# INTERNATIONAL STRUCTURAL COMPETITIVENESS AND THE HIERARCHY IN THE WORLD ECONOMY

Theoretical and Empirical Research Evidence

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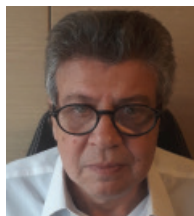
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Abstract: The aim of this paper is to determine the level of competitiveness of national economies and their resulting hierarchy in the world economy. Based on the assumption that there is a structural relationship between the competitiveness of a national economy and the level of its economic development, we identify the main structural factors of international competitiveness. These factors are the degree of diversification of the productive structure of a national economy and the strength of its domestic sectoral productive linkages—which are both related to the level of industrial and technological development and the technological structure of exports. The Technologically Advanced Domestic Value Added in Exports, which condenses the above structural factors, is proposed as a measure of the level of competitiveness of national economies. This measure is implemented in order to determine the hierarchical position of 43 economies in terms of their international competitiveness. In addition, another measure of international competitiveness, the Economic Complexity Index, is examined and tested. When comparing the examined economies' hierarchical positions obtained by using the two measures, a high correlation and a strong positive linear relationship between them is revealed.

Keywords: international structural competitiveness; economic diversification; productive linkages; technological level; global value chains

Introduction

In this paper the main structural factors that determine the level of international competitiveness of national economies are investigated. On the basis of the assumption that there is a structural relationship between the competitiveness of a national economy and the level of its economic development, we identify as the main structural factors of international competitiveness of a national economy the degree of diversification of its productive structure and the strength of its domestic sectoral productive linkages. Both of these factors are related to the level of industrial and technological development and the technological structure of exports. The Technologically Advanced Domestic Value Added in Exports (TADVA) is proposed in the paper as a measure of international structural competitiveness. TADVA is based on the global value chains methodological framework and input–output analysis and condenses the above structural factors. TADVA is applied to 43 economies in order to provide evidence of their hierarchical position in terms of international competitiveness and is compared with a well-known index of international competitiveness, the Economic Complexity Index (ECI).

The paper is organized as follows. An analytical description of the concept of international structural competitiveness is given in the following section. The quantitative methods used to measure the international structural competitiveness are presented in the third section. The empirical results obtained from the empirical application will follow in the fourth section. In the final section, the conclusions of the research are discussed.

International Structural Competitiveness: Theoretical Framework

The competitiveness of a national economy "refers to the ability of a country to realize central economic policy goals, especially growth in income and employment, without running into balance-of-payments difficulties" (Fagerberg 1988, 355). According to the OECD (1992, 242), international competitiveness arises from a country's level of development and is defined as "the degree to which a nation can, under free trade and fair market conditions, produce goods and services which meet the test of international markets, while simultaneously maintaining and expanding the real income of its people over the long-term." The above underline the structural connection of international competitiveness with economic development. Based on this connection, it could be supposed that the competitiveness of a national economy depends on the same structural factors on which its economic development also depends. The assumption that international

competitiveness arises from a country's economic development level provides the theoretical basis for an appropriate structural competitiveness measure.

Economic Development and International Competitiveness

We accept that the international competitiveness of a national economy arises from its level of economic development. This implies that a methodological approach to the concept of international competitiveness should start from the position that it is not predominantly dependent on "price" (or "cost") factors, expressed by unit labor costs ("price" or "cost" competitiveness). Instead, international competitiveness is based on "structural" factors, such as technological opportunities, technical infrastructure, and production capacities, which constitute the productive structure and the related "externalities" of a national economy and mirror its development level ("structural" competitiveness) (Amable and Verspagen 1995, 197; Ilzkovitz et al. 2009, 2; Nurbel 2007, 65). "Kaldor's paradox" confirms the validity of the distinction between "price" or "cost" and "structural" competitiveness. According to "Kaldor's paradox," there is

> a lack of empirical relationship between the growth in unit labor costs and output growth [. . .] Kaldor found, for the postwar period, that those countries that had experienced the greatest decline in their price competitiveness (i.e., the highest increase in unit labor costs) also had the greatest increase in their market share. (Felipe and Kumar 2011, 3–4)

The more developed countries mostly produce and export commodities of a higher technological level and higher income elasticity of demand compared to those produced by the less developed countries (Economakis, Androulakis, and Markaki 2015; Economakis, Markaki, and Anastasiadis 2015; Economakis et al. 2018; Krugman 1989; Prebisch 1959; Thirlwall 1999). Thus, there is a dissimilarity in the structure of production-trade between the more and the less developed countries, which is reflected in the different "relative" income elasticities of demand (that is, income elasticities of demand for an economy's exports against those for its imports): higher for the more developed and lower of the less developed countries (Krugman 1989; Thirlwall 1991; Trigg 2020). Consequently, as income increases, the demand for products from the more developed countries becomes higher than that for products from the less developed countries (the so-called "Engel's Law"). This results, *ceteris paribus*, in faster-growing prices for the products produced by the more developed countries, that is, the terms of trade change against the less developed countries. Thus, economic growth for the less developed countries is accompanied by increasing import payments, in other words, trade deficits, creating pressure for

increasing capital inflows (i.e., external debt) in order to finance a growing current account deficit (Economakis, Androulakis, and Markaki 2015; Economakis, Markaki, and Anastasiadis 2015; Economakis et al. 2018; Love 1980; Ocampo 1986; Prebisch 1959; Singer 1950).

In the following analysis, we will investigate the structural factors behind the dissimilarity in the structure of production-trade between more and less developed countries—which is reflected in the different "relative" income elasticities of demand between the former and the latter—and the resulting different levels of international competitiveness of national economies in the world economy.

Structural Factors of International Structural Competitiveness

The question under investigation concerns the determination of the link between the international structural competitiveness and the aspects of a country's economic performance. A large and growing body of literature has investigated the specific structural factors of competitiveness at the country level, highlighting that it is connected with (i) the sectoral diversification of the production system and (ii) the level of the interconnectedness of the production system—that is, the strength of domestic sectoral productive linkages.

