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Journal of Economic Structures (2023) 12:23
https://doi.org/10.1186/s40008-023-00317-8

Journal of Economic Structures

RESEARCH **Open Access**

The economic fitness of nations in value added. 2000–2014

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Abstract

In this paper, we explore the Economic Fitness (EF) indicator from the World Bank Database that measures the nations level of international competitiveness. At the same time, using input–output tables, we present our estimations of this new metric, replacing the revealed comparative advantages (RCA) from exports in gross value with an estimate of RCA from exports in domestic value-added (DVA). We find that between 1995 and 2015, there is a positive relationship between Economic Fitness and per capita GDP for low and middle-income countries. Besides, we also show that the estimations of the EF using the domestic value-added content of exports changed significantly from 2000 to 2014 since there has been a widening gap between global exports in gross value and exports in value-added. The latter suggests that, given the increasing levels of productive links at the international level, the competitiveness of nations is also conditioned by how they participate in global production networks.

Keywords: Economic fitness, Economic development, Trade, Exports in value-added

1 Introduction

One of the most widely accepted ideas in economic theory is that the division of labor and productive specialization leads to higher levels of efficiency and welfare. Conventional approaches to international trade reproduce this argument and extrapolate the benefits of specialization and commerce at the country level, predicting more elevated economic growth rates and higher levels of development. However, in Hidalgo and Haussman (2009) and Tacchella et al. (2012), we find some theoretical arguments contradicting this idea. Concepts such as *economic complexity*, *product complexity*, and, more recently, *Economic Fitness* have emerged. Particularly, Hidalgo and Haussman (2009) emphasized that labor division and specialization at the individual level do not imply product specialization at the country level. Instead, a more significant division of labor could lead to greater diversification of goods and services.

The empirical evidence around the complexity of developed economic structures suggests that economic development is more related to the diversification of production (and exports) and the capacity to produce "unique" or "complex" goods than to the specialization patterns predicted by trade theories based on the analysis of comparative advantages. According to this evidence, developed countries tend to export goods not produced by other countries within a much more diversified basket of goods. Therefore: "Development is a process that transforms the economic structure of a country towards the production and export of more complex products" Felipe et al. (2012. P, 36). We can understand economic development more as the set of capabilities that allows producing more in quantity and variety. Thus, the causal relationship goes from something other than international commerce to specialization and growth and development, but from development to diversification and trade under more competitive conditions. Alternatively, that development is not a consequence of specialization derived from trade.

The objective of this paper is twofold. First, we present the evolution of international competitiveness measured through the Economic Fitness Indicator (EF) published in the World Bank database (2021). Secondly, we present our estimations using revealed comparative advantages based only on the domestic value-added content of exports. As Koopman et al. (2014) point out, the gross value of exports can overestimate a country's export capacity if the exported goods have a high content of imported inputs. Therefore, we show that the Economic Fitness of nations also depends on how domestic economic structures are related to the rest of the world in the context of a new international division of labor and changing global value chains.

The rest of the paper is organized as follows: Sect. 1.1 has a brief literature review on Economic Fitness and the relationship between trade and economic development. In the second section, we describe the method developed by Tacchella et al. (2012) and our approach to estimating the RCA in value-added. In the third section, we present the estimation results and conclude in the fourth section.

1.1 Trade and development: from specialization to diversification

The positive correlation between productivity and exports is one of the most robust results of international trade (Bombardini et al. 2012). At the industry level, this correlation shows that the Ricardian model provides solid reasons to explain the advantages of international trade since differences in relative productivity determine trade patterns: producers tend to increase their export volume as they reach higher relative productivity levels in specific industries. [1]Similarly, at the firm level, it is suggested that exporters succeed because some firms have sufficient productivity to overcome the cost of exporting (Bernard et al. 2003; Melitz 2003; Melitz and Ottaviano 2008).

The standard model assumes a single factor of production (labor) with constant returns to scale. Still, different forms of production between countries and between goods predict that countries will export the goods with a comparative advantage in their production. Equilibrium can occur in two ways: when both countries specialize entirely and benefit from trade or when only one country produces both goods and neither gains nor loses through trade (Ricardo 1817). Therefore, for firms, industries, and nations, one is more competitive because it exploits the comparative advantage in producing the good with a relatively lower cost and obtains a more significant market share.

[1] The empirical support is extensive and includes contributions such as McDougall, 1951 & 1952; Stern 1962; Harrigan 1997; Eaton and Kortum 2002; Kerr 2009; and Costinot et al. 2012.

However, empirical evidence shows that most prosperous countries, in terms of economic performance, tend to have more diversified production and export baskets (Hidalgo and Haussman 2009; Tacchella et al. 2012). Similarly, the evidence presented by Imbs and Wacziarg (2003), Klinger and Ledderman (2006), and Bustos et al. (2012) shows that the level of diversification observed in the productive structure of nations is directly related to their levels of economic development. Less developed countries' diversification is much lower, and production would be limited to unsophisticated goods in more competitive markets.

