domestic economies (Portella-Carbó, 2016), the drivers of European youth unemployment (Carrascal-Incera, 2017) and the employment changes in the Spanish economy (Madariaga, 2018).

More recently, Garbellini and Wirkierman (2014), Brondino (2018), and Wirkierman (2022) have revived this approach, not only by providing new estimates of total labour productivity for various economies but also by including the analysis in terms of vertically *hyper-integrated* sectors (following Pasinetti, 1988), making it more suitable for the analysis of growing economies.

Most studies have adopted the measure of domestic total labour productivity, leaving aside the role of imported inputs. Some works include the imports by building the technical coefficients matrix and analysing the *notional* measure of productivity. Gupta and Steedman (1971) applied this approach to the British economy. Later, Ruiz and Wolff (1996) compared the domestic measure with the notional one to study technological change and import leakages in the employment growth of Puerto Rico.

[11] However, the definition of the coefficient technical matrices used in the calculation in both works is very ambiguous. Whether it is based on domestic intermediate inputs or total intermediate inputs is not defined.
[12] Structural decomposition analysis is a widely used input-output technique to break down the growth of a variable into changes of its determinants.

Table 1 – *Summary of the literature addressing the physical productivity analysis within the classical tradition*

Article	Sample	Period	Measure
Productivity measures in a domestic scheme			
Gossling and Dovring (1966)	United States (agriculture)	1919-1954	D
Gupta and Steedman (1971)	United Kingdom	1954-1966	N
Gossling (1972)	United States (agriculture)	1919-1958	D
Rampa (1981)	Italy	1970-1975	D
Rampa and Rampa (1982)	Italy	1959-1975	D
Ochoa (1986)	United States	1947-1972	D
Gowdy (1992)	Australia	1974-1987	D
Elmslie and Milberg (1992)	Germany, Italy, Japan, Norway, Portugal, Canada, US	1959-1975	D
Panethimitakis (1993)	Greece (manufacturing)	1958-1980	D
Han (1995)	Japan	1975-1985	D
Ruiz and Wolff (1996)	Puerto Rico	1967-1987	D, N
Elmslie and Milberg (1996)	Portugal and Japan	1959-1975	D
De Juan and Febrero (2000)	Spain	1970-1988	D
Wolff (2006)	United States	1950-2000	D
Garbellini and Wirkierman (2010)	Italy	1995-2000	D
Garbellini and Wirkierman (2014)	Italy	1999-2007	D*
Portella-Carbó (2016)	Spain, Italy, France, Germany, UK, US, Japan, China	1995-2011	D
Carrascal-Incera (2017)	EU-15	1995-2011	D
Madariaga (2018)	Spain	1995-2005	D
Wirkierman (2022)	US, Germany, UK, France, Italy	1995-2015	D*
Brondino (2018)	China	1995-2009	D*
Lind (2020)	Denmark, Finland, Norway, Sweden	2001-2014	D
Wirkierman (2022)	US, Germany, UK, France, Italy	1995-2015	D*
Productivity measures in a global scheme			
Dietzenbacher et al. (2000)	Germany, Netherlands, France, Denmark, Belgium, Italy	1975-1985	G**
Garbellini (2014)	Italy and Germany	1995-2011	D, G
Grodzicki and Skrzypek (2020)	Germany, UK, Spain, France, Italy (automotive)	2000-2014	G**
Savin and Mundt (2022)	40 countries	1995-2009	D, G
Mundt et al. (2023)	43 countries (manufacturing)	2000-2014	D, G

D (domestic), N (notional), G (global).
Notes: * Unit of analysis is growing subsystems; ** Global productivity is calculated assuming the rest of the world to be an exogenous region.
Source: authors' elaboration.

Finally, dealing explicitly with a many-region input-output framework, other studies computed global total labour productivity. For example, Dietzenbacher et al. (2000) measured productivity at the international level by computing the ratio of value added and labour induced by the final output of a global vertically integrated sector. In the same way, Grodzicki and Skrzypek (2020) developed a measure of vertically integrated unit labour costs, which includes foreign employment in the production chains.[13]

Garbellini (2014) compared the evolution of total labour productivity at domestic and global levels for Italy and Germany between 1995 and 2011. This analysis allowed the author to determine whether productivity advancements resulted from domestic economic improvements or the reorganisation of the sourcing of inputs. Similarly, Savin and Mundt (2022) and Mundt et al. (2023) explored the role of input linkages for most of the OECD countries by using this procedure.

Table 1 summarises the alternative measures found in the empirical literature. Most of the studies are focused on developed economies, mainly because of the difficulty of building input-output databases. Furthermore, the table illustrates a growing type of comparative study that includes more countries and more up-to-date data, thanks to the efforts of projects like the World Input-Output Database (WIOD), Inter-Country Input-Output (ICIO) from OECD, and the Eora Global Supply Chain Database. The widespread use of multi-regional input-output databases has led to the study of productivity in a global scheme.