(i)   According to the theoretical model of Krugman (1989), the high-income elasticity of demand of technologically advanced products that characterizes the exports of the developed countries reflects the greater diversification of the domestic production, toward the production of the countries with low exports' income elasticity of demand. As mentioned in Rodrik (2007, 9), "productive diversification is a key correlate of economic development." Less developed countries are usually associated with the production and export of a narrow range of products and the concentration of their activities in low productivity services, while developed countries produce and export a diversified mix of manufacturing products and modern services, as they are engaged in a broad range of economic activities. Imbs and Wacziarg (2003) examine the patterns of sectoral diversification in a wide range of countries and diversification changes within these countries. They conclude that diversification is a stylized fact of the development process. Furthermore, they show that the development process is not only expressed as a reallocation of resources from primary to industrial sectors, but also as a process of diversification and expansion of the range of activities within manufacturing. Finally, according to the findings of Hausmann and Klinger (2007), manufacturing sectors provide an economy with the capability to increase product diversification to a greater degree compared to the primary and services sectors. It must be noted that although the size

of a national economy matters in the degree of diversification, this is not always the case (see below).

(ii) Greater diversification of a national economy's productive structure means a more complete, articulated, and interdependent economic structure. Peres (2006, 68) supports that the diversification of the productive structure of a national economy is related to greater domestic sectoral productive linkages; the latter strengthens "the positive impact of economic growth on overall productivity." In a similar direction, Rios-Morales and O'Donovan (2006, 55–56, 64) maintain that domestic sectoral productive linkages are related to spillover effects "in terms of technology transfer and absorption." Furthermore, due to their inter-industry transactions, the development of manufacturing sectors would generate productive linkages, spillover effects, capital accumulation, and technological externalities (Cimoli, Primi, and Pugno 2006, 88; Hirschman 1958, 109–110; Pilat et al. 2006, 26). On the contrary, if a national economy is highly dependent on primary economic activities and services, this expresses a lower level of interconnection (Fotopoulos 1985, 178). Specifically, services are more independent from other sectors, in comparison to the manufacturing sector (Pilat and Wölfl 2005, 3, 36). As a consequence, it is supported that the more developed an economy is, the more complete and articulated is its economic structure (Leontief 1986, 169–170). On the contrary, the most typical characteristic of economic underdevelopment is the relative absence of interdependencies and strong linkages (Hirschman 1958, 109).

According to the European Commission (2009, 75), "competitiveness [. . .] is not the result of merely aggregating individual industries' performances but is the result of a complex network of relationships between them." A complex network of sectoral transactions mobilizes the production of many sectors in order to meet the intermediate demand needed for the production of the exporting sectors. As a result, more value-added is generated in national economies with a more complex network of sectoral transactions than those with a less complex one. Accordingly, the more diversified the production structure of a national economy, the greater are the domestic sectoral productive linkages, and consequently the higher its international competitiveness (see Cimoli, Primi, and Pugno 2006, 92).

Therefore, the international structural competitiveness of a national economy depends on

- the degree of diversification of the productive structure of a national economy, and
- the strength of its domestic sectoral productive linkages,

These are both related to the level of industrial and technological development and the technological structure of exports.

These structural factors also codify the main aspects of the dissimilarity in the structure of production-trade between the more and the less developed countries: compared with an internationally more developed and more competitive national economy, a less developed and less competitive one is characterized by a relatively low level of industrial and technological development, strong specialization, and relatively weak productive linkages. As a result, less developed and less competitive national economies exhibit unfavorable structural factors. These factors are expressed by relatively low-income elasticities of demand for the products they produce and export, and consequently by negative terms of trade and trade deficits.

A more developed and more competitive national economy that exhibits a high degree of diversification of its productive structure and strong domestic sectoral productive linkages, is characterized by a high degree of industrial development and the effective use and diffusion of technology among sectors, as Cohen and Zysman (1988, 24) point out. Lall (2000, 337–338) argues that the structure of exports has important implications for growth and development, while, in addition, stressing that industrialization remains an engine of development. He also highlights the importance of the technological structure of manufactured exports as an indicator of "quality." A large share of technologically advanced manufacturing products in exports is a sign of an efficient development path, while the opposite would hold if a country mainly exports less advanced products. This view is supported by Petralia, Balland, and Morrison (2017, 967), who point out the importance of technology in the determination of the level of development, and find that the more developed countries tend to specialize in the production of more diverse and more valuable products by the use of more complex and less concentrated technologies, in comparison to less developed countries.

Consequently, it could be assumed that in a more developed and more competitive national economy that exhibits a high degree of diversification of its productive structure and strong domestic sectoral productive linkages, as well as a high degree of industrial development, the advanced technology sectors obtain a specific weight in the production process, and especially in the production of export products. This results in a higher share of value-added generated in the advanced technology sectors to the value-added generated in all the sectors of the domestic economy, during the process of exports' production.

The determination of a reliable and valid single measure for the assessment of structural competitiveness at the country level and the resulting hierarchy in the world economy is the question that follows. In our approach, a measure capable of specifically meeting the structural factors of international structural competitiveness is the *Technologically Advanced Domestic Value Added in Exports* (TADVA).

The TADVA is a measure based on the methodological framework of *global value chains* and input–output analysis, and it is inferred from the theoretical framework of our analysis. It condenses the structural factors of international competitiveness, and expresses the value-added generated in the advanced technology sectors of the domestic economy in the process of exports' production. The following section provides a short description of this approach.

Measures of International Structural Competitiveness

This section is concerned with the methodology employed for the estimation of TADVA, regarding both the mathematical formulation of the measure and how it captures the notion of international structural competitiveness.