Comparative historical analyses (Akamatsu 1962; Kuznets 1966; and Lall 2000) of different economic systems show that developing countries embark on a sustained growth path when profound changes in their production structure occur. However, such transformations are neither explained nor considered in neoclassical theories of economic growth. Instead, it has been development economists (Rosenstein-Rodan 1943; Prebisch 1950; and Hirschman 1958), evolutionists (Nelson 1982 and Alcouffe and Kuhn 2004), and post-Keynesians (Pasinetti 1981 and Thirlwall 2002) who have incorporated these transformations and their implications for economic growth into their analyses. A nation's productive diversity is associated with its local capabilities, so economic development is a process in which firms and institutions create and adapt skills, know-how, and infrastructure. Growth is possible because tacit productive knowledge is expanded through learning dynamics (Castañeda and Romero 2018). Such production capabilities can be human (know-how), physical (infrastructure), and institutional (governance) and are a form of knowledge that is difficult to transfer through the acquisition of patents, imitation, foreign investment, or imports. In other words, firms cannot trade this set of capabilities internationally.

Bahar et al. (2012) and Tacchella et al. (2012), among others, have further developed these ideas through new concepts and methodologies, which provide strong empirical support. The methodological alternatives focus on the intensive use of data and network theory. Moreover, with complex system analysis, it is proposed that competitiveness is a property that emerges from a system with interacting productive units. Hidalgo and Hausmann (2009) argue that if the division of labor increases productivity, a network of interdependent market relations is built to reach higher efficiency and production levels. Their analogy of the *building blocks* follows that the greater the diversity of building blocks, the more interdependent the relations in the market; therefore, more trade is needed.

Moreover, the smaller the blocks, the greater the variety of items that can be produced. Thus, there is an apparent paradox between specialization and diversification. The more refined the division of labor, the greater the specialization that allows the production of a greater variety of goods; specialization is necessary for diversification. However, the paradox is not such if we associate specialization with individuals' specific skills, capabilities, and knowledge and not with the specialization of production *a la* Ricardo. For example, developing information, computer, and communication technologies requires specific and sophisticated mathematics, physics, and engineering knowledge.

The complexity of the system, continuing with the example, implies that it is impossible to design computer hardware and software without mathematics. Designing and building the machines necessary for computing is only possible with electrical and electronic physics and engineering. Furthermore, in the design and production processes, the supply chain is not linear but a network of multiple interactions with processes that directly and indirectly provide feedback. So, developing new technologies and knowledge requires a complex web of "trade" between mathematicians, physicists, engineers, and blue-collar workers, to mention a few.

For economic systems, the division of labor implies a certain level of specialization in the tasks, skills, and knowledge that each person (firm or institution) has and that make up the *building blocks* that allow the design and production of a greater variety of goods and services. Therefore, *Economic Fitness* arises from using complex systems to define competitiveness (Tacchella et al. 2012).

Methodologically, as shown in the next section, the proposal is based on a non-linear and iterative approach (with feedback within the economic system) that can efficiently capture the intrinsic relationship between the export baskets of different nations and their industrial competitiveness. This indicator of international competitiveness results from manipulating a binary matrix that represents each nation's export basket by iteratively combining measures in its rows and columns. Therefore, a nation is competitive depending on the quantity and quality of products it can ship. Moreover, the complexity of products depends on the countries' Fitness that produce them. However, while it is possible to measure *the competitiveness of an economy* by the sum of the quality and complexity of its products, it is not possible to adopt the same approach to measure the *quality and complexity of products*. In particular, the complexity of a product cannot be the average "fitness" of the countries that produce it.

Consequently, the only way for a product to be complex is to be produced by a highly competitive country. The *Economic Fitness* method then consists of non-linear coupled maps. The fixed point defines a new fitness metric for a nation and the complexity of its products. It represents an alternative approach to fundamentally analyzing nations' production systems, introducing a non-monetary classification of product complexity.

The Economic Fitness concept proposed by Tacchella et al. (2012) has yet to be systematically and deeply analyzed as the literature is still limited. For example, Morrison et al. (2017) conclude that more work is needed to find and identify reliable and stable measures of *Fitness* and complexity. Specifically, they provide theoretical and empirical evidence on the intrinsic instability of the non-linear definition of the algorithm behind the concept of *Fitness*. However, Servedio et al. (2018) present an adjusted and stable metric of *Fitness* and complexity through a non-linear and non-homogeneous map applied to the available information on country exports. According to the authors, the non-homogeneous estimates guarantee convergence and stability.

Moreover, Zaccaria et al. (2018) extend the concept to include trade in services (initially, the idea applies to trade in complex goods) and achieve a universal trade matrix that allows for a complete analysis of global competitiveness. Using two algorithms to the universal goods and services trade matrix contrasted country-level competitiveness and changes in complexity and diversification after including services in the matrix. The results show that the competitiveness of many countries was over or underestimated and that services tend to cluster together with complex manufacturing, suggesting a similar capability structure. They conclude that "complex services" complement the diversification strategy of developing countries. Vinci and Benzi (2018) also study the causal relationship between EF and gross domestic product per capita. The authors show sufficient evidence for a causal relationship between a nation's *Economic Fitness* and GDP per capita, mainly in high-income countries.