4. Toward an adjusted measure of total labour productivity

In his book *Structural Change and Economic Growth*, Pasinetti suggests an alternative way of tackling the issue:

> 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, ch. IX, p. 185).

Pasinetti goes no further, leaving room for further development in formal analysis. Previously, Riedel (1976) proposed a similar framework for measuring factor intensities. Within the classical approach, Steedman (1999) extended this idea by developing a two-output model with noncompetitive imports to analyse the small open economy. In this model, the author interpreted the labour-commanded prices corresponding to zero profits as the quantities of vertically integrated labour required to produce commodities. Our purpose is to develop a measure of productivity that departs from the quantity relations of the economy. We will adopt the following simplifying assumptions:

- Prices are given (small open economy)
- Balanced trade
- No international lending (the current account balance equals the trade balance)
- Labour is internationally immobile

[13] We mention this measure in these works because it is very close but not equivalent to global productivity. To be equivalent, the global economic system must be considered a closed economy in which global final demand would coincide with global value added (Wirkierman, 2023). However, these studies treat the *rest of the world* category in WIOT as exogenous, excluding it from value-added calculations, so the world is not a fully closed economy.

Based on the quantity system of an open economy, a vertically integrated sector is now represented as follows:

$$[1, \quad 1, \quad \mathbf{h}_i^m, \quad v_i]$$

where $\mathbf{h}_i^m$ is the *i*-th column of matrix $\mathbf{A}^m\left(\mathbf{I}-\mathbf{A}^d\right)^{-1}$. The challenge lies in translating vector $\mathbf{h}_i^m$ into a domestic labour equivalent. As Pasinetti indicates, imports must be paid for with export revenue. Therefore, attention must be moved to the exporting subsystem.

Let $\mathbf{e}$ be the vector of exogenous exports and $\mathbf{p}$ be the price received per unit sold in international markets; $\epsilon = \mathbf{p}^{\mathrm{T}}\mathbf{e}$ is the total value of exports. The labour content in producing one dollar's worth of exports is:

$$v^* = \mathbf{a}_n^{\mathrm{T}}\left(\mathbf{I}-\mathbf{A}^d\right)^{-1}\mathbf{e}/\epsilon \tag{12}$$

Imports are required to produce an export basket. Letting $\mathbf{p}_m$ be the vector of price paid per unit bought in international markets, the value of imports required to produce one dollar's worth of export is:

$$\mu^* = \mathbf{p}_m^{\mathrm{T}}\mathbf{A}^m\left(\mathbf{I}-\mathbf{A}^d\right)^{-1}\mathbf{e}/\epsilon \tag{13}$$

Note the similarity of this measure with the frequently used "vertical specialisation" index (Hummels et al., 2001), also called "import content of exports".

The exporting sector can use its revenue to pay for these imports. The labour required to produce μ^* dollars of exports is $\left[\mathbf{a}_n^{\mathrm{T}}\left(\mathbf{I}-\mathbf{A}^d\right)^{-1}\mathbf{e}/\epsilon\right]\mu^* = v^*\mu^*$. However, a new round of imports is required to obtain the export revenue to pay for the first import round. Specifically, μ^* dollars of exports require $\left[\mathbf{p}_m^{\mathrm{T}}\mathbf{A}^m\left(\mathbf{I}-\mathbf{A}^d\right)^{-1}\mathbf{e}/\epsilon\right]\mu^* = (\mu^*)^2$ dollars of imports. As before, the labour required to produce the exports to finance this second round of imports is $v^*(\mu^*)^2$.

As can be seen, the logic is circular. The total labour required to produce one dollar's worth of exports, including the labour required to finance all imports, is an infinite sum of the sort:

$$v^* + v^*\mu^* + v^*(\mu^*)^2 + \cdots$$

It can be shown that $0 \leq \mu^* < 1$ (see Appendix), and therefore the series is convergent to:

$$\frac{v^*}{1-\mu^*}.$$

We may now return to the analysis of a typical sector. The value of vertically integrated imports required by sector i is $\sigma_i = \mathbf{p}_m^{\mathrm{T}}\mathbf{h}_i^m$. Thus, σ_i dollars' worth of exports must be committed to pay for these imports. Therefore, the total labour required to produce σ_i dollars' worth of exports is:

$$\frac{v^*}{1-\mu^*}\sigma_i,$$

And the total labour required to produce one unit of net output in sector i will be:

$$v_i + \frac{v^*}{1-\mu^*}\sigma_i. \qquad (14)$$

The reciprocal of this index may be called *adjusted* total labour productivity.

The indicator obtained reveals that, in an open economy, new industrial interdependencies emerge. As observed, the export sector plays a fundamental role. Productivity improvements in this sector spill over to the rest of the sectors. Furthermore, the greater the dependence on foreign capital goods and intermediate inputs, the more labour is required to finance imports, leading to a decline in productivity across all sectors. In contrast, changes in the origin of the sourcing of inputs and capital goods within a non-exporting sector affect its own productivity, not that of others.