In recent years, there has been increasing research interest in the structural analysis of economic systems. Developments in this specific subject were reinforced after the introduction of the *global value chains* (GVCs) methodological framework (Humphrey and Schmitz 2002). A widely used definition for a global value chain is that it "describes the full range of activities undertaken to bring a product or service from its conception to its end use and how these activities are distributed over geographic space and across international borders" (Amador and Di Mauro 2015, 14; adopted from the GVC Initiative at Duke University). Although "much of the recent chains literature, and particularly the GVC variant, has become increasingly oriented analytically toward the meso level of sectoral dynamics and/or the micro level of firm upgrading" (Bair 2005, 154) and "[a]t the most general level, the relations that structure GVC are [. . .] those of cross-branch competition" (Starosta 2010, 548) the GVC methodological framework could also provide a detailed mapping of the global economic network. The micro-approach to measuring GVCs uses firm-level data to document how multinational firms organize their production network (Johnson 2018), while the macro approach captures how GVCs are affecting competitiveness and macroeconomic developments (Amador and Cabral 2016). Moreover, the macro approach to GVCs is based on sectoral (meso level) data regarding production and trade. In this way, it allows the determination of a country's involvement in different productive activities, its economic ability to realize new value through international trade and thus, reveals its competitiveness position. Consequently, the position of a country in GVCs is linked to its international competitiveness and its technological features (Taglioni and Winkler 2016).

Based on the GVC approach, selected indicators are widely used in the literature to determine the level of competitiveness of an economy (Cheng et al. 2015).

In this study, first, the Domestic Value Added in Exports (DVA), which expresses the domestic value-added created to satisfy the demand per unit of exports, will be

estimated as an indicator connected with the structural factors of diversification and interconnectedness. According to the GVC terminology, the "domestic value-added in exports" or the "domestic content of exports" (DVA) is a measure suitable for expressing the level of participation in the GVCs (Johnson and Noguera 2012) and—as used in the present study—in the world trade in general. Second, the Technologically Advanced Domestic Value Added in Exports (that is, the TADVA), which expresses the participation of technologically advanced sectors in DVA, is proposed in this paper as an indicator of a country's structural competitiveness, assuming that it condenses the structural factors of international structural competitiveness.

The quantitative impact of GVCs in international trade and macroeconomic measures presupposes the construction of an intercountry (or global) input–output table (ICIO) that combines national input–output tables with bilateral trade data. A global input–output table captures all the intermediate transactions across sectors and countries, allowing to trace the value-added embodied in final goods and services back to its source (Johnson 2014). Thus, the domestic value-added in exports can be estimated and also disaggregated in different technological level categories. The basis for evaluating all GVCs macroeconomic measures lies in the sectoral linkages resulting from the input–output analysis.

Input–output analysis was introduced by Leontief (1986) in order to analyze the sectoral interdependencies of an economic system and to define the productive linkages developed within its sectors. Input–output analysis is a theory of production based on the Leontief (or fixed proportions) production function. The assumptions made are i) each industry produces a single homogeneous product, ii) production follows the law of constant returns to scale; thus, the intermediate inputs of each industry are proportional to the level of its output, iii) the technological coefficients are fixed (or the substitution among inputs in the production of any good or service is not possible), and iv) there are no external economies and diseconomies included in the production. Kurz and Salvadori (2000) raise the question as to whether the input–output analysis is consistent with the classical approach to the theory of value and distribution. They conclude that the assumptions of input–output analysis are fully compatible with the assumptions of the classical approach and that input–output analysis is an offspring of classical (radical) economics. Furthermore, Davar (2016) shows that although Marx did not formulate a model with more than two sectors, his description of the relationship between industries is equivalent to Leontief's approach.

The national input–output table is found at the core of the input–output analysis. This table provides the ability to distinguish the direction of a sector's production toward i) the final demand and ii) the intermediate demand, and also the ability to determine the source of a sector's intermediate inputs, that is, if it is domestically produced or imported from abroad. Furthermore, based on linkages

analysis, the impact of an economy's exporting activities on domestic production (and the domestic value-added) can be estimated, capturing both the direct and the indirect effects (see below).

The following presentation is founded on the extension of the standard Leontief model using an ICIO table. The methodology is built on the "world perspective" for the decomposition of exports suggested by Miroudot and Ye (2020).

In a world divided into $m \in N$ countries, each of which is split into $n \in N$ sectors of economic activity, the world production is described by the following equation:

$$x = (I_{mn} - A)^{-1} y \tag{1}$$

where $x \in R^{mn \times 1}$ is the vector of output by country and sector, $y \in R^{mn \times 1}$ is the vector of final demand by country and sector, $A \in R^{mn \times mn}$ is the global matrix of technological coefficients for each country, $I_{mn} \in R^{mn \times mn}$ is the identity matrix.

The matrix A is split into matrices $A^* \in R^{mn \times mn}$ and $A^I \in R^{mn \times mn}$, following the Equation (2):

$$A = A^* + A^I \tag{2}$$

Where A^* is the block diagonal matrix with the diagonal matrices $A_i^* \in \mathbb{R}^{n \times n} (i = 1, \ldots, m)$ lying on its diagonal and A_i^* is the matrix of the technological coefficient for the country i derived from its national (domestic) input–output table. A^I is derived if the diagonal blocks A_i^* of matrix A equal to the zero matrix. The off-diagonal blocks equal the matrices of intermediate export coefficients from country i to country j, $A_{ij}^j \in \mathbb{R}^{n \times n}$.