Finally, Roster et al. (2018) introduced an application of the concept of *Economic Fitness*: *Country Opportunity Spotlight* (COS), which assesses a nation's current capabilities and demonstrates which industries have the potential to diversify given those capabilities, adding to the explanatory and predictive power of the *Economic Fitness* concept. Applying the methods to Mexico and Brazil, they concluded that *Economic Fitness is a* unique contribution to the literature on economic development and trade as it provides a quantitative perspective on who is good at doing what and how they got there. According to the authors, the methodology allows us to understand a nation's development path and make predictions about future directions. The following section describes the method developed by Tacchella et al. (2012). Then, we add to their proposal the consideration of measuring exports in value-added, not gross value. Since there has been significant growth in the fragmentation of production internationally, in the exports of many developing and developed economies, the imported input content can be high. Therefore, we must avoid overestimating the participation of some economies in the global market.

2 Methods

Following the original proposal of Tacchella et al. (2012), in this section, we rewrite the equations in matrix notation to illustrate in another way how to estimate the *Economic Fitness* of nations. From the interaction between the level of diversification of a country's exports with the quality of existing products at a given time, in Eq. (1), M is a binary matrix of relevant exports by country and product and elements $m_{c,p}$ equal to 1 if country c has a revealed comparative advantage (RCA) in product p, and equal to zero otherwise, given by the values in Eqs. (2). The dimension of this matrix is CP, where C is the number of countries and P is the number of products. Therefore, in Eq. (1), the dimensions of the vectors for the fitness, $\mathbf{f}^{(n)}$, the quality of products, $\mathbf{q}^{(n)}$ are the number of countries and the number of products, respectively.

With this formulation, for Tacchella et al. (2012), the fitness, $\mathbf{f}^{(n)}$, of a country depends on the quality of its exported products, $\mathbf{q}^{(n)}$. Vice versa, any product's quality is a function of the countries that produce it; at the same time, getting any fitness or quality estimation without considering all the information in the system is impossible. So, Eq. 1 represents a two-step iterative method. From left to right, two vectors at each step are estimated simultaneously:

$$\begin{cases} \widetilde{\mathbf{f}}^{(n)} = M\mathbf{q}^{(n-1)} \\ \widetilde{\mathbf{q}}_r^{(n)} = \mathbf{f}_r^{(n-1)}M \end{cases} \rightarrow \begin{cases} \mathbf{f}^{(n)} = a\widetilde{\mathbf{f}}^{(n)} \\ \mathbf{q}^{(n)} = b\widetilde{\mathbf{q}}^{(n)} \end{cases} \tag{1}$$

First, we multiply the M matrix by the $\mathbf{q}^{(n-1)}$ column vector to get the fitness of each country. To get the reciprocals of the quality for each product, $\widetilde{\mathbf{q}}_r^{(n)}$, we multiply the row vector of the reciprocals of the fitness, $\mathbf{f}_r^{(n-1)}$, of each country by the same matrix M. So, in $\widetilde{\mathbf{q}}_r^{(n)}$ and $\mathbf{f}_r^{(n-1)}$, the variable r means that the entries in these vectors are the multiplicative inverse of the elements in the quality,$\widetilde{\mathbf{q}}^{(n)}$, and the fitness,$\mathbf{f}^{(n)}$, vectors.

Since the method is iterative, n is the iteration variable. For, $n = 1$, and setting $\mathbf{f}^{(0)}$ and $\mathbf{q}^{(0)}$ as vectors of ones, $\widetilde{\mathbf{f}}^{(1)}$ and $\widetilde{\mathbf{q}}_r^{(1)}$ are the sums by row and by column of the M matrix, respectively. This means that in the first computation, countries with a revealed comparative advantage in more products will be the more competitive in the global economy. But, the opposite holds for the quality of the products; in the first computation, the products that reflect an RCA for more countries will be the less complex products.

For the second step, in Eq. (1), we normalize the vectors $\widetilde{\mathbf{f}}^{(n)}$ and $\widetilde{\mathbf{q}}^{(n)}$ at each iteration so that the sum of the elements in vector $\mathbf{f}^{(n)}$ equals the total number of countries and the sum in $\mathbf{q}^{(n)}$ equals the total number of products. Hence, using scalar multiplication, in $a\widetilde{\mathbf{f}}^{(n)}$, a is the multiplicative inverse of the average of $\widetilde{f}_c^{(n)}$. Similarly, the new values in the $\mathbf{q}^{(n)}$ vector are estimated by multiplying the original values by b, which also is the needed scalar for normalization (the multiplicative inverse of the average of $\widetilde{q}_p^{(n)}$[2]).

In sum, in Eq. (1), $\widetilde{\mathbf{f}}^{(n)}$ and $\widetilde{\mathbf{q}}^{(n)}$ are intermediate variables and $\mathbf{f}^{(n)}$ and$\mathbf{q}^{(n)}$[3] will be the final vectors for the Economic Fitness of Nations and the complexity of the products once the algorithm converges [4]To use this algorithm, the following variables are needed:

$$C : number\ of\ countries (scalar)$$

$$P : number\ of\ products (scalar)$$

$$\mathrm{M} : exports\ matrix\ (binary)\ of\ dimension\ CP$$

$$\widetilde{\mathbf{f}}^{(n)} : fitness\ column\ vector\ of\ dimension C$$

$$\mathbf{f}_r^{(n-1)} : row\ vector\ with\ elements f_{r,c}^{(n-1)} = \frac{1}{f_c^{(n-1)}}$$

$$\mathbf{f}^{(n)} : normalized\ fitness\ column\ vector$$

$$\widetilde{\mathbf{q}}_r^{(n)} : row\ vector\ of\ dimesion P$$

$$\widetilde{\mathbf{q}}^{(n)} : quality\ row\ vector, with\ elements\ \widetilde{q}_p^{(n)} = \frac{1}{\widetilde{q}_{r,p}^{(n)}}$$

$$\mathbf{q}^{(n-1)} : column\ vector$$

[2] We want to thank two anonymous referees for their insights and dedication to ensuring the method description was accurate and readable. Nonetheless, any misinterpretation of the original formulation made by Tacchella et al. (2012) is our sole responsibility.