A fundamental difference from the case of a closed economy is that constructing adjusted productivity requires relative prices. Using Pasinetti's (1981) terminology, productivity is not expressed in terms of pure labour, meaning considering exclusively the technical conditions of production, but rather in terms of labour equivalents. Regardless of how the terms of trade are determined (in this model, they are the ratio between an index of import prices and an index of export prices), their variation impacts the measure and productivity. An improvement in the terms of trade in favour of the country enhances productivity, while a decline worsens it.

5. A numerical example

It may now be interesting to clarify, with the help of a numerical example, the features of our measure compared to the other indices previously mentioned. We will begin by comparing their results for the case of a small open economy in a global input-output scheme, such as the one formalised in equations (9) and (10) of section 3 above. Then, we will change the trade structure and, later, the technology in use to see how each measure behaves on the face of these two different phenomena.

In our first scenario, we assume that the world economy consists of two regions: the small country (index 1) and the consolidated "rest of the world" (index 2). If the economy produces two commodities, 1 and 2, the global technology can be described by the following equations:

$$\mathbf{\Lambda} = \begin{bmatrix} \mathbf{A}^{11} & \mathbf{A}^{12} \\ \mathbf{A}^{21} & \mathbf{A}^{22} \end{bmatrix} = \begin{bmatrix} a_{11}^{11} & a_{12}^{11} & a_{11}^{12} & a_{12}^{12} \\ a_{21}^{11} & a_{22}^{11} & a_{21}^{12} & a_{22}^{12} \\ a_{11}^{21} & a_{12}^{21} & a_{11}^{22} & a_{11}^{22} \\ a_{21}^{21} & a_{22}^{21} & a_{21}^{22} & a_{22}^{22} \end{bmatrix} \qquad (15)$$

$$\boldsymbol{\alpha}_n^{\mathrm{T}} = [a_{n1}^1 \quad a_{n2}^1 \quad a_{n1}^2 \quad a_{n2}^2] \qquad (16)$$

At this point of the analysis, we also assume that any sector of any region requires more inputs from its own sector than from any other sector, that domestic sectors are always more relevant than foreign ones, and that all sectors have the same total inputs' requirements. Instead, direct labour coefficients, measured in working hours, are different for every sector. More precisely, we shall assume that:

$$\mathbf{\Lambda} = \begin{bmatrix} 0.3 & 0.1 & 0.2 & 0.05 \\ 0.1 & 0.3 & 0.05 & 0.2 \\ 0.2 & 0.05 & 0.3 & 0.1 \\ 0.05 & 0.2 & 0.1 & 0.3 \end{bmatrix} \quad (17)$$

$$\boldsymbol{\alpha}_n^{\mathrm{T}} = [2 \quad 3 \quad 4 \quad 5] \quad (18)$$

Moreover, let us pose that the vectors of exports, of exports' prices, and of imports' prices (expressed in dollars) are, respectively:[14]

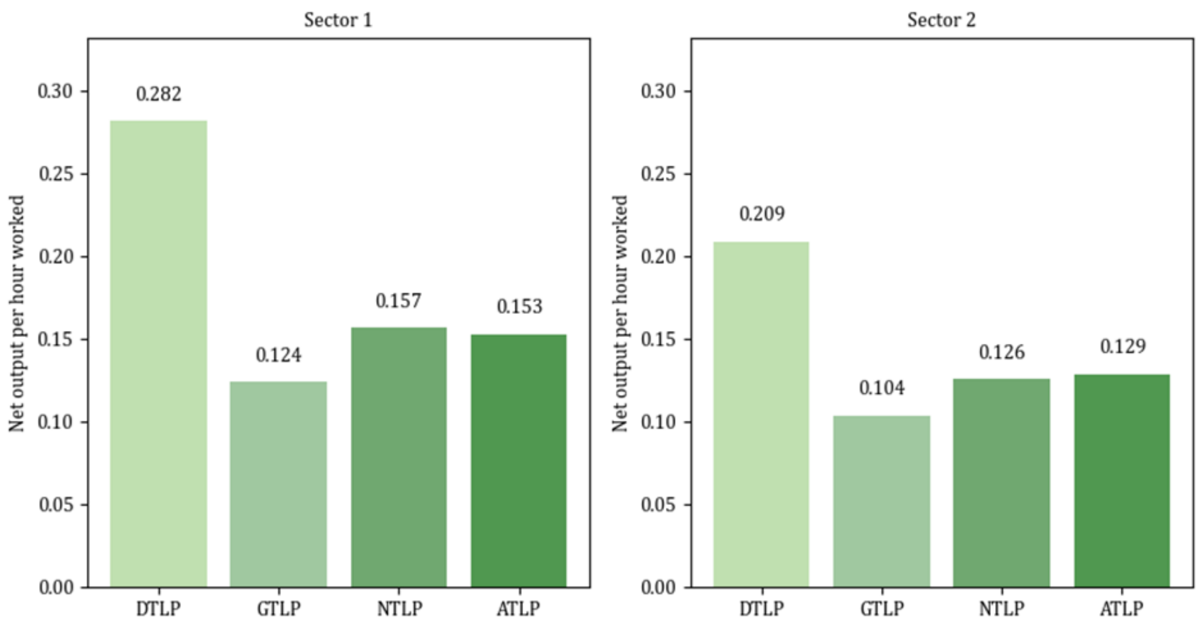
$$\mathbf{e} = \begin{bmatrix} 0.25 \\ 0.25 \end{bmatrix} \quad (19)$$