Or,

$$
\begin{bmatrix}
A_1^* & A_{12}^j & \cdots & A_{1M}^j \\
A_{21}^j & A_2^* & \cdots & A_{2M}^j \\
\vdots & \vdots & \ddots & \vdots \\
A_{M1}^j & A_{M2}^j & \cdots & A_M^*
\end{bmatrix}
=
\begin{bmatrix}
A_1^* & 0 & \cdots & 0 \\
0 & A_2^* & \cdots & 0 \\
\vdots & \vdots & \ddots & \vdots \\
0 & 0 & \cdots & A_M^*
\end{bmatrix}
+
\begin{bmatrix}
0 & A_{12}^j & \cdots & A_{1M}^j \\
A_{21}^j & 0 & \cdots & A_{2M}^j \\
\vdots & \vdots & \ddots & \vdots \\
A_{M1}^j & A_{M2}^j & \cdots & 0
\end{bmatrix}
$$

Then, Domestic Value-Added in Exports per unit of exports (**DVA**) is estimated as follows:

$$DVA = t \, (v^T \, (I_{mn} - A^*)^{-1} \, \hat{e})^T \tag{3}$$

Where $DVA \in R^{mx1}$ is the vector of the domestic value-added in exports by country, $v \in R^{mx1}$ is the vector of value-added per unit of output by country and sector, $e \in R^{mx1}$ is the vector denoting the sectoral structure of exports of each country, $t \in R^{mxmn}$ is a diagonal block matrix with the unit vector $u \in R^{1xn}$ (that is, $u = \begin{bmatrix} 1 & 1 & \ldots & 1 \end{bmatrix}$) lying on its

diagonal. The symbols ^{T} and $\wedge$ denote the transpose and the diagonal matrix, respectively.

It should be noted that:

$$(I_{MH} - A^*)^{-1} = \left(\begin{bmatrix} J_M & 0 & \cdots & 0 \\ 0 & J_M & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & J_M \end{bmatrix}_{J^A} - \begin{bmatrix} A_1^* & 0 & \cdots & 0 \\ 0 & A_2^* & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & A_M^* \end{bmatrix}_{A} \right)^{-1}$$

$$= \begin{bmatrix} J_M - A_1^* & 0 & \cdots & 0 \\ 0 & J_M - A_2^* & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & J_M - A_M^* \end{bmatrix}^{-1} \tag{4}$$

$$\Rightarrow (I_{MH} - A^*)^{-1} = \begin{bmatrix} \left(J_M - A_1^*\right)^{-1} & 0 & \cdots & 0 \\ 0 & \left(J_M - A_2^*\right)^{-1} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & \left(J_M - A_M^*\right)^{-1} \end{bmatrix}$$

Thus, the matrix $(I - A^*)^{-1}$ is also a block diagonal matrix with the diagonal matrices $\left(I - A_i^*\right)^{-1} \in \mathbb{R}^{MxH} (i = 1,\ldots,m)$ lying on its diagonal, where $\left(I - A_i^*\right)^{-1}$ is the Leontief inverse matrix for country i. As shown in Equation (3) and Equation (4), the estimation of **DVA** requires only the availability of national input–output tables (the A^* diagonal blocks of A). An ICIO table enables the use of only one equation (Equation [3]) for the estimation of **DVA** at the country level (as also highlighted in Los, Timmer, and de Vries [2016]). Furthermore, the use of an ICIO table ensures that the national input–output tables originate from the same source; thus, their compilation follows the same methodology and the same sectoral classification. On the contrary, input–output tables from different national statistical agencies often follow different compilation methodologies and different sectoral classifications. Moreover, ICIO tables provide data on the bilateral trade flows that are connected with the input–output tables denominated in the same currency (Timmer et al. 2015).

The specific formation of the ICIO matrix can be used for the estimation of the domestic double-counting value-added in exports ($DDC \in \mathrm{R}^{mx1}$), which represents

the domestic value-added of intermediate inputs that were first exported as intermediate inputs for re-importation embodied in foreign intermediate inputs used to produce one unit of exports. Analytically:

$$\boldsymbol{DVA} + \boldsymbol{DDC} = \boldsymbol{t}\ (\boldsymbol{v}^T\ (\boldsymbol{I}_{mn}-\boldsymbol{A})^{-1}\ \hat{e})^T \tag{5}$$

Contrary to the suggestion of OECD (2019), which defines the right-hand side of Equation (4) as domestic value-added in exports, in this research $\boldsymbol{DDC}$ is, clearly, not considered as a part of the domestic value-added in exports. $\boldsymbol{DDC}$ is equivalent to the value-added that has crossed the national border more than once (Borin and Mancini 2017); thus, it is already counted in the estimation of $\boldsymbol{DVA}$ in Equation (3). Although $\boldsymbol{DDC}$ is only a small percentage of exports, its inclusion in the domestic value-added in exports would alter the concept of the examined value and its relevance to international structural competitiveness.

Finally, the TADVA, the indicator proposed in this research to express the structural competitiveness of a country, is described by Equation (6):

$$\boldsymbol{TADVA} = \boldsymbol{t}_{TA}\ (\boldsymbol{v}^T\ (\boldsymbol{I}_{mn}-\boldsymbol{A}^*)^{-1}\ \hat{e})^T \tag{6}$$

Where $\boldsymbol{TADVA} \in \mathrm{R}^{mx1}$ is the vector of the TADVA by country and $\boldsymbol{t}_{TA} \in \mathrm{R}^{mxmn}$ is a diagonal block matrix with the vector $\boldsymbol{u}_{TA} \in \mathrm{R}^{1xn}$ lying on its diagonal. A typical element $\boldsymbol{u}_{TA,j}$ $(j = 1, \ldots, n)$ equals 1 if sector j is a technologically advanced sector and 0 if it is not.

In the following analysis, the link of the $\boldsymbol{TADVA}$ with the structural factors (the degree of production diversification and the strength of the domestic productive linkages) that determine the level of international competitiveness of a country is explained.

The Degree of Production Diversification

A country with a high degree of diversification is expected to produce and export a wide range of products with strong productive linkages. On the contrary, a country with a low degree of diversification (or a specialized one) tends to concentrate on both production and exports within a narrow range of products and limited productive linkages. As Szyrmer (1986) points out, in a specialized economy, each sector is directly linked to a small number of suppliers and buyers and shows relatively low diversity in the direct flows. Siegel, Johnson, and Alwang (1995) and Hirschman (1989) suggest that input–output analysis could be used as an integrating framework for analyzing economic diversification. More precisely, the level of diversification can be observed in the matrix of the domestic technical coefficients $(\boldsymbol{A}^*)$. The production of a diverse range of goods and services is reflected in the matrix by widening and deepening the intersectoral production linkages. The degree of economic diversification is directly included in the estimation of the TADVA.