[3] For computational purposes, at each iteration, it is also needed to transpose the resulting vectors so we can multiply the new vectors by matrix M.

[4] To avoid any non-convergence problems, a second version of this algorithm was presented by Servedio et al. (2018). Here, given the limitations of the available data, we decided to use the first version of the EF algorithm to show the benefits of this kind of methods and another way in which they can be improved by explicitly considering the increasing rise of intermediate inputs trade.

$$\mathbf{q}^{(n)} : \textit{normalized quality vector}$$

$$a = \frac{1}{\textit{The average of} f_c^{(n)}}$$

$$b = \frac{1}{\textit{The average of} \widetilde{q}_p^{(n)}}$$

If the algorithm converges to a fixed point, the elements in each vector will indirectly reveal how competitive each economy is and how complex the products are. Higher values of $f_c^{(n)}$ reflect more developed domestic economic structures with a higher capacity to produce a more diversified basket of goods and services that includes more sophisticated or complex products.

To get the elements of the M matrix, the revealed comparative advantage is estimated as follows:

$$RCA_{c,p} = \frac{\frac{x_{c,p}}{X_p}}{\frac{X_c}{X_w}} \tag{2}$$

where $x_{c,p}$ is the total exports of p, by country c; X_p is the total exports of product p; X_c represents the total exports of country c, and X_w is the global volume of exports. If $RCA_{c,p} > 1$, country c has a comparative advantage in product p.

As Koopman et al. (2014), we consider that is necessary to estimate the revealed comparative advantages from the exports in domestic value-added. With the input–output tables from the World Input–Output Database (WIOD, 2021) [5]we estimated the revealed comparative advantages for 43 countries, the rest of the world, and 56 industrial sectors. Assuming that these can be measured more accurately if we only account for the domestic value-added in the exported goods. Moreover, at the industrial and product level, indirect exports of intermediate inputs could reveal other advantages not measured when we use exports in gross value. Therefore, Eq. (2) is modified as follows:

$$RCAV_{c,p} = \frac{\frac{vx_{c,p}}{VX_p}}{\frac{VX_c}{VX_w}} \tag{3}$$

where $vx_{c,p}$ is the domestic value-added content in the exports of product p from country c. The value of imported inputs incorporated in the exports of p, plus net taxes and international transport margins, are deducted. Thus, VX_p, is the total world exports of p, just in value-added. On the other hand, VX_c is the total exports of country c in domestic value-added; and VX_w is the total exports in value-added at the aggregate level; in this case, only we subtract net taxes and international transport margins. Since this information is not available at the product level, in the exercise presented here, we replace p with the industrial sector, i, in which value-added is generated by the direct and indirect

[5] For a detailed description of the tables, see Timmer et al. (2015).

exports of its products. The main advantage of estimating at the industry level is that, as shown below, it is possible to incorporate into the analysis of the competitiveness of nations the capacity to create domestic supply networks that provide intermediate inputs to the directly exporting sectors. Thus, the value-added of the direct and indirect exports of the industrial sector i is estimated as follows:

$$vx_{c,i} = vxi_{c,i} + vxg_{c,i} \quad (4)$$

where $vxi_{c,i}$ is the value-added generated by the direct and indirect export of intermediate inputs of the industry i, country c to satisfy the global demand for final goods; and $vxg_{c,i}$ is the value-added generated by the direct export of final goods. Each value of $vxi_{c,i}$ is obtained from the sum of all the elements that represent a direct or indirect export of intermediate inputs from the matrix of value-added generated by the country's industry:

$$\mathrm{VA}_t = \widehat{\mathrm{V}}_t(\mathrm{I} - \mathrm{B}_t)^{-1}\widehat{\mathrm{G}}_t \quad (5)$$