$$\mathbf{p}^{\mathrm{T}} = [1 \quad 1] \quad (20)$$

$$\mathbf{p}_m^{\mathrm{T}} = \mathbf{p}^{\mathrm{T}} \quad (21)$$

In this case, from the equations provided in the sections above, it is straightforward to compute the different measures of productivity described in this paper: Direct Total Labour Productivity (DTLP), Global Total Labour Productivity (GTLP), Notional Total Labour Productivity (NTLP) and Adjusted Total Labour Productivity (ATLP). For sectors 1 and 2 of region 1, the small open economy, figure 1 shows the results in terms of commodities per unit of labour.

Figure 1 – *Total labour productivity measures*



[14] Exports and imports of final goods are ignored in this example. For this reason, the matrix of imports for region 1 is the $\mathbf{A}^{21}$ of the global sourcing matrix, and its vector of exports is $\mathbf{e} = \mathbf{A}^{12} \cdot \mathbf{u}$ where $\mathbf{u} = \begin{bmatrix} 1 \\ 1 \end{bmatrix}$.

DTLP is the highest because region 1 has lower labour requirements in the production of both commodities and this measure neglects all foreign inputs and the labour associated with them. The opposite case is that of GTLP, for which foreign inputs, and the foreign labour required in their production, enter in the calculation in the same ways as domestic inputs and labour. Therefore, when measuring productivity of the sectors of region 1, this measure will always yield the lowest result as far as both sectors of region 2 use more labour than those in 1.

NTLP and ATLP, on the other hand, are in between the other two measures because, contrary to DTLP, they take into account that production in sector 1 of region 1 requires inputs produced abroad, but, in these indices, the labour required for their acquisition is not that which is performed in the foreign country (as in the case of GTLP). In the case of NTLP, the labour that is relevant to account for the imported inputs is that which would have been needed if those inputs had been produced at home. In the case of ATLP, instead, the labour that is relevant in its computation is that which is required to produce the exports with which to finance the imports from region 2 required by each domestic sector.

The labour required to finance imports will always be the same for any sector of a given economy. However, each of its sectors will import its specific amount of each of the foreign commodities, so both the total amount of imports and the composition of its basket will be peculiar to it. In the current example, sector 1 of region 1 imports commodities for the same value as sector 2; however, in its composition of imports, commodities produced by sector 1 abroad have a higher weight than the weight they have in the composition of imports of sector 2 of region 1. For this reason, while ATLP is lower than NTLP for sector 1, it is higher for sector 2.[15]