First through the distribution of exports by sector of economic activity (vector e) and second through the matrix A^*: on the one hand, if the exports of the examined country are specialized (diverse), then the exporting process will activate a small (large) number of sectors; on the other hand, if the production structure of the economy is specialized (diverse), then the technological coefficients will be relatively weak (strong), and the multiplying impact of the productive system will be less (more) significant.

Finally, when confronting the issue of international structural competitiveness, the national economies' size should be taken into account. Hilferding (1981, 311) argues that "[t]he more extensive the territory, the more diversified is the production and the more probable it is that the various branches of production will complement one another." Thus, larger countries are expected to have a more diversified production structure (in this connection, see the European Commission 2009, 9, 60). However, it should be noted that, as the European Commission (2009, 60) also supports, concerning the EU, some of the EU countries "despite their relatively small size [. . .] exhibit a [. . .] balanced sectoral structure." Consequently, as already noted, although the size of a national economy matters in the degree of diversification, this is not always the case.

The Strength of Domestic Productive Linkages

Based on the expression of the Leontief inverse matrix as a convergent matrix power series, namely, $\left(1 - A_i^*\right)^{-1} = \sum_{k=0}^{\infty} \left(A_i^*\right)^k$ (Miller and Blair 2009, 31–33), Equation (6) can be transformed as follows:

$$TADVA = \left(t_{ZA} \cdot v^T \cdot \tilde{e} \right)^T_{\underbrace{}_{1^{st} term}} + \left(t_{ZA} \cdot v^T \cdot A^* \cdot \tilde{e} \right)^T_{\underbrace{}_{2^{nd} term}}$$
$$+ \left(t_{ZA} \cdot v^T \cdot \left(A^*\right)^2 \cdot \tilde{e} \right)^T_{\underbrace{}_{3^{rd} term}} + \cdots + \left(t_{ZA} \cdot v^T \cdot \left(A^*\right)^k \cdot \tilde{e} \right)^T_{\underbrace{}_{k^{th} term}} + \cdots \quad (7)$$

Equation (7) highlights the most important advantage of employing an input–output analysis for the estimation of the domestic value-added in exports, that is, the ability to estimate both the direct and the indirect effects by accounting for the level of interconnectedness of the production system (Chen et al. 2012; Koopman, Wang, and Wei 2012). When an extra unit of export is produced in the examined country, new value-added is generated directly and indirectly. The direct new value-added is estimated by the first term of the power series, which expresses the first round of the production process and demonstrates the new value-added directly created by a unit of export. The first round of production will lead to

another round due to the request for new intermediate demand, and so on. This process results in the indirect generation of value-added, expressed by the summation of the second to the kth term (with $k \to \infty$) of Equation (7). The terms of Equation (7) after the second contain elements lower than the elements of the previous term since $\lim_{k \to \infty}\left(A^*\right)^k = 0$ (i.e., A^* is a convergent matrix). The summation of all the terms (or the total impact of all the rounds) expresses the total (direct and indirect) value-added in exports. In other words, **TADVA** calculates both the direct and the indirect impact of exports in value-added generation of the technologically advanced sectors, and manages to capture the value-added generation from both the demand for exports and the intermediate demand for inputs used in the exports' production.

At this point, a crucial issue should be clarified: the relationship between value-added generation and the intermediate transaction density in input–output analysis. An international comparison of input–output linkages carried out by Shishido et al. (2000) concludes that developing countries tend to have higher linkages than the developed countries, due to the higher intermediate input ratios in the former compared to the latter. According to this approach, linkages tend to weaken in developed economies due to higher value-added ratios. In Equation (6), the ratio of value-added is expressed by v, while the linkages (the backward linkages, specifically) are expressed by $(I_{mn} - A^*)^{-1}$. As a result, an increasing density of intermediate inputs in the production process will decrease the (direct) value-added generation per unit of output in a specific sector. Consequently, at the sector level, there is a negative relation between the amounts of intermediate inputs per unit of exports and the (direct) value-added per unit of exports. Similarly, the direct value-added of an economy per unit of exports is relatively low (high) when the sum of intermediate inputs is high (low).

Although the above-described negative relation is valid for understanding the nature of input–output economics at the micro and meso level, it overlooks that the distinction between domestically produced and imported intermediates is important at the level of national economies. Furthermore, as discussed in connection with Equation (7), domestic intermediate demand participates in the domestic value-added generation throughout all the production rounds, apart from the first one. On the contrary, imported intermediate imports participate in the value-added generation of their country of origin.

As a result, a sector with a low ratio of value-added (or a high ratio of intermediate input) that purchases a significant part of its intermediate imports from the domestic economy could generate a relatively high value-added per unit of output (and, subsequently, of exports), since production of domestic inputs also produces value-added. Moreover, even a non-technologically advanced sector that receives intermediate inputs from domestic technologically advanced sectors participates in the generation

of TADVA throughout the domestic productive linkages. However, such a sector that purchases a significant part of its intermediate imports from the domestic economy could only be a sector belonging to a developed economy, according to the framework of this analysis.

Empirical Investigation: International Competitiveness and Economic Hierarchy in the World Economy

The previous analysis identified the structural factors of international competitiveness. On this basis, the TADVA is introduced as an appropriate measure to compare the level of international competitiveness of different economies. In the following analysis, the question of the empirical estimation of the TADVA for 43 economies included in the World Input–Output Database—WIOD (Timmer et al. 2015) and the consequent hierarchy of the economies is addressed.