where B_t is a square matrix of technical coefficients (representing the volume of inputs required from industry i country c to produce one unit of product in industry j country q. $(\mathrm{I} - \mathrm{B}_t)^{-1}$ is the matrix of total requirements, the well-known Leontief Inverse, which quantifies the total of inputs directly or indirectly demanded and supplied at the inter-and intra-industry level. $\widehat{\mathrm{V}}_t$ is a diagonal matrix of value-added coefficients; all nc dimension, where n represents the number of industries (56 for the exercise presented in this paper); and c is the number of countries (43 individual countries plus the rest of the world). t represents the year for a given volume final demand, which, with the available information, varies from 2000 to 2014. The elements $b_{i,j,t}^{c,q}$ at B_t and $v_{j,t}^{q}$ at $\widehat{\mathrm{V}}_t$ are the proportion of intermediate inputs supplied by sector i to sector j from country c to country q, and the share of direct inputs, measured as compensations to labor and capital over the final value of the goods produced in sector j, in country q, respectively. Thus, if $i = j$, we get the volume of intra-industry trade. When $c = q$, we have domestic transactions; otherwise, we account for inter-industry and international transactions of intermediate inputs. $\widehat{\mathrm{G}}_t$ is the diagonal matrix for the global final demand vector. Therefore, in VA_t, we have a total value-added matrix that, by rows, decomposes the value-added generated in a sector and country according to the final destination of its products. By columns, we broke down the value-added that a particular industrial sector in a country generates according to the industry and country where the input factors (capital and labor) are located. Therefore, each element $va_{i,j,t}^{c,q}$ in the VA_t matrix quantifies the income (directly or indirectly) generated in sector i country c given the volume of final demand in sector j, country q. For each $va_{i,j,t}^{c,q}$ where $c \neq q$, we account for the total value-added content in the direct and indirect exports of intermediate inputs from country c to country q.

To get the domestic value-added content in the exports of final goods, $vxg_{c,i}$ we estimate the corresponding value-added matrix:

$$\mathrm{VAX}_t = \widehat{\mathrm{V}}_t(\mathrm{I} - \mathrm{B}_t)^{-1}\widehat{\mathrm{X}}_t \quad (6)$$

where $\widehat{\mathrm{X}}_t$ is the diagonal matrix of exported final goods by industry and country of origin. In VAX_t, for each element $vax_{i,j,t}^{c,q}$ where $c = q$ we account for the domestic value-added content. Given that global input–output matrices only contain information at

Table 1 GDP per capita, 1981–2020 (US 2010 dollars)

	GDP per capita				Ratio of high income to		
	High income	Upper middle income	Lower middle income	Low income	Upper middle income	Lower middle income	Low income
1981	23,298	2656	970	603	8.8	24.0	38.7
1991	29,452	3058	1091	550	9.6	27.0	53.6
2001	35,932	3845	1251	561	9.3	28.7	64.1
2011	39,878	6666	1860	743	6.0	21.4	53.6
2020	42,131	8774	2284	824	4.8	18.4	51.1

Source: World Bank (2021)

the industry level for 43 countries and the rest of the world, we set that a country has a revealed comparative advantage in domestic value-added if the value of $RCAV_{c,p}$ is greater than 1.5.

The following section presents an estimate of the Economic Fitness published by the World Bank (2021) from 1995 to 2015 and our calculation using the criterion of revealed comparative advantage based on the volume of exports by the industrial sector in domestic value-added.

3 Results and discussion

One of the world economy's main challenges is the inequality in average income levels between countries. Even though between 2001 and 2020, the ratio of per capita income between high-income and low-income countries declined from 64.1 to 51.1 dollars, that income gap remains very high. Moreover, as shown In Table 1, the gap was much lower (38.7) in 1981 than in 2020. In this period, rich countries' average income increased from $23,298 to $42,131 per person, while the average income in the poorest countries increased from $603 to $824 per person.

On the other hand, during these forty years, the gap ratio between High-Income countries and Upper Middle-Income countries decreased from 8.8 to 4.8 dollars, considering that the average income rose from $2656 per person to $8774 in the Upper Middle-Income countries.

As argued previously, one of the reasons for these variations in income levels inequality between countries will be the differences among the set of productive capacities in the domestic economic systems, i.e., some production structures will be able to produce and offer a greater diversity of goods and services worldwide, because they are more flexibles and capable to innovate.

The EF estimates published by the World Bank (2021)[6] for the period 1995 to 2015 show that China, Japan, Germany, Italy, and the United States are the countries with the highest levels of EF, given the diversity and sophistication of their export basket, as of 2015. During this period, there was a pattern of swapping positions between

[6] In the World Bank database, we can find three different estimations of Economic Fitness named *Economic Fitness (Legacy)*, *Economic Fitness Metric*, and Universal Economic Fitness. We choose to present the first estimation because it goes from 1995 to 2015, and it is clearer to observe changing patterns and positions.

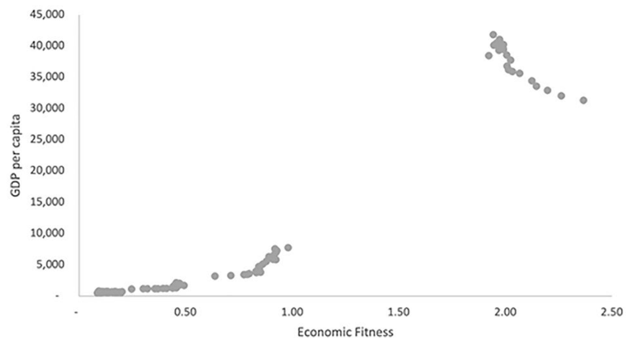

Fig. 1 GDP per capita and economic fitness by income group, 1995-2015 Source: World Bank (2021)

China and Germany. However, the United States is the country that loses the most competitiveness.[7]

In general, the behavior of international competitiveness indicators follows a similar pattern to that observed in per capita income levels; on average, developing countries exhibit lower levels of Economic Fitness than High-Income countries. Nevertheless, in Fig. 1, between 1995 and 2015, the relationship between the average Economic Fitness by income group and GDP per capita shows a very particular pattern. Higher EF levels correlate with higher GDP per capita for middle- and low-income countries. In contrast, for high-income countries, the data shows that more competitive economies do not have higher income levels. As argued, one possible explanation for this inverse correlation for the developed economies could be a misestimation of the EF due to differences in the intensity of the import content of their exports. However, the pattern shown in Fig. 1 could also be explained by an adequate econometric analysis before concluding that such correlations are an empirical regularity or the consequence of a biased estimation of EF.