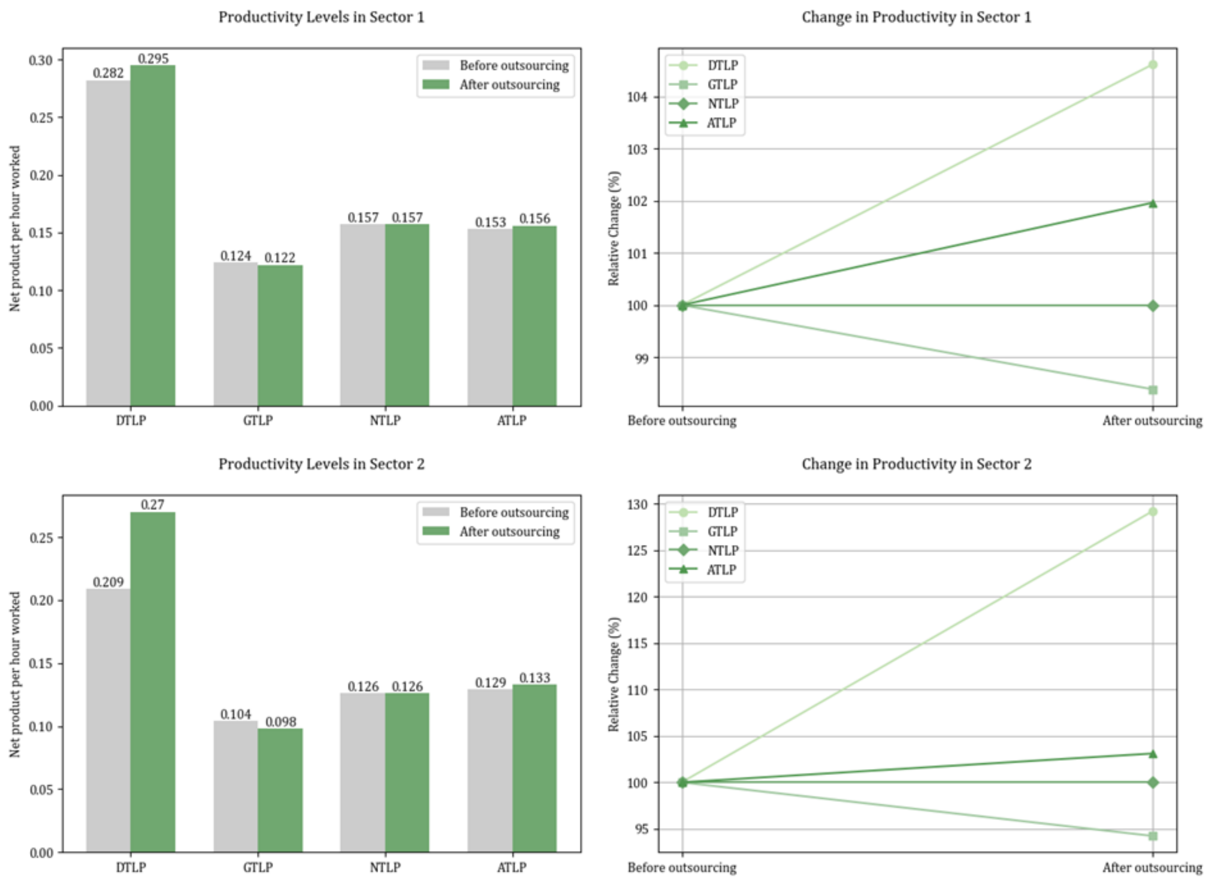
The previous reasoning makes it clear that, in the face of changes in the trade structure, each measure will behave differently. For example, imagine that in the previous economy, formalised in equations (17) to (21), there is outsourcing from sector 2 of region 1 to sector 2 of region 2, in such a way that element α_{22}^{11} goes from a value of 0.3 to a value of 0.1, while element α_{22}^{21} goes from 0.2 to 0.4. The matrix of technical coefficients would become:

$$\mathbf{\Lambda} = \begin{bmatrix} 0.3 & 0.1 & 0.2 & 0.05 \\ 0.1 & 0.1 & 0.05 & 0.2 \\ 0.2 & 0.05 & 0.3 & 0.1 \\ 0.05 & 0.4 & 0.1 & 0.3 \end{bmatrix} \tag{22}$$

And each measure would yield the results presented in figure 2.

[15] Note that ATLP and NTLP will behave exactly in the same manner when i) both sectors of the region under consideration have the same share in its basket of exports, and ii) each commodity exported has the same price and at least one of the two following conditions is satisfied: either both sectors of the "foreign' region have the same share in the vertically integrated imports basket of the sector under consideration, and/or DTLP is equal in both sectors of the region under consideration.

Figure 2 – *Effect of outsourcing in sector 2*



DTLP informs of a reduction in the labour required to produce commodities 1 and 2 because what was previously produced at home is now produced abroad, and this index neglects foreign inputs. GTLP, at its turn, will be negatively or positively affected, depending on whether the DTLP of the outsourcing sector is higher or lower than that of the sector where production begins to take place after outsourcing. In this case, it registers an increase in total labour requirements to produce both commodities because, after outsourcing, the more labour-intensive inputs have a bigger share in the total cost structure.

NTLP is unaffected because the labour that is attributed to foreign inputs is that which would have been needed to produce them at home; therefore, wherever production takes place, if there is no technical change, this index will not change. Finally, our adjusted measure will increase because the labour requirements of the commodities with which the increased imports are financed are lower than the labour requirements of producing the outsourced commodity at home. The reason for this is that the outsourced commodity is the one that requires more domestic labour to be produced at home, while exports are a composite commodity in which both domestic commodities have the same share. Therefore, when region 1 outsources the production of its most labour intensive commodity and starts paying for it with the revenue obtained from exports that are less labour intensive, ATLP is increased.