Data Description

The methodology's application is built on the most recent WIOD input–output table, which is based on the year 2014. Given that the values in the WIOD are expressed in millions of US dollars, the TADVA counts the technologically advanced domestic value generated in the economy per unit of US dollars of the exports. The economies' abbreviations are listed in Table 1. The technological level of the manufacturing sectors follows Eurostat's taxonomy (Eurostat 2014): high-technology (HT), medium-high-technology (MHT), medium-low-technology (MLT) and low-technology (LT). In determining the technological level of a sector, data on its technological intensity (R&D expenditure to value-added) are taken under consideration. The level of R&D intensity serves as a criterion of the sector's classification into a specific technological level.[1] Following Miotti and Sachwald (2003), who characterized the HT and the MHT sectors as technological frontiers, the estimation of the TADVA is performed summing the HT and the MHT parts of the DVA.

Results on International Structural Competitiveness

In this section, we study the various economies in terms of their international structural competitiveness based on TADVA. The hierarchy resulting from the applied method is discussed in detail, and some important findings are highlighted. We compare the results with another measure of international competitiveness: the ECI.

The TADVA is estimated by Equation (6) where the following technologically advanced sectors are included: the high-technology sectors "Manufacture of basic pharmaceutical products and pharmaceutical preparations" and "Manufacture of computer, electronic, and optical products," and the medium-high-technology sectors "Manufacture of chemicals and chemical products," "Manufacture of electrical

equipment," "Manufacture of machinery and equipment," "Manufacture of motor vehicles, trailers and semi-trailers," and "Manufacture of other transport equipment" (Eurostat 2014).

Figure 1 provides the results obtained from the analysis of the international structural competitiveness provided by the TADVA. The economies are depicted in descending ranking order with regards to the TADVA. The economies in the highest positions of the hierarchy are as follows: 1st Japan, 2nd Chinese Taiwan, 3rd Germany, 4th South Korea, and 5th the USA. The economies in the lowest positions of the hierarchy are as follows: 39th Australia, 40th Greece, 41st Luxembourg, 42nd Cyprus, and 43rd Malta.

Figure 1   Technologically Advanced Domestic Value Added in Exports (TADVA), WIOD Economies, 2014

Sources: WIOD, and authors' calculations.

The average value of TADVA among the WIOD economies is 0.109. Notably, the ratio of maximum to average TADVA equals 2.41, while the ratio of median to minimum TADVA equals 7.28. Hence, the technologically advanced value-added per unit of exports is at least twice the median for the economies at the top of the rank order. In contrast, for the economies in the middle of the rank order, the corresponding value is at least seven times greater than that of the bottom economies.

The research findings do not support that larger economies, which usually have a more diverse production relatively to smaller ones, tend to show a relatively high structural competitiveness level. For example, as shown in Figure 2, Sweden, the Czech Republic, Austria, Finland, and Slovenia exhibit high values for TADVA, similar to that of larger economies, such as Italy and France, and close to Germany's values. On the contrary, several relatively large economies such as Russia, Brazil, and Australia are found in the lower positions of the ranking order, indicating that their exports are not strongly connected with technologically advanced activities.

This finding supports the European Commission argument, seen above, about the "balanced sectoral structure" of some smaller EU countries.

Figure 2 illustrates the sectoral distribution of TADVA for the ten top economies of the ranking order. What stands out in this figure is that when TADVA is broken down into the sectoral level, the economies show mixed results. The participation of the sectors that exceeds 20% of TADVA in an economy will be analytically examined.

For all the top ten economies, the participation of sector C26 in TADVA is greater than 20%, except for Germany, where the corresponding value is 10.4%. For Japan, Germany, Mexico, and the Czech Republic, the participation of sector C29 exceeds 30% of the TADVA. Germany, China, the Czech Republic, and Sweden show that the participation of C28 is greater than 20%. The participation of C21 in Switzerland is 41.2%, while the USA exhibits important participation of C20 in TADVA, equal to 21.7%. These findings reveal that the more competitive economies usually base their exporting activities on the sectors of computer, electronic, and optical products (C26), the automotive industry (C29), and the production of machinery and equipment (C28). Although the pharmaceutical industry (C21) and the chemical industry (C20) play a rather subordinate role, they emerge as critical sectors for particular economies' structural competitiveness.
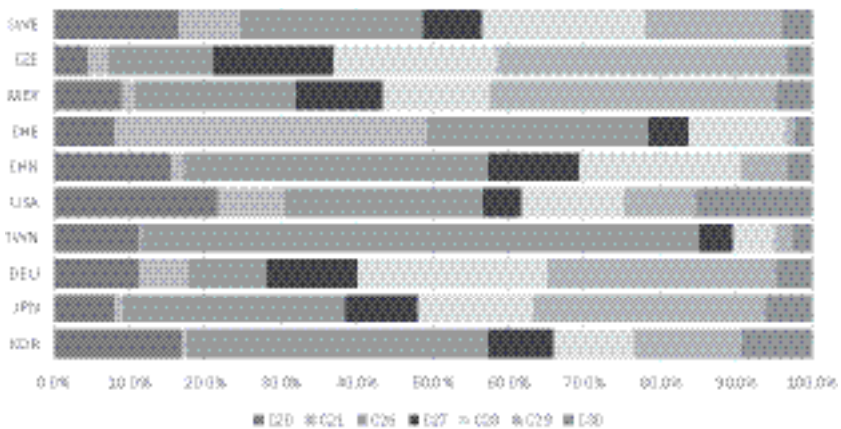

Figure 2   Distribution of TADVA by Sector* for the Top Ten Economies, 2014

Sources: WIOD, and authors' calculations.

Notes: The included sectors are C20 (Manufacture of chemicals and chemical products), C21 (Manufacture of basic pharmaceutical products and pharmaceutical preparations), C26 (Manufacture of computer, electronic and optical products), C27 (Manufacture of electrical equipment), C28 (Manufacture of machinery and equipment), C29 (Manufacture of motor vehicles, trailers and semi-trailers), C30 (Manufacture of other transport equipment).