Thus, we could confirm that the production system's accumulated capabilities and flexibility explain the slow per capita income convergence between the poorest and wealthiest economies. On the other hand, based on the world input–output tables from the WIOD (2021), Fig. 2 shows the trade's well-known double accounting problem. From 2000 to 2014, there was an increasing gap between the gross exports and its domestic value-added, with peaks of a 30% difference.

The difference between gross and domestic value-added exports at the country level could be higher than 30%. In Table 2, we present the domestic value-added content (DVA) via direct exports of goods and services for 2000 and 2014 (the latest data available) sorted by the share of DVA. Most individual countries in the input–output tables are developed and emerging economies. Therefore, it is worth highlighting an evident heterogeneity in the DVA share, ranging from 32.22 percent of domestic value-added content in Luxembourg's exports in 2000 to 86.74% in Russian exports.

[7] In the case of the other two estimations, China remains the most competitive country in 2017 and 2016, but the US holds second place, while Germany and Japan present minor changes in their respective levels of Economic Fitness (World Bank 2021).

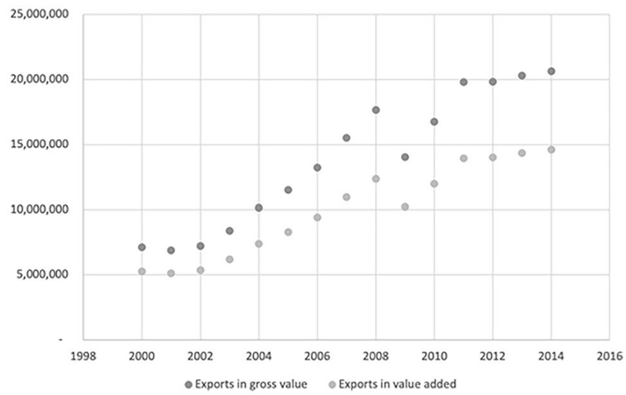

Fig. 2 World exports in gross value and value-added. Source: Authors' estimations based on WIOD (2021)

Table 2 Domestic value-added content in total exports, 2000 and 2014

	Country	2000	2014		Country	2000	2014
1	Russian Federation	86.74	86.34	23	Spain	67.92	64.97
2	Australia	81.87	83.38	24	Poland	68.88	64.93
3	United States	84.73	83.31	25	Greece	77.52	64.68
4	Indonesia	80.03	81.02	26	Mexico	63.40	64.47
5	China, People's Republic of	81.45	80.14	27	Portugal	65.47	62.04
6	Norway	82.20	78.17	28	Finland	70.33	60.82
7	Brazil	78.59	77.55	29	Austria	68.25	60.79
8	United Kingdom of Great Britain and Northern Ireland	75.36	76.51	30	Netherlands	66.70	59.99
9	Japan	88.66	73.91	31	Lithuania	74.43	59.85
10	Canada	69.16	73.91	32	Republic of Korea	65.62	59.82
11	India	81.12	72.69	33	Denmark	65.57	59.21
12	Switzerland	73.56	71.74	34	Slovenia	62.84	58.28
13	Rest of the World	70.83	70.10	35	Bulgaria	64.24	57.22
14	Italy	74.00	69.76	36	Taiwan	58.70	54.23
15	Cyprus	65.45	68.85	37	Estonia	62.12	52.39
16	Romania	69.98	68.29	38	Belgium	54.99	50.11
17	Germany	73.36	68.14	39	Czech Republic	63.91	49.38
18	Sweden	68.50	67.78	40	Ireland	54.98	48.53
19	Croatia	69.51	67.50	41	Slovakia	56.38	46.99
20	France	70.84	67.48	42	Hungary	47.12	43.49
21	Turkey	79.64	66.16	43	Malta	40.42	33.30
22	Latvia	72.93	65.61	44	Luxembourg	41.85	32.22

Source: Authors' estimations based on WIOD (2021)

In 2014, just the United States and China were in the top five countries with DVA shares higher than 80%. On the other hand, Germany, the second most competitive country in the World Bank's Economic Fitness estimation, only had 68 percent of DVA.