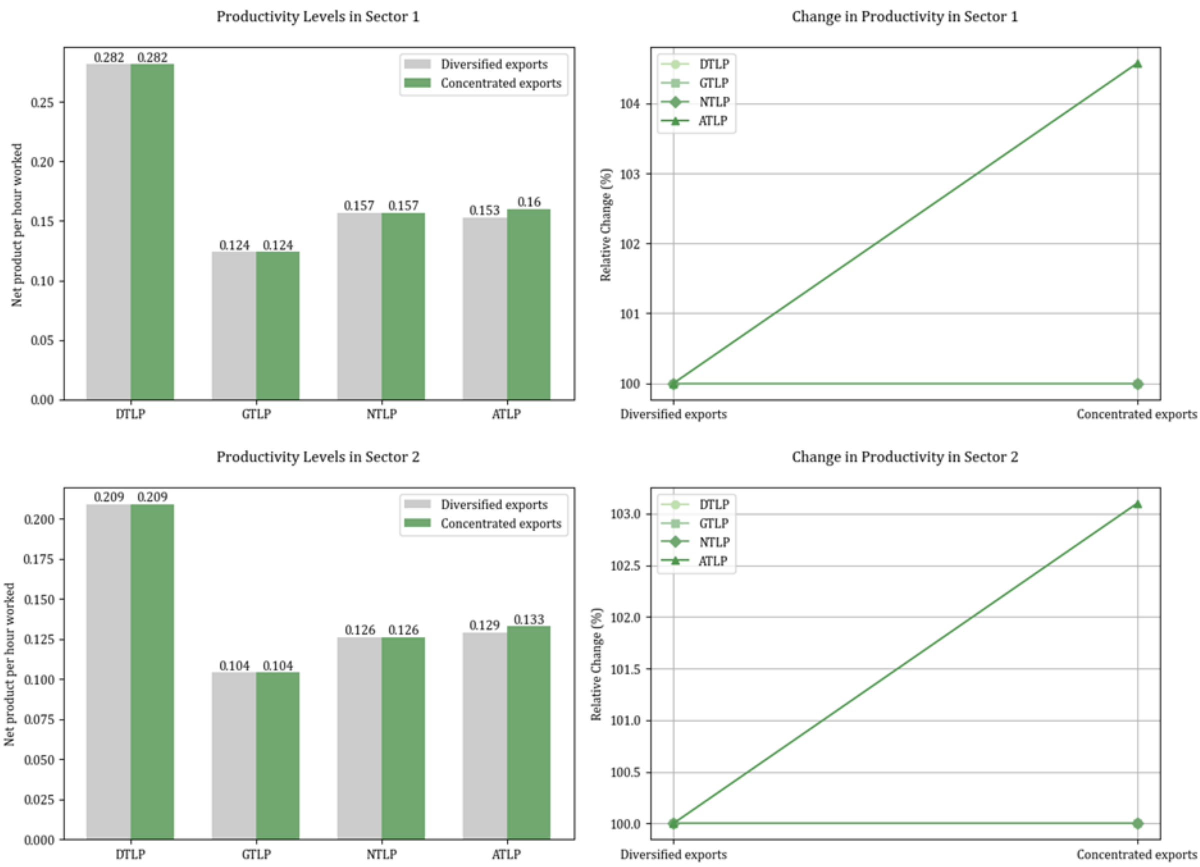
Following the previous reasoning, if the relative weights of each commodity in the exports basket (measured in money terms) change, the same will happen to our ATLP measure, which will be the only index affected by changes in this variable. More precisely, the bigger the weight of the most productive sector on the exports basket (measured in money terms), the bigger the ATLP of this sector and that of the others of the same region.

To see this, imagine an economy, such as that of our first example, that is characterized by the technology described in equations (17) to (21). Now, though, think that the vector of exports changes from equation (19), as it has been so far, to:[16]

$$\mathbf{e} = \begin{bmatrix} 1 \\ 0.25 \end{bmatrix} \tag{23}$$

Each measure of productivity will now yield the results presented in figure 3.

