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A Quantitative Assessment of Inter-Sectoral Linkages in Tunisia

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Abstract

This study offers a nuanced examination of Tunisia's economic structure through the lens of input-output analysis, emphasizing the significance of inter-sectoral linkages beyond mere contributions to gross domestic product. While traditional assessments often prioritize sectoral output, this research underscores the importance of understanding the interconnected roles that sectors play as enablers of broader economic activity. Utilizing Rasmussen's (1956) and Watanabe-Chenery's (1958) methodologies, we analyze the forward and backward linkages among key industries, drawing on 2018 data from the OCDE statistics. Our findings identify the chemical and petroleum sectors, along with mechanical and electrical industries, as the primary drivers within Tunisia's industrial network. These sectors exhibit strong bidirectional linkages, positioning them as critical engines of growth with the capacity to influence the entire economic system. The analysis also highlights the strategic importance of the agri-food sector, which demonstrates high levels of both demand and supply-side connectivity, underscoring its role as a catalyst for sustainable development and diversification. Conversely, sectors such as machinery, equipment, and construction appear more peripheral, constrained by technological obsolescence and limited integration into supply chains. The results suggest that targeted policy measures aimed at strengthening backward linkages in resource-dependent industries and fostering innovation in manufacturing could significantly enhance economic resilience. Overall, this research advocates for a comprehensive approach to economic development—one that recognizes the vital interdependencies among sectors—and underscores the need for policies that promote technological upgrading and structural diversification in Tunisia's evolving economy.

Keywords: *input-output analysis, forward and backward linkages, Tunisia, demand-driven, resources-based sectors.*

JEL Classification: C67, D57

1-Introduction

The Tunisian economy, like many others, is characterized by a complex web of intersectoral relationships that significantly influence its overall performance and growth trajectory. Traditional economic analyses often prioritize the services sector as the primary driver of Gross Domestic Product (GDP) formation, potentially obscuring the vital contributions of other sectors. This article seeks to challenge this prevailing narrative by employing an input-output (I-O) analysis, a method pioneered by Wassily Leontief (1936), which allows for a detailed examination of the interdependencies among various economic sectors.

Input-output analysis provides a framework for understanding how output from one sector serves as input to another, thereby highlighting the interconnectedness of economic activities. As noted by Miller and Blair (2009), this approach not only quantifies the direct and indirect effects of sectoral outputs on the economy but also reveals the intricate leakages that underpin economic resilience and growth. In the context of Tunisia, the 2018 OECD I-O table (OECD, Input output database) serves as a critical resource for identifying key sectors, including mining, energy, pharmaceuticals, and fabricated metal products, which exhibit in our results strong forward and backward linkages.

Recognizing these intersectoral dynamics is essential for effective policymaking, particularly in a rapidly evolving economic landscape. As suggested by Stiglitz and Greenwald (2014), a nuanced understanding of sectoral interactions can inform strategies that promote sustainable economic development. This article aims to illuminate the

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synergies among Tunisia's key sectors, advocating for a comprehensive approach to economic strategy that acknowledges the importance of these interdependencies.

This article is structured to systematically explore the inter-sectoral dynamics within the Tunisian economy through a comprehensive input-output analysis. The review of existing literature (section 2) provides theoretical foundation, emphasizing the importance of sectoral linkages in understanding economic development beyond simple contribution to GDP. The methods and data section (section 3) provides a comprehensive overview of the empirical framework employed in this study. It begins with a detailed explanation of the methodological approach, including the application of Rasmussen's (1956) and Chenery-Watanabe's (1958) techniques to calculate forward and backward linkage indices, utilizing the 2018 OECD input-output table as the primary data source. This section also elaborates on the foundational concepts underpinning the analysis, such as the construction of the direct requirement table and the Ghoshian allocation system. Drawing on insights from leading scholars in input-output analysis—such as Oosterhaven (1989, 1996, 2017, 2019); Oosterhaven et al. (2001, 2002), Dietzebacher (1997, 2001, 2002), and De Mesnard (2002a)—the section clarifies that the traditional form of Ghosh's model functions as a pricing model, emphasizing that price variations for primary commodities are considered inflationary rather than productivity-enhancing. The results and discussion section (section 4) presents the key findings, highlighting the distinct sectoral links identified through the analysis—such as the demand-driven nature of sectors like services and the upstream role of resource-based industries. Finally, the conclusion (section5) synthesizes these insights, discussing their policy implications and suggesting avenues for fostering a more resilient and interconnected economic structure in Tunisia.

2- Literature Review

Input-output tables are an important tool for identifying industrial connections as they provide a systematic representation of the economic relationships between the different sectors. These tables quantify the flows of inflows and outflows between different sectors of the economy, thereby providing information about the amount of inputs required for a unit of production of a good or service, as well as the distribution of the income generated by that production. Regarding industrial links, input-output tables make it possible to highlight the interdependencies between different economic activities, thereby identifying key sectors that have significant knock-on effects on the rest of the economy. The information contained in the table is very useful for policy makers and economic analysts to understand the economic impact of policies and the industrialization process.