At the industry level, in Fig. 3, we present the shares of exports (including services) in both gross and value-added. At this level, indirect exports seem more critical for the service sectors. For example, the share of total exports of high-tech manufactures accounts for 35%, while in value-added, this sector gets only 20% of the whole share in 2000 (in

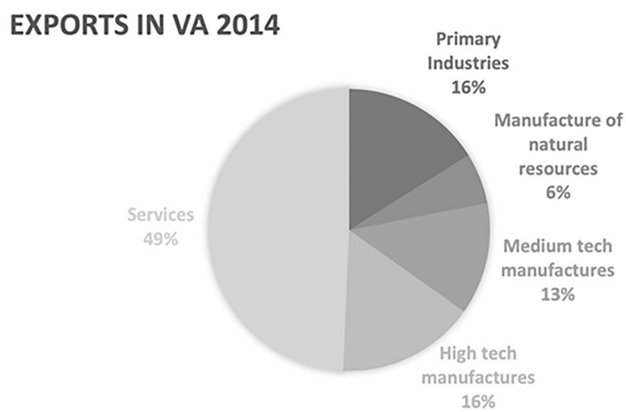

Fig. 3 Shares of gross and value-added exports by industry groups, 2000 and 2014. Source: Authors' estimations based on WIOD (2021)

2014, those figures were 30 and 16%). On the other hand, services accounted for 26% of total exports and 48% of VA in 2000, while in 2014, the share of value-added was almost half. At a very aggregated level, this value-added distribution pattern results from more fragmented production processes at the international level that gave rise to "trade-in tasks" and the value-added distribution as is shown in the "smile curve".[8]

We found a significant difference in competitiveness levels by estimating the EF indicator using the revealed comparative advantages (RCA) from the domestic value-added in exports. As we argued in the method section, estimating any indicator of international competitiveness using the gross value instead of the domestic value-added exports could over or under-estimate the country's comparative advantage in shared production processes. The cases of the Mexican and Chinese economies are well-known as examples of how their shares of exports in "high-tech" products might not reflect the production capabilities each country had at the beginning of the 21st Century or still has.

Figure 4, Table 3 show how competitiveness positions change when considering global market shares in domestic value-added, i.e., after eliminating the double-accounting problem. Estimations of the EF using exports in DVA, as shown in Eqs. (3) to (6), better reflect the development level of the domestic economy as a supply network. The revealed comparative advantages in domestic value-added consider how "well endowed" an economy is in natural and human resources; at the same time, it is considered the network's structure.

With information for just 55 industries, including all services that directly or indirectly export, only the United States remains in the most competitive group, as is shown in Fig. 5. At the industry level, with this estimate, China, Japan, Germany, and Italy would have a high combination of diversification of their exports with the sophistication and complexity of their products. Secondly, when estimating RCA in value-added, the picture changes significantly: by 2014, only the United Kingdom remained the most competitive, with a lower EF value. The United States is not the

[8] In Baldwin and Ito (2022), we can find a more recent analysis of the Smile Curve and the sources of Value-Added in global production networks.

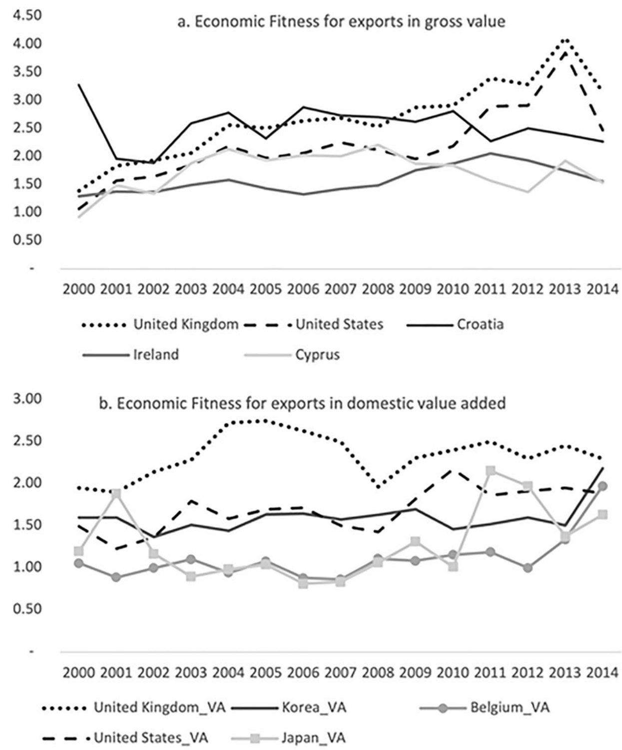

Fig. 4 Economic fitness from gross value and domestic value-added exports, 2000–2014. Source: Authors' estimations based on WIOD (2021)

second most competitive, but the fourth, and Korea, Belgium, and Japan are more competitive in value-added than Croatia, Ireland, and Cyprus.

As mentioned before, an essential limitation of estimating EF from exports in domestic value-added lies in a significant reduction in the number of countries included in the input–output tables. Therefore, countries such as Germany, Norway, and China exhibit lower competitiveness indicators, and we cannot observe the behavior of developing economies. In the table, 27 out of 43 countries included are developed economies; no single African country is listed, and only two Latin-American economies. However, in Table 3, we can see that some less developed economies are more competitive from the domestic value-added content of their exports (Mexico and Brazil). On the other hand, China is less competitive in terms of DVA. Surprisingly, the United Kingdom, Canada, and the United States are some developed countries that are less competitive when considering their exports' direct and indirect domestic value-added content; the opposite occurs in the cases of Korea, Japan, Belgium, and Germany.

These results are consistent with the estimates made by Marcato et al. (2019). They found that comparative advantages significantly change when they use the share of exports in domestic value-added. Furthermore, they considered that presenting a higher revealed comparative advantage in domestic value-added depends on the countries' position in the respective industrial sector value chain.