Figure 3 – *Effect of a change in the exports basket share*



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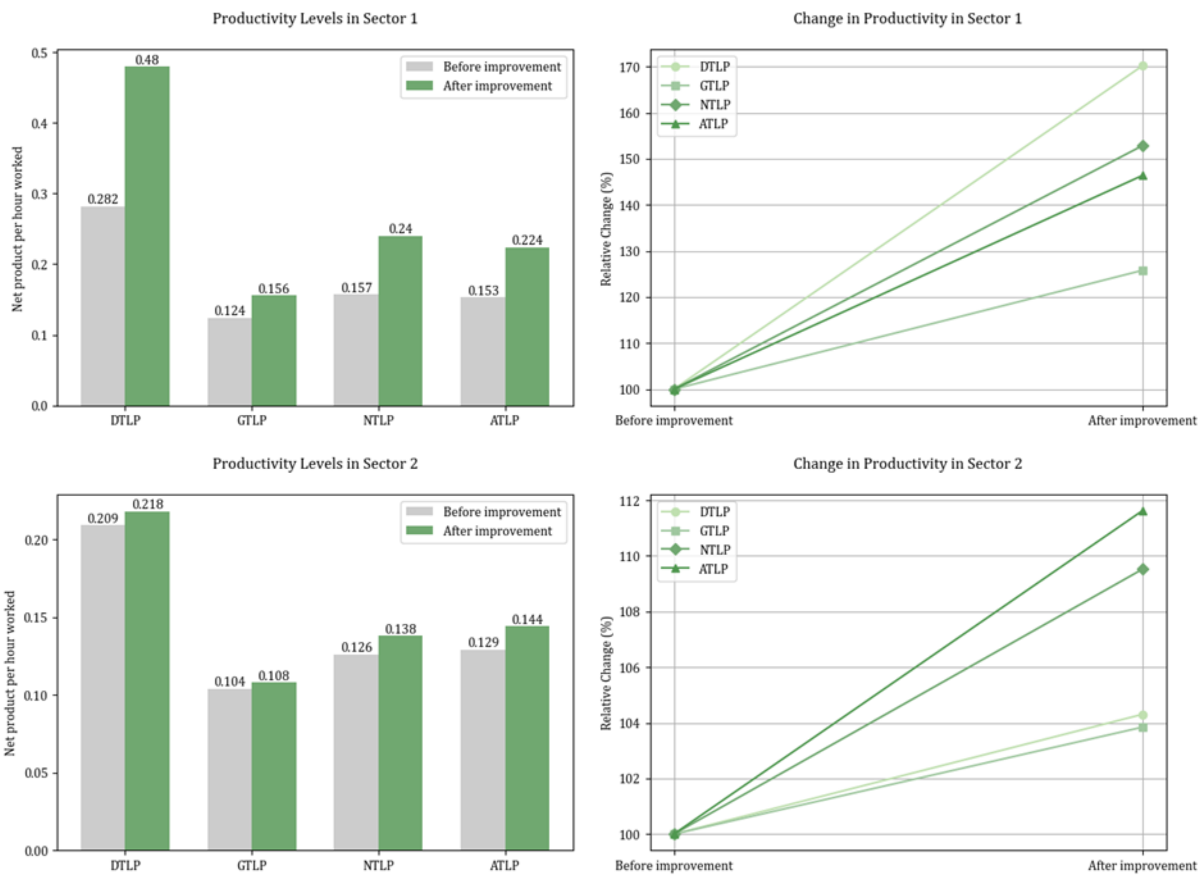
[16] Contrary to the assumptions established at the beginning of this section, the change in exports shown in (19) must be thought of as an increase in the final demand of region 2. That is, it is not the result (or the cause) of any change in the technical coefficients matrix. This is done to isolate the impact of a change in the composition of the basket of exports without changing the technology of region 2.

At this point of analysis, it should be clear that technical progress will have different impacts on each of the indicators described in the paper; and these impacts will also depend on several elements, such as the trade structure or the differentials in productivity between sectors. For example, imagine that we are analysing, once again, the first economy described in this section which was formalised in equations (17)-(21). If, instead of the change in the trade structure analysed before, we pose a technical change entailing a 50% reduction in the direct labour coefficients of sector 1, in such a way that the vector of direct labour coefficients becomes:

$$\boldsymbol{\alpha}_n^{\mathrm{T}} = [1 \quad 3 \quad 4 \quad 5] \tag{24}$$

we can see the changes in the productivity measures shown in figure 4.

Figure 4 – *Effect of a technical improvement in sector 1*



DTLP of sector 1 of region 1 changes the most because this sector's weight in the costs considered by this measure is higher than the weight that this same sector has in any other index. Instead, GTLP changes the least because, as explained above, the labour requirements of one single sector have a low weight in its structure of costs, which includes the labour performed abroad to produce the inputs that are imported in the region under consideration. In the case of sector 1, NTLP and ATLP changes are found between the other two measures because, contrary to DTLP, they take into account that production in sector 1 of region 1 requires inputs produced abroad, but, in these indices, the labour required for their acquisition is not that which is performed in the foreign country (as in the case of GTLP).

In the case of NTLP, the labour that is relevant to account for the imported inputs is that which would have been needed if those inputs had been produced at home. In the case of ATLP, instead, the labour that is relevant for their computation is that which is required to produce the exports with which to finance the imports from region 2 required by each domestic sector. Given that, in this example, the inputs coming from sector 1 of both regions have a higher weight in the cost structure than those inputs coming from sector 1 of region 1 – even when we take into account that they are needed to produce the exports with which to import any good – NTLP increases more than ATLP in the face of a technical improvement in sector 1 of region 1. Had sector 1 had a high enough share in the basket of exports, then ATLP growth would have been higher than that of NTLP.

In the case of sector 2, the situation is different. DTLP still reaches the highest value in absolute terms; however, its growth rate after technical progress is not the most relevant one. This is so because the weight on total costs of the inputs coming from sector 1 – which is the one where technical progress has taken place – is lower in this measure than in those measures – NTLP and ATLP – in which the domestic labour used to account for imported inputs has a bigger weight. Moreover, in the case of sector 2 of region 1, inputs coming from sector 1 of both regions have a lower weight in the total cost structure than the one they had in the case of sector 1 of this same region; this difference is enough to make ATLP higher than NTLP in this other sector, and a higher share of sector 1 in the exports basket would make this difference even greater. Finally, GTLP still yields the lower absolute measure of productivity and the lowest increase: remember that foreign inputs are included in its calculation, weighted according to the labour that must be performed in the country of origin, which is less technically advanced in both sectors under the current assumptions.