Comparison with an Alternative Measure

This section seeks to compare TADVA with an alternative measure that also condenses the structural factors of international structural competitiveness, the Economic Complexity Index. Although in a different theoretical context, the approach of "economic complexity" leads to similar conclusions regarding the structural competitiveness of an economy. ECI is constructed by Hausmann et al. (2014) to provide a measure of the relative economic complexity of national economies by taking into account the diversity and the ubiquity of the products included in their exports' basket.

Hausmann et al. (2014, 20) introduce the notion of ubiquity, defined as:

> The number of countries that make a product [. . .] Using this terminology, we can observe that complex products—those that contain many personbytes of knowledge—are less ubiquitous. The ubiquity of a product, therefore, reveals information about the volume of knowledge that is required for its production. Hence, the amount of knowledge that a country has is expressed in the diversity and ubiquity of the products that it makes.

According to this approach,

> [c]omplex economies are those that can weave vast quantities of relevant knowledge together, across large networks of people, to generate a diverse mix of knowledge-intensive products. Simpler economies, in contrast, have a narrow base of productive knowledge and produce fewer and simpler products, which require smaller webs of interaction [. . .] Increased economic complexity is necessary for a society to be able to hold and use a larger amount of productive knowledge, and we can measure it from the mix of products that countries are able to make. (Hausmann et al. 2014, 18)

Consequently,

> The economic complexity of a country is calculated based on the diversity of exports a country produces and their ubiquity, or the number of the countries able to produce them (and those countries' complexity). Countries that are able to sustain a diverse range of productive know-how, including sophisticated, unique know-how, are found to be able to produce a wide diversity of goods, including complex products that few other countries can make. (Simoes and Hidalgo 2011)

Given the above, a higher ECI indicates an economy that produces a more diverse range of products, and products that are less ubiquitous in the world trade system.

Thus, the economies of high "economic complexity" or the "complex economies" correspond with what this study has identified as the internationally more developed and more competitive economies due to the following factors:

- larger "webs of interaction," according to the "economic complexity" approach, which correspond to a strongly interconnected economic system;
- "diversity" of products and exports, according to the "economic complexity" approach, which corresponds to a greater diversification;
- "knowledge-intensive products," "complex products that few other countries can make," "sophisticated, unique know-how" products and exports, according to the "economic complexity" approach, which correspond to a relatively high level of industrial and technological development and the structure of exports favoring the technologically advanced products.

Correspondingly, "simpler economies" match what has been identified as less developed and less competitive economies, at least in relation to the same interrelated issues:

- "smaller webs of interaction," according to the "economic complexity" approach, which correspond to a weakly interconnected economic system;
- production of "fewer products," according to the "economic complexity" approach, which corresponds to strong specialization;
- "narrow base of productive knowledge," production of "simpler products," according to the "economic complexity" approach, which corresponds to a relatively low level of industrial and technological development and the structure of exports not favoring the technologically advanced products.

The results obtained from both measures are depicted in Table 1, where the hierarchy based on the results is listed in the two last columns. The required data on the ECI for 2014 are extracted from the Atlas of Economic Complexity.[2]

Table 1   Comparative Analysis of TADVA and ECI, WIOD Economies, 2014

Abbreviations	Name	TADVA	ECI	Hierarchy based on TADVA	Hierarchy based on ECI
JPN	Japan	0.264	2.297	1	1
TWN	Chinese Taiwan	0.257	n.a.	2	n.a.
DEU	Germany	0.243	2.107	3	2
KOR	South Korea	0.242	1.966	4	4

USA	USA	0.190	1.571	5	10
CHN	China	0.190	1.314	6	17
CHE	Switzerland	0.184	2.031	7	3
MEX	Mexico	0.173	1.288	8	18
CZE	Czechia	0.159	1.760	9	6
SWE	Sweden	0.157	1.741	10	7
SVN	Slovenia	0.153	1.553	11	11
ITA	Italy	0.146	1.478	12	14
HUN	Hungary	0.145	1.702	13	8
AUT	Austria	0.141	1.784	14	5
FIN	Finland	0.139	1.595	15	9
FRA	France	0.132	1.441	16	15
DNK	Denmark	0.115	1.152	17	20
GBR	UK	0.111	1.531	18	12
ESP	Spain	0.109	0.957	19	25
SVK	Slovakia	0.108	1.524	20	13
ROU	Romania	0.100	1.085	21	23
CAN	Canada	0.094	0.616	22	33
POL	Poland	0.093	1.133	23	21
TUR	Turkey	0.092	0.663	24	30
IRL	Ireland	0.091	1.372	25	16
IDN	Indonesia	0.089	0.066	26	37
BEL	Belgium	0.083	1.184	27	19
IND	India	0.072	0.233	28	35
NLD	Netherlands	0.071	1.087	29	22
HRV	Croatia	0.064	0.861	30	26
PRT	Portugal	0.061	0.764	31	27
EST	Estonia	0.060	1.023	32	24
BRA	Brazil	0.058	0.232	33	36
LTU	Lithuania	0.056	0.679	34	29
BGR	Bulgaria	0.054	0.616	35	32
LVA	Latvia	0.044	0.650	36	31
NOR	Norway	0.044	0.682	37	28
RUS	Russia	0.041	−0.011	38	39
AUS	Australia	0.027	−0.593	39	40
GRC	Greece	0.023	0.061	40	38
LUX	Luxembourg	0.024	n.a.	41	n.a.
CYP	Cyprus	0.019	0.474	42	34
MLT	Malta	0.015	n.a.	43	n.a.

Note: n.a.: Not available.

To compare the hierarchy based on TADVA and ECI, the Spearman's Rank Correlation Coefficient is used in order to measure the ordinal association between the rankings according to each variable (Newbold, Carlson, and Thorne 2013). The Spearman's Rank Correlation Coefficient equals 0.874 ($p < 0.01$), indicating high degrees of similarity in the examined economies' hierarchical positions derived by the two measures.
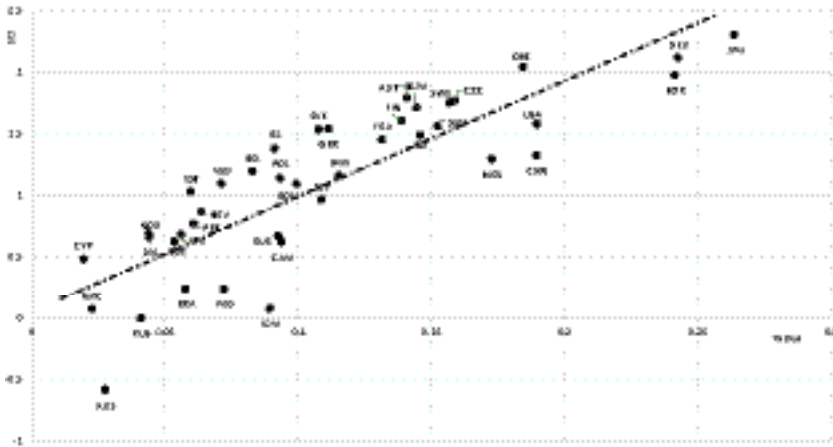

Figure 3   Correlation between Technologically Advanced Domestic Value Added in Exports and Economic Complexity Index, 2014

Notes: The horizontal axis measures the Technologically Advanced Domestic Value Added per unit of exports (TADVA), and the vertical axis measures the Economic Complexity Index (ECI).

The scatter plot presented in Figure 3, which illustrates the correlation between TADVA and ECI for all the examined economies, provides further evidence for evaluating the results. A strong positive linear relationship is determined when measuring the linear relationship between the two measures using the Pearson Correlation Coefficient, which equals 0.844 ($p < 0.01$).

However, the relation between the TADVA and the ECI has to be carefully interpreted. Differences between the hierarchical positions of the examined economies, in terms of their international structural competitiveness, given by the two measures, mainly reflect differences in the "nature" of these measures. ECI uses gross trade data, meaning that both intermediate and final products are included in the calculations, while TADVA considers only the domestic value generated in the exporting economy. As a result, significant differences between the TADVA and the ECI are expected when an economy participates in the last stages of

complex products' production, which involve low value-added activities (such as assembly or packaging). In this case, a relatively low level of value-added generation is accompanied by high economic complexity, and a deviation above the dashed line of Figure 3 is observed. On the contrary, an economy involved in high value-added activities of a complex product could generate value-added not only by the final product but in all sectors involved in the process. In that case, the impact on TADVA could exceed the impact on ECI, leading to a deviation below the dashed line of Figure 3.

The findings confirm the association between the TADVA and the ECI, showing that both are valid measures of structural competitiveness and can be used to determine national economies' hierarchy.

Conclusions

This paper aimed to identify the structural factors that determine the level of competitiveness of national economies and their resulting hierarchy in the world economy. We have assumed that there is a structural relationship between the competitiveness of a national economy and the level of its economic development. On this basis, the degree of diversification of the productive structure of a national economy and the strength of its domestic productive linkages, which are both related to the level of industrial and technological development and the technological structure of exports, were identified as the main structural factors of international competitiveness. The Technologically Advanced Domestic Value-Added in Exports (TADVA), which condenses the above structural factors, was proposed in the paper as a measure of international structural competitiveness. For the estimation of TADVA, the global value chains methodological framework and the input–output analysis were employed, using data for 43 economies.

The economies found at the top of the hierarchy regarding international structural competitiveness are Japan, Chinese Taiwan, Germany, South Korea, and the USA, while Australia, Greece, Luxemburg, Cyprus, and Malta are at the bottom. A comparison of the sectoral structure of TADVA among the more competitive economies reveals that, usually, these economies base their exporting activities on the sectors of computer, electronic and optical products, the automotive industry, and the production of machinery and equipment. Although the pharmaceutical industry and the chemical industry play a rather subordinate role, they emerge as critical sectors for particular economies' structural competitiveness. Moreover, according to the empirical findings, an economy's size cannot, on its own, determine that economy's position in terms of its competitiveness.

The comparison of the TADVA hierarchy of the examined economies with the hierarchy resulting from the ECI, another well-founded measure of international

structural competitiveness, reveals a strong positive linear relation between them and a high degree of similarity. The empirical results' compatibility verifies that both measures are suitable to express the structural competitiveness of an economy. Finally, the findings' combination provides some support for the conceptual premise that international competitiveness is structurally driven and not cost-driven.

In future research, the analysis of structural competitiveness could further benefit from the contribution of Hummels, Ishii, and Yi (2001), who introduced the foreign value-added in exports (FVA), that is, the value-added of imported intermediates which is embodied in a country's exports. The FVA measures the extent to which a country depends on imports for the production of its exports. A further step to the research could be the investigation of a possible link between FVA and structural competitiveness. Notably, the existing literature pays particular attention to the substantial increase of FVA in most developed countries (Chen, Kondratowicz, and Yi 2005; Duan et al. 2018; Hummels, Ishii, and Yi 2001) and, more importantly, to the increase of the FVA for the high-technology products (Amador and Cabral 2009). The examination of a possible link between the dependency on technological advanced intermediate imports and TADVA could provide new evidence on the concept of structural competitiveness.

Notes

1. See Eurostat. "High-tech Industry and Knowledge-Intensive Services (htec)." Reference Metadata in Euro SDMX Metadata Structure (ESMS). Accessed June 2, 2021.https://ec.europa.eu/eurostat/cache/metadata/en/htec_esms.htm.
2. See Atlas of Economic Complexity—Center for International Development at Harvard University. Accessed March 21, 2021. https://atlas.cid.harvard.edu/rankings.

Acknowledgments

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