Table 3 Economic fitness from gross value and domestic value-added exports, 2000–2014

	EF for exports in gross value		EF for exports in domestic value added	
1	United Kingdom of Great Britain and Northern Ireland	3.15	United Kingdom of Great Britain and Northern Ireland	2.30
2	United States	2.47	Korea	2.18
3	Croatia	2.27	Belgium	1.97
4	Ireland	1.56	United States	1.88
5	Cyprus	1.54	Japan	1.63
6	Portugal	1.48	Malta	1.59
7	Switzerland	1.44	Ireland	1.59
8	Rest of the World	1.42	France	1.46
9	Malta	1.39	Croatia	1.44
10	France	1.28	Finland	1.16
11	Belgium	1.28	Italy	1.12
12	Luxembourg	1.23	Switzerland	1.10
13	Canada	1.22	Romania	1.09
14	Netherlands	1.22	Bulgaria	1.06
15	Slovenia	1.11	ESP	1.04
16	Sweden	1.07	Austria	1.01
17	Latvia	1.04	Germany	1.00
18	Austria	1.00	Slovenia	0.99
19	Estonia	0.99	Sweden	0.99
20	Romania	0.97	Chequia	0.98
21	Chequia	0.91	Hungary	0.96
22	Denmark	0.91	Luxembourg	0.95
23	Korea	0.90	Estonia	0.94
24	Bulgaria	0.87	Denmark	0.90
25	Japan	0.83	Portugla	0.90
26	Italy	0.82	Slovakia	0.85
27	Finland	0.81	Rest of the World	0.84
28	Poland	0.80	Netherlands	0.84
29	Tukey	0.77	India	0.82
30	Lithuania	0.76	Australia	0.76
31	India	0.72	Turkey	0.74
32	Spain	0.64	Poland	0.74
33	China	0.59	Lithuania	0.71
34	Indonesia	0.56	Indonesia	0.70
35	Brazil	0.52	Cyprus	0.61
36	Australia	0.49	Canada	0.59
37	Hungary	0.48	Mexico	0.59
38	Slovakia	0.46	Latvia	0.57
39	Mexico	0.42	China	0.56
40	Greece	0.34	Brazil	0.53
41	Norway	0.34	Russia	0.49
42	Russia	0.33	Greece	0.41
43	Germany	0.32	Norway	0.24
44	Taiwan	0.32	Taiwan	0.17

Source: Authors' estimations based on WIOD (2021)

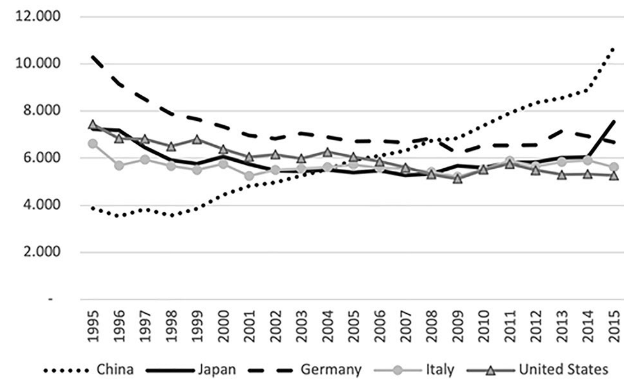

Fig. 5 World's most competitive countries Source: World Bank (2021)

4 Conclusions

The relationship between trade and development has been widely studied since economics became a science. Conventionally, most economists have considered that the causal relationship goes from the division of labor and the formation of markets and trade to economic growth and development. However, it is possible to have a non-linear relationship. The division of labor requires certain conditions of human development that allow for the specialization (of individuals) necessary for forming efficient and flexible market structures. Then, efficient markets lead to higher international competitiveness and gains of trade that positively feed the domestic economic system.

In this paper, we analyze one metric for the economic development of countries that should reflect their international competitiveness using a binary matrix of exports based on the estimation of the revealed comparative advantages: Economic Fitness. We have shown a positive relationship between the Economic Fitness indicator and GDP per capita for the low- and middle-income countries. Besides, the behavior of the EF is associated with per capita income gaps. Also, when estimating the EF indicator using exports in domestic value-added, it is found that results vary significantly for the estimation of comparative advantages revealed from gross exports.

Therefore, the methodological approach that considers the complexity of economic systems represents an addition to studying the advantages of trade and its relationship with development levels. Moreover, such complexity involves considering that there are many products produced internationally. Therefore, domestic value-added content might reveal more efficiently the competitiveness of nations.

Acknowledgements

The Article Processing Charge was covered by the funds of PAPAIOS and JSPS (KAKENHI Grant Number JP 21HP2002). And to all the Economics Department personnel for supplying materials and technical support.

Author contributions

RC is responsible for the study's design, methods section, computations, and conclusions. JV is responsible for the literature review, theoretical framework, and the first English version of the paper.

Funding

The authors did not receive funding from any source in the study's design, the collection, analysis, and interpretation of data, or in writing the manuscript.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
All authors read and approved the final manuscript.

Competing interests
The authors declare that they have no competing interests.

Received: 27 September 2021 Revised: 10 November 2023 Accepted: 21 November 2023
Published online: 05 December 2023

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