The use of input-output tables is also widespread in many economic topics, as it allows the measurement of direct, indirect, and even induced effects of an activity on the entire economy. In the field of trade, the input-output model serves as a valuable tool for the analysis of the global value chain, breaking down the source of added value in the final products and considering primary inputs (such as labor and capital) in the production process. Other related work has been interested in the classic question of explaining the productivity differences observed between countries by a consistent relationship between industry linkages and overall productivity (Bartelme and Gorodnichenko, 2023) and by highlighting the distortions in input markets (Jones, 2011; Baqaee and Farhi, 2020) or take advantage of the microeconomic changes that lead to misallocation of resources between sectors and affect overall efficiency (Vollrath, 2009; Gollin et al., 2014). Recent work (David Kay, G. Jason Jolley, 2023; Mejean & Schoch, 2023) captures the impact of carbon tax policy through an I-O model (with a $100/ton or $200/ton carbon tax scenario) on relative factor costs by industry, on sectoral production or on the tax burden and economic prosperity.

Since our paper tend to identify which sectors could be considered as "enabler" or "trigger" industries for the rest of economic activities, keys sector analysis would be a perfect methodological framework to deserve our purpose. The I-O literature has a long history of using key sectors analysis (Seung, 2020). Several works are executed entirely based on I-O tables and the interindustry links that this table indicates. The first studies of sectoral linkages analysis are attributed to Rasmussen (1956), Chenery & Watanabe (1958), Hirschman (1958) and Yotopoulus & Nugent (1977). In this lineage, the two fundamental linkages– backward linkage and forward linkage are the framework considered to perform key sectors analysis. The first linkage states the interconnection between a sector (let it be 'industry i') and the supporting industries, which encompass various sectors and provide the essential intermediate goods and inputs necessary to produce the sector's output. The primary concept discussed in this segment revolves around the notion that when sector i expands its output to meet a positive change in final demand, it will lead to: (i) a direct effect, which refers to the increase in industry i's output as perceived by economists and, (ii) an indirect effect, which refers to an increase of the sector's purchase of intermediate inputs from the supporting industries. Each industry which supplies industry i with the necessary inputs must in turn increase these purchases from other industries to reply to its own production expansion. This process is created through the interconnection between activities in the intermediate consumption matrix will remain and expand turn- in-turn to the whole economy. Forward linkage occurs when the 'industry i' sells its outputs to other industries and stimulates uses of intermediate inputs in the purchasing activities. In this first wave of works, Dhawan and Saxena (1992) consider that the Rasmussen's approach has proved to be superior to the approaches of Watanabe (1958) and Yotopoulus and Nugent (1977) and what explains this widely used in empirical literature. Also, these economists argue that under unbalanced growth strategy, the keys sectors should observe an increased investment to speed up the industrialization process. Ojaleyeand Narayanan (2022) undertake the two methods: Chenery-Watanabe (1958) method where sectoral links are determined directly from the Leontief matrix and Rasmussen (1958) method where intersectoral linkages are based on the coefficients of the inverse matrix. They conclude that the results obtained are sensitive to the various linkage measures. Furthermore, a comprehensive analysis spanning multiple sectors and countries has been conducted using global input-output tables. These tables, primarily sourced from the World Input-Output Database (WIOD) as seen in the research of Timmer et al. (2015) and Bartelme and Gorodnichenko (2023), along with the Global Trade Analysis Project (GTAP) utilized by Aguiar et al. (2019), integrate national input-output tables, data on production factor requirements, and bilateral international trade statistics.

Another wave of works, such M. Alejandro et al. (2008) use a social accounting matrix (SAM) which is a "*more complex database*" (p84) and even better "*reflect the complete circular flow of income*" (p84). Cardenete and Sancho (2006)2 pursue an extended input-output approach in their SAM model to comprehensively depict the interdependencies among sectors, factors, and demand. To describe the distributional effects within the non-industrial sectors, both factors and households are considered as endogenous sectors. The research investigates the substantial disparities in outcomes when comparing the analysis of key sectors using the IO and SAM models, particularly in terms of lost gross production and shifts in sectoral hierarchy.

3- Methods and Data

Analytical framework

Despite the problem of inputs with fixed coefficients (which is the main criticism we allow for the Leontief table) and the unique technique for each sector, the Leontief model is a good way to estimate supply and demand within an economy. In general literature, two versions of the Leontief model are adopted: the closed model and the open model. The first version (e.g. the closed model) is based on the core hypothesis that the industry uses all its production. In other words, the model shows that for a country or region, if there are N industries, each producing n different products, then all production is returned to the different sectors as inputs. Therefore, production equals consumption and there is no external demand (exports). The open version of the model generally illustrates an economy with N outputs used as inputs, one output that is not produced (most commonly labor), and final demand. So, it shows which different sectors of the entire economy directly influence each other. The open Leontief table is the original work of Wassily Leontief (1906–1999), which earned him the Nobel Prize in Economic Sciences in 1973. Since this

[2]Cardenete and Sancho (2006) cited in Seung (2020).

significant contribution to economic accounting, the input-output (I-O) table has been widely used, namely in macroeconomic analysis, whose works tend to identify the interdependencies between different economic sectors or industries.

Combining data from various sources is often essential for conducting input-output analysis. Household expenditure surveys, along with other economic surveys, are particularly relevant for this methodology. This approach can be extended to describe the local community economy, exemplified by the creation of a Village Input-Output Table (VIOT) derived from household survey data (Hongsakhone et al., 2021). However, the primary database for IO analysis remains the National Accounts of each country. As an accounting framework, several key tables can be generated for economic analysis, including:

- The Supply-Use Table in its standard form, and
- The Symmetric Input-Output Table (SIOT), which facilitates a range of analytical and predictive studies.

The data contained in supply and use tables (organized by product and industry) and other supplementary sources are utilized to construct symmetric input-output tables. These tables serve as the theoretical foundation for further analysis. For a specific accounting period, SIOT provides a matrix representation of transactions within an economy, making it a valuable analytical tool. The supply-use table, expressed in basic prices, can be employed to derive symmetric input-output tables under various technological assumptions. It is feasible to create symmetric tables based on specific products or industries. Essentially, an industry-specific IOT maps the purchases and sales of each industry sector in relation to every other industry sector. This involves recording the financial inventory of all products used to produce a particular product individually. Alternatively, IOT tables can be generated and made available for each product. The flows of intermediate and final goods and services are defined based on product outputs and are displayed in a product-by-product table.

In our analysis, we utilize the input-output table prepared by the Organization for Economic Co-operation and Development (OECD). We propose to illustrate the structure and specifics of this table in the accompanying diagram, which closely aligns with the international approach. As depicted in Diagram 1, the table showcases the cross-sector primary inputs, imports, intermediate consumption, and the overall demand structure.

Diagram 1-A symmetric Input-Output Table Structure

	OCDE symmetric industry-by-industry Input- output table	Intermediate Demand			Final Demand				Output at basic price
		Industry 1	..	Industry 45 (n)	Domestic demand	Cross-border exports	Direct purchases by non-residents	Direct purchases abroad	
1	Industry 1 (domestic)								
..	..								
45(n)	Industry 45 (domestic)								
46	Product 1 (imports)								
..	..								
90(n)	Product 45 (imports)								
91	Taxes less subsidies in intermediate and final imported products								
92	Taxes less subsidies in intermediate and final products paid in the domestic territory								
93	Total intermediate consumption								
94	Value-added at basic price								
95	Output at basic price								

Noted that: Sector j is a buying sectors (output sector) and Sector i is a selling sector (input sector)

Source: Compilation from OCDE statis.com

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From a demand perspective, gross production value (at basic price) is the product of final demand and intermediate demand, which excluded imported goods. The production structure of every industry i in raw (1x45 rows) is made up of sectors that need domestic intermediate inputs to be produced. The domestic demand is determined by final consumption expenditure of households, final consumption expenditure of general government, gross fixed capital formation, changes in inventories. Besides the domestic demand, the final demand also covers the direct purchases abroad by residents (imports) and by non-residents on both the domestic and on the third-country territories(exports). Cross-border imports and exports are also components of the final demand.

In diagram 1, we can monitor the total income from other perspectives. The supply perspective allows us to calculate the total output of the economy by summing the column totals, as the sum of the intermediate inputs cost, intermediate imported inputs and the gross value-added. The value-added matrix, also known as GVA calculated at basic price, illustrates the proportion of labor and capital inputs in the output of each industry. It quantifies the overall surplus of employee remuneration for the labor component and the operating surplus for the capital3. This matrix includes mandatory contributions and taxes minus subsidies (state revenue) to show how wealth creation is distributed among different economic agents.

We noted however that the OCDE I-O table typically contains NxN (N=45) matrix of imported intermediate inputs (rows/columns 45 to 90 in the Diagram 1) that includes the total of inputs that each domestic sector imports specifying the sector of origin of the inputs. This matrix may be aggregated to be a vector of 1xN of imported inputs. Also, given the fundamental identity, the computation results for output from both perspectives are necessarily the same.

From an open economy model (integrating trade), we can identify furthermore the technical links, such that an activity j, to obtain the calculated product, must have consumed a quantity of a product i. The coefficients can thus be obtained: $a_{ij} = \frac{pursaches\ of\ product\ i\ by\ the\ activity\ j}{output\ j}$ where aij represents Leontief coefficients. These technical coefficients can be used for two purposes: either to determine what impact the variation in the price of a product i will have on the activity j; or to calculate how much consumption of a product should be increased to a higher production level of one sector.

Methodological Background

In this research, we use a simple framework in the spirit of many works in this field [Blair and Miller, 2009; Ojaleye & Narayanan, 2022] to link the observed input-output structure of the economy to both backward and forward inter-industrial effects.

The **direct requirement table**, illustrating the direct links between the economic sectors that tie the entire industrial structure, is a representation of the technical coefficients matrix. Equation (1) clearly represents the corresponding input coefficient in the requirement table, while equation (2) states that the total production value (Xi) for each industry I, which is approximately the sum of the domestic intermediate demand (Xij) and the final demand (FDi). The input coefficient a_{ij} refers to the total input required from industry i to produce a unit of product j, and Xij represents the input of industry i that is necessary for industry j:

$$a_{ij} = \frac{X_{ij}}{X_j} \quad ; \quad i,j = \overline{1,n} \qquad (1)$$

$$X_i = \sum_{j=1}^{n} X_{ij} + FD_i \quad ; \quad i = \overline{1,n} \qquad (2)$$

The total supply and total demand for each good are balanced using equations (1) and (2), and they can be expressed as follows:

$$X_i = \sum_{j=1}^{n} a_{ij} X_j + FD_i \quad ; \quad i = \overline{1,n} \qquad (3)$$

Where total sectoral output is represented by column vectors denoted by Xi.

A simplified version of input-output economics is possible with a linear matrix algebra (Ojaleye and Narayanan, 2022). The primary formula of an open Leontief system asserts that the final demand, FD, and all intermediate products, AX, add up to the total output vector, X (equation 4). Whereas the final

[3]Note that the gross operating surplus generally encompasses mixed income, which comprises the profits of both public and private companies, along with the rents received by capitalist households.

demand column vector FD is exogenous, the output column vector X is endogenous.

$$X = AX + FD \quad (4)$$

Let I denote an identity matrix4 and the matrix I-A the technology matrix, we can solve equation (4) for X by:

$$X = (I - A)^{-1} FD \quad (5)$$

The matrix (I − A)−1 exists since the matrix I-A is considered non-singular, indicating that it is invertible when I − A ≠ 0. The Leontief inverse, also referred to as the total requirements coefficients matrix, is the inverse of the technology matrix (I − A) and it serves as a fundamental mathematical element in the basic static input-output model.

Let denote this matrix by the total requirements coefficients of bij (B= (bij)). In the inverse Leontief matrix, the coefficients in columns show "the input requirements, both direct and indirect, on all other producers, generated by one unit of output" (Miller & Blair, 2009). That's mean that "an increase in demand for a sector's output has a greater impact on the economy then the direct effect. Industries that supply inputs to the sector experiencing the increase in demand must also increase their purchase of inputs for their production" (Dayo& Narayanan, 2022).

If we allow the matrix to incorporate a supplementary household consumption sector within the industrial transaction table, The closed Leontief model, with inputs coefficients $\breve{A} = (\breve{a}ij)$, is acquired, giving rise to a Leontief system that can be described by a matrix with dimensions of (N+1)×(N+1). The closed Leontief model may also assume that "there is no external demand, and all productions stays within the economy" (LenkaL´ıˇskov´a, 2015).

Basically, if either the final demand or the technology is altered, the output can be shifted. But as explained by Mendoza (2023) the Leontief system assumes by construction that the output is determined by the final demand while the technology remains unchanged. This relationship is illustrated by the multiplier effect (Mendoza, 2023).

[4]The computations can only be carried out if the identity matrix I has the exact same dimensions as the direct requirements coefficient matrix A.

This may normally lead us to criticize the assumptions connected to the Leontief production function so that a degree of instability must be included within the work in this field. This effort, as substantial and improving for future input yield examinations, is not the reason for this article.

In parallel, from the supply-driven perspective, the exogenous variable is value-added, which, when modified, whereas keeping the distribution coefficients constant, leads to changes in total outcome. In any case, it is challenging to legitimize the steadiness of these relationships, and it is not essentially clear to follow to the assumption that value-added decides the output.

Ghoshian Allocation system. The discussion surrounding Ghosh's (1958) 'supply-driven' input-output model appears to resurface periodically and is frequently discussed (Guerra and Sancho, 2010). This holds particularly true for us, especially in the present scenario where essential resources for production are facing growing threats. Dietzenbacher (1997) reinterpreting the Ghosh model as "formally equivalent" to Leontief's price model. Oosterhaven's (1989) pointed unresponsive value-added to output changes. For DeMesnard (2009), the Ghosh model is deemed as redundant in terms of being a price model and lacks the level of information provided by Leontief's dual quantity and price models. Leontief's model incorporates value-added components as the primary inputs. Furthermore, the use of inputs is based on predetermined ratios, and each sector employs a distinct technology system. As input substitution is prohibited, alterations in relative prices do not impact the technical coefficients. Some other works (Jones (1976); Callaghan and Yue, 2004) suggest that forwards linkages are more to be calculated from the Ghosh inverse matrix. The Ghosh model consists of a set of linear equations that are applicable to an economy with n products and industries. The given expression can be represented in matrix form as follows:

$$X' = (I - A')^{-1} PD' \quad (6)$$

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The transpose of the Nx1 output vector is denoted as X', while the transposed Nx1 vector of primary inputs is represented as PD'. Additionally, $A' = [a'_{ij}]$ refers to a matrix of direct output coefficients (European Commission, 2008, Miller and Blair, 2009). Let G be the inverse matrix (the Ghosh inverse):

$$G = (I - A')^{-1} = [g_{ij}] \quad (7)$$

Experts in the field of I-O analysis, Oosterhaven et al. (2001), Dietzebacher (1997, 2002) and De Mesnard (2002a, 2002b) agree that the traditional form of Ghosh's model is a pricing model. It follows that price increases for primary goods are merely inflationary and not productive.

Multipliers in the I-O table. The Leontief input-output quantity basic model, as depicted in equation (5), considers the changes in the final demand (FD) as exogenous factors. It determines the alteration in gross production (X) needed to ensure that supply matches demand in each sector. The direct requirement matrix (A) comprises the dinar inputs from industry i necessary to produce one monetary unit of output from industry j, utilizing the given monetary transaction table:

$$\Delta X = (I - A)^{-1} \Delta FD \quad (9)$$

The equation (9) represents the core equation of input-output analysis, utilizing the Leontief Inverse to illustrate the relationship between a country's production and final exogenous demand. Specifically, by examining the Leontief inverse matrix column-by-column, we can determine the impact of a one-unit increase in final demand on production in a sector, considering both direct and indirect effects on output.

From a supply perspective of the model, we can compute a various of multipliers: the simple output multipliers, gross value-added multipliers, and income multipliers, calculated from the corresponding given formulas:

$$M_y = (I - A)^{-1} \quad (7)$$

$$M_v = v(I - A)^{-1} \quad (8)$$

$$M_h = h(I - A)^{-1} \quad (9)$$

In the above equations system, v signifies the vector of coefficients that is derived by dividing the added value in each sector by the corresponding sector output. Likewise, h represents the vector of household coefficients, obtained by dividing the income generated by each sector for households by the corresponding sector's output.

Forward and Backward Linkages in I-O Table Analyzing sectoral linkages is important for understanding the processes by which large numbers of diverse resources are complexly combined and transformed into usable goods and services. This process is based on the input-output system and refers to the use of resources originating from different industries by other sectors of the economy (Ojaleye & Narayanan, 2022). Nugroho & Murti (2020) emphasize the forward and backward linkages within the table structure as informative links measuring the economic interdependency of sectors in terms of trade volumes. Flow of goods and services emerging in the table can be viewed from both supply and demand sides, which are best distinguished by the following questions: "Where do they come from?" and Where do they go?" (Augustinovics, 1970)5. Backward linkage places emphasis on the demand structure and showcases how an expansion in the output of a particular sector will generate a corresponding increase in the sector's demand for inputs. Conversely, forward linkage arises when an expansion in the output of specific activities drives a growth in the output of other sectors within the analysis of a single country. This linkage reveals the chain analysis related to input structure and shows the use of inputs in the intermediate consumption matrix. Key sectors with strong backward and forward linkages can play a dynamic role in the development strategy of a country (Ojaleye & Narayanan, 2022).The original Chenery-Watanabe (1958) method uses the Leontief matrix to determine intersectoral linkages, where: backward linkage is calculated as the sum of the appropriate column of the Leontief matrix and, the forward linkages as the sum of the appropriate row. Considering the technical coefficients (aij) matrix, the backward linkages (BLj^{CW}) of an industry j and forward linkages (FLi^{CW}) of a sector i are expressed

[5] Cited in Ojaleye & Narayanan, 2022.

by:

$$BL_j^{CW} = \sum_{i=1}^{N} a_{ij} \quad (11)$$

$$FL_i^{CW} = \sum_{j=1}^{N} a_{ij}^{\omega} \quad (12)$$

a_{ij} constitutes the Leontief coefficients while a_{ij}^{ω} represents the proportion of sector i's output that is directed towards sector j.

While assuming the Rasmussen method (1956), which does not neglect either direct or indirect linkages between industries, the inverse Leontief matrix (described by equation (5) and denoted as matrix B) allows us to explore the linkages between the various industries. By summing the columns of the inverse matrix, the backward linkage can be easily calculated, while the forward linkage can be identified by summing the rows. Then, it is possible to proceed with the normalization of these linkage indicators using the following formulas:

$$\boldsymbol{IFL_i} = \frac{\sum_{j=1}^{n} b_{ij}}{\sum_{i=1}^{n}\sum_{j=1}^{n} b_{ij}} \boldsymbol{n} \quad (13)$$

$$\boldsymbol{IBL_j} = \frac{\sum_{i=1}^{n} b_{ij}}{\sum_{i=1}^{n}\sum_{j=1}^{n} bij} \boldsymbol{n} \quad (14)$$

In the above equations, we assume that IFL_i represents the forward link index of sector i, IBL_j represents the backward link index of sector j, $\boldsymbol{b_{ij}}$ represents the flow from sector i to sector j, and n represents the total number of sectors.

Forward linkage refers to providing the products of one industry as a material to another industry. Given the expanding industries, this linkage may enable the emergence of other new industries. While, backward linkage refers to the fact that the product of the newly emerging industry induces demand for materials and enables the emergence of supply industries (Hirschman, 1958). Morris & Fessehaie (2014) discus from the viewpoint of forward-backward linkage how African countries, where primary products are abundant, can realize value-added commodity-based industrialization (such as expanding the supply side of resources or the need for new products to part of the global value chain). We noted that Jones (1976) suggests to use the Ghosh inverse (matrix G) for the calculation of forward linkages to ovoid the double counting of causal linkages, inasmuch as sales from sector i to sector j are recognised as i's forward linkage and j's backward linkage. Using the above G matrix, normalized forward linkages (IFGhj)6 is given by:

$$\boldsymbol{IFGh_j} = \frac{\frac{1}{n}\sum_j^n g_{ij}}{\frac{1}{n^2}\sum_i \sum_j g_{ij}} \quad (15)$$

Given equations (13) and (14), the rule dictates that the leading sector is determined by the IFL and IBL values. A sector is classified as leading if it satisfies the condition of having IFL > 1 and IBL > 1. The leading sector holds significant importance in economic activity and necessitates enhancements. Apart from the initial set of key sectors, we propose dividing the remaining sectors into three separate categories. A sector is considered to have strong backward linkages if its backward linkages exceed one. Similarly, a sector is classified as having strong forward linkages if its forward linkages are greater than one. Sectors with both backward and forward linkages values less than one are grouped under the weak linkages category.

Type and sources of data

In Tunisia, symmetric input output tables are non-existent in official publications. Only the standard supply-use tables are published annually. It is crucial to remember that converting a supply-use table into an input-output table can be a challenging procedure that calls for cautious data gathering, balancing, and modeling strategies. To account for insufficient or missing data, it could entail estimating and making assumptions. On the other hand, this change makes it possible to analyze economies in greater detail and to comprehend the relationships and interdependencies that exist inside them. Typically, a few steps are taken to convert a normal supply-use table into a symmetric input-output table. These actions could consist of: (i) *Supply and Demand Balancing*: unbalances may result when the overall supply of products and services does not equal the total demand in a typical supply-use table. Adjustments are made to guarantee that supply and demand are equal to resolve this. This can be accomplished by employing statistical methods like proportionate balancing or by scaling the data according to the size of the economy as a whole; (ii) *Symmetricization*: in this stage, the standard supply-use table is enhanced with symmetric flows. The

[6] Adopted from Freytag & Fricke (2017).

interdependencies between sectors are represented by symmetric flows, which also capture the indirect effects of intermediate inputs on the economy. Typically, input-output modeling methods like the Leontief matrix algorithm are used to estimate symmetric flows.

For our empirical investigation, rather of building a symmetrical table from the most recent supply-use table, our research will employ an IO that has previously been published for the Tunisian economy. OCDE's online publications provided the data. The primary data source for this study is the 2018 I-O data, which was utilized to calculate the inter-industry connection coefficients. The supply and use table for the 45 sectors of the Tunisian economy in 2018 is symmetric and balanced. The statistical office created the I-O table using current million-dollar values. The NCTS classification of activities is included at the disaggregate level for sectors (table 3 in the Appendix).

4- Results and discussions

For Tunisian data (I-O table for the year 2018), the Chenery-Watanabe method shows (Figure 1) low economic integration for all included sectors, especially backward linkages. It may because the same sector largely responds to its own final demand and often using imports. Only "Mining and quarrying, energy producing products" and "Other tradable sector" activities have a forward linkage index where values exceed one. Nevertheless, no sector shows evidence of both significant backward and forward linkages.

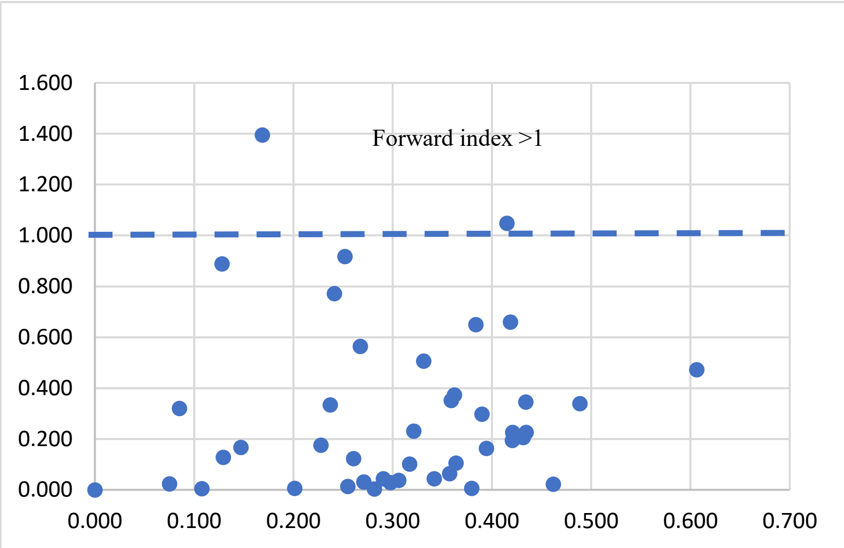

Figure 1. Coefficients of Backward and Forward Linkages Using Chenery-Watanabe method (1958)

Source: Author's calculation based on OCDE I-O Table constructed for the year 2018.

The result driven from Rasmussen method seems to differ largely from the Chenery-Watanabe outcome. Also using Rasmussen method, our calculations depict that the result for leading sectors do not vary if we calculated our index from standard Rasmussen method or with the normalized method, and even for the other activities which have only backward index or forward index superior to the average. We note at this point that, in the empirical literature, the study proposed by Hirschman (1958), who used the Rasmussen linkage indicators identify "Key sectors" as sector with forward and backward linkages above average. The outcome presented in table 3 (in the Appendix) aligns with the result obtained when considering the Rasmussen normalized index, which is explicitly depicted in Figure 2. It is worth noting that Hirschman (1958) assigns greater importance to backward linkages over forward linkages, as they are "more effective in activating decisions and employment compared to induced supply by forward linkages" (Park 1989, cited in Dettmer and Fricke, 2014). In our specific case, the Rasmussen-Hirschman indexes and the Rasmussen normalized indexes translate to a significant number of sectors belonging to the chemical, mechanical, and manufacturing industries being included (refer to table 3).

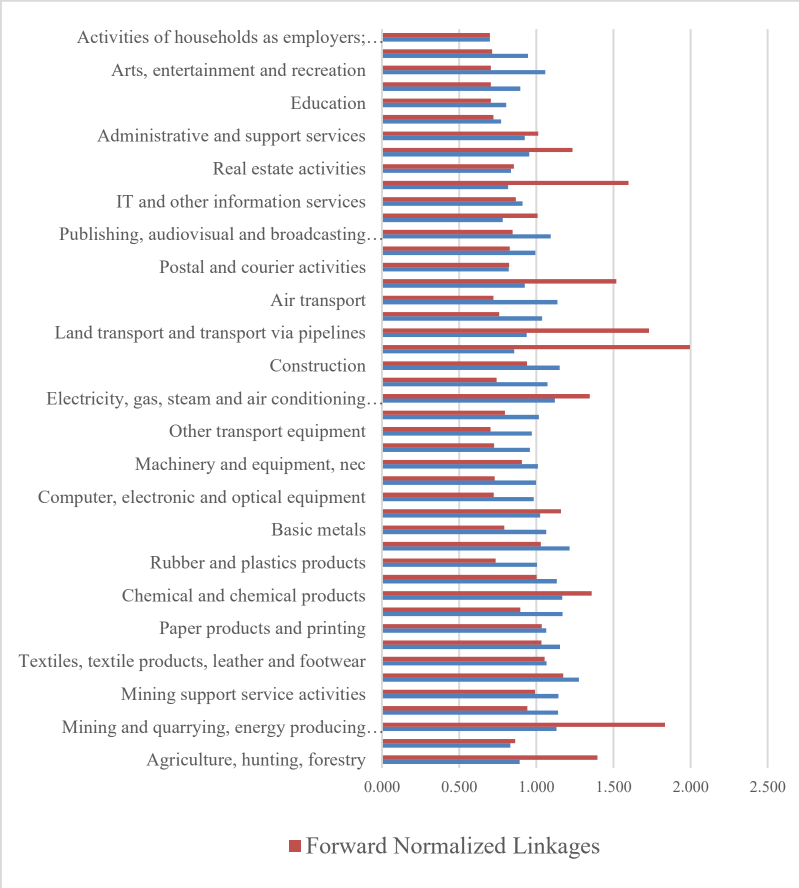

Figure 2- Backward and Forward Linkages Using Rasmussen method

Source: Author's calculation based on OCDE I-O table constructed for the year 2018.

Table 3 in the appendix shows in fact the normalized values of forward and backward linkages of all considered sectors in the Tunisian economy based on Rasmussen method. We first used the symmetric I-O table to obtain the inverse coefficients matrix (matrix B=(bij)). According to indicators, the sector's group may be defined as follows: if the normalized values of both backward and forward linkages is greater than one, the sector is consider as "leading" or "key" sector (ks); if only the normalized value of backward linkages is greater than one, the sector is called a strong backward sector or (bs); if only the normalized value of forward linkages is greater than one, the sector is termed as strong forward sector (fs); and in the case of lower normalized value for both backward and forward index (less than one), the sector refer to a weak linkages sector (ws). A similar classification is given by Miller & Blair (2009) and shown in diagram 1 where we distinguish between driven sectors (with strong backward linkages: sb); driving sectors (with strong forward linkages: fs); independent sectors (with weak backward and forward index: ws) and the key sectors.

For Tunisian economy, according to the I-O table for the year 2018 (whose data are at current price), nine sectors are considered as key sectors: (i) Mining and quarrying, energy producing products; (ii) Food products, beverages and tobacco; (iii) Textiles, leather and footwear; (iv) Wood and products of wood and cork; (v) Paper products and printing; (vi) Chemical and chemical products; (vii) Pharmaceuticals, medicinal chemical and botanical products; (viii) Fabricated metal products and, (ix) Electricity, gas, steam and air conditioning supply (Figure 2 & Diagram 1). These nine sectors have both backward and forward index greater than one. They are then considered more dynamic within the economic structure and thus, they are essential sectors to spur the output generation.

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Diagram 1 Classification of economic sectors based on backwards and forwards indexes

(Most representative sectors from I-O table 2018)

	Backward linkages < 1	Backward linkages > 1
Forward linkages > 1	Agriculture, hunting, forestry; Wholesale and retail trade; repair of motor vehicles; Land transport and transport via pipelines; Warehousing and support activities for transportation; Telecommunications; Financial and insurance activities; Professional, scientific, and technical activities; Administrative and support services (Quadrant I)	Mining and quarrying, energy producing products; Food products, beverages, and tobacco; Textiles, leather, and footwear; Wood and products of wood and cork; Paper products and printing; Chemical and chemical products; Pharmaceuticals, medicinal chemical and botanical products; Fabricated metal products Electricity, gas, steam, and air conditioning supply (Quadrant III)
Forward linkages < 1	Fishing and aquaculture; Computer, electronic and optical equipment; Electrical equipment; Motor vehicles, trailers and semi-trailers; Other transport equipment; Postal and courier activities; Accommodation and food service activities; IT and other information services; Real estate activities; Public administration and defence; compulsory social security; Education; Human health and social work activities; (Quadrant II)	Mining support service activities; Mining and quarrying, non-energy producing products; Coke and refined petroleum products Rubber and plastics products; Other non-metallic mineral products; Basic metals; Machinery and equipment, nec; Manufacturing nec; repair and installation of machinery and equipment; Water supply; sewerage, waste management and remediation activities; Construction; Water transport; Air transport; Publishing, audiovisual and broadcasting activities; (Quadrant IV)

Source: Prepared by author based on Muller and Blair (2009), Durán Lima and Banacloche (2022) classification and the Rasmussen normalized index.

Based on the normalized Rasmussen coefficients and their classification according to Miller and Blair (2009) and Durán Lima and Banacloche (2022), the structural analysis of Tunisia's economy reveals distinct sectoral linkages that align with the typologies of forward and backward linkages. The results indicate that sectors such as agriculture, hunting, forestry; wholesale and retail trade; land transport; telecommunications; financial and insurance activities; professional, scientific, and technical activities; and administrative and support services exhibit strong forward linkages (greater than 1) but weaker backward linkages (less than 1). These sectors (in Quadrant I) primarily serve as demand-driven sectors that rely on inputs from other sectors but do not significantly contribute to upstream production, consistent with the characteristics of consumer-oriented or service sectors in Tunisia's economy.

The sectors (in Quadrant III) identified as prominent in Tunisia's input-output framework reflect the country's economic structure and dependencies, supported by empirical research and industry analysis. The reliance on natural resource extraction and energy sectors, such as mining and energy production, underscores their critical role in both domestic consumption and export activities. According to Abid & Mraihi (2015), these sectors are vital for Tunisia's economic stability, given their contribution to gross domestic product (GDP) and export revenues. Energy consumption, particularly from oil, natural gas, and electricity, has in fact a correlation with GDP growth in Tunisia and directly impacts industrial production, further linking energy use to economic development. Long-term studies indicate that total energy consumption drives GDP growth, emphasizing the importance of these sectors for economic stability (Abid & Mraihi, 2014).

The food industry, including beverages and tobacco, highlights Tunisia's agricultural base and its integration into regional and global markets. They are characterized by both high backward and forward linkages (indices > 1), so they are often considered driving or leading sectors, as they significantly influence and are influenced by other sectors. Their central position suggests they are pivotal in propagating economic activity. Empirical studies by Taghouti (2017) & Thabet et al. (2015) confirm agriculture's significant role in employment and value addition within the Tunisian economy, aligning with the observed prominence of these sectors. The agri-food sector contributes around 9% to Tunisia's GDP and employs 16% of the active population in Tunisia, underscoring its importance in the national economy (Thabet, 2024).

Manufacturing sectors such as textiles, leather, footwear, wood products, paper, and chemicals are traditionally labor-intensive and form the backbone of industrial output. These sectors exhibit high input-output coefficients and interconnected supply chains, emphasizing their importance for employment and economic diversification. The textile, leather, and footwear sectors are among the most labor-intensive, providing substantial employment opportunities (Sassi & Goaied, 2016). They also have high output-employment elasticities, meaning that growth in output directly correlates with job creation (Sassi & Goaied, 2016). As pointed by Ouerghi (2023), Tunisia shows strong participation in global value chains, particularly in textiles, clothing, and leather sectors. The pharmaceutical and medicinal chemical sectors indicate Tunisia's move toward more sophisticated manufacturing, with potential for export diversification and technological upgrading. Studies by Jelassi & Delhoumi, 2017 highlight the sector's growth potential and its role in fostering innovation-driven industrial development. Utilities like electricity, gas, steam, and air conditioning supply are classified as core infrastructure sectors. Their centrality in input-output analyses underscores their importance in supporting industrial productivity and ensuring energy security, which are crucial for economic resilience. Empirical evidence from Tunisian studies supports also our findings. Studies indicate a unidirectional causality from electricity and gas consumption to industrial GDP in the long run, emphasizing the role of energy in driving industrial growth [Abid & Mraihi, 2015; Abid et al., 2012]. The analysis of social accounting matrices (SAM) shows that energy investments can lead to significant job creation and economic multipliers, reinforcing the importance of these sectors in economic planning (Jaouadi & Zorgui, 2024). The SAM models reveal that energy sectors have strong linkages with other industries, suggesting that investments in energy infrastructure can stimulate broader economic activity [Howells et al., 2021; Jaouadi & Zorgui, 2024].

Conversely, sectors (in Quadrant IV) such as mining and quarrying, energy-producing products, food manufacturing, textiles, paper products, chemicals, and electricity supply display high backward linkages (greater than 1) but relatively moderate or weak forward linkages (less than 1). These sectors are primarily upstream producers that supply inputs to other sectors, indicating their foundational role in the Tunisian industrial structure. The presence of such sectors aligns with the traditional resource-based and manufacturing sectors that underpin Tunisia's economic development. Resource-based sectors are characterized by their reliance on the extraction, processing, or utilization of natural resources. In this context, mining and quarrying, along with the production of coke, refined petroleum, and non-metallic mineral products, directly depend on the availability of natural mineral and energy resources. For example, mining activities involve the extraction of minerals and non-energy mineral products, which are inherently resource-dependent. Similarly, the production of coke and refined petroleum products relies on the availability of fossil fuel resources, making it a resource-based sector. We noted at this point that an industry has significant backward linkages when its production requires substantial intermediate input from many other industries. Moreover, from a policy perspective the backward linked industries, which influence the rest of the system through the multiplier effect, are