All this brings to the fore that, while (domestic) technical progress will impact all our measures, although in particular ways, changes in the trade structure will affect only DTLP, GTLP and ATLP. The first two indices will be affected in quite intuitive and straightforward manners: DTLP will improve (deteriorate) whenever there is outsourcing (insourcing) and GTLP will improve whenever outsourcing (insourcing) is done from a sector with a lower DTLP than the one in which production has been insourced. ATLP, on the other hand, will improve or deteriorate, and will do so at a higher or lower degree, due to changes in the trade structure, depending on the terms of trade. More precisely, outsourcing will have a positive (negative) impact on ATLP whenever the vertically integrated labour required to produce the outsourced commodity is greater (smaller) than the labour required to produce the exports with which to finance the imports of the outsourced commodities; something that is ultimately determined by the magnitudes of the exports and imports baskets in money terms.

6. Concluding remarks

This paper has examined the index of total labour productivity as a key measure of productivity within the classical framework. The measure has several advantages for assessing technical progress, compared to other commonly used indicators, such as total factor productivity or value added per worker. However, as argued, the presence of imported capital and intermediate goods may pose some difficulties in its interpretation. Specifically, the saving of domestic labour may occur due to technological and nontechnological factors.

We have identified several alternative ways of measuring total labour productivity in this setting. Firstly, imported inputs can be treated as nonreproducible factors and domestic productivity can be computed without distinguishing the alternative sources of labour-saving. Secondly, imported inputs can be treated as if they were produced internally and a notional measure of productivity can be computed. Finally, in the case of having information on inter-industry relationships amongst countries, a measure of global productivity can be computed, including domestic and foreign labour. Each measure captures one aspect of the labour-saving process and leaves out others.

In this paper, following a suggestion by Pasinetti, we have put forward a fourth alternative, which consists of taking into account the labour required to produce the commodities given in exchange for the imports. We have discussed the measure for the case of a small country that does not affect international prices and has balanced trade. A novel aspect of this measure is that more industrial interdependencies emerge, relative to the case of a closed economy. Specifically, exporting sectors play a critical role for productivity growth in all sectors. On the downside, productivity is no longer expressed in terms of pure labour but in terms of labour equivalents, which are affected by the terms of trade. Further research should investigate the factors influencing terms of trade and the bidirectional effects. Furthermore, nonbalanced trade and alternative ways of financing imports should be considered in forthcoming contributions.

The measure also has strong potential for empirical analysis. Its use may improve the measuring of commodities' real cost of production in terms of labour units. Furthermore, it may help to assess the drivers of productivity growth in the age of globalisation. To this end, future research should focus on developing the empirical counterparts of the theoretical magnitudes involved in the measure.

Appendix

Consider the following price system.

$$\mathbf{p}^{\mathrm{T}} = w\mathbf{a}_n^{\mathrm{T}} + \mathbf{p}_m^{\mathrm{T}}\mathbf{A}^m + \mathbf{p}^{\mathrm{T}}\mathbf{A}^d$$

For simplicity, the rate of profit is assumed to be nil (the result is unaffected by this assumption).

Rearranging the terms:

$$\mathbf{p}^{\mathrm{T}} = w\mathbf{a}_n^{\mathrm{T}}\left(\mathbf{I} - \mathbf{A}^d\right)^{-1} + \mathbf{p}_m^{\mathrm{T}}\mathbf{A}^m\left(\mathbf{I} - \mathbf{A}^d\right)^{-1}$$

Post-multiply all terms by $\mathbf{e}$:

$$\mathbf{p}^{\mathrm{T}}\mathbf{e} = w\mathbf{a}_n^{\mathrm{T}}\left(\mathbf{I} - \mathbf{A}^d\right)^{-1}\mathbf{e} + \mathbf{p}_m^{\mathrm{T}}\mathbf{A}^m\left(\mathbf{I} - \mathbf{A}^d\right)^{-1}\mathbf{e}$$

The expression can be simplified to get:

$$1 = wv^* + \mu^*$$

From this result, it follows that:

- If wages are greater than zero, $\mu^* < 1$
- If $\mathbf{A}^m = \mathbf{O}$, $\mu^* = 0$
- If wages are equal to zero, $\mu^* = 1$. The series would not converge. Nevertheless, within this framework, wages cannot reach zero. Given international prices, the wage rate varies to ensure that at least one activity is internationally competitive and profitable (see Deardorff, 2005). Note, however, that the latter does not hold if the rate of profit is positive and there is free capital mobility (see Crespo et al., 2021). If the economy does not have any competitive activity, it does not export and thus does not import; trivially, $\mu^* = 0$. See Brondino and Dvoskin (2023) for a discussion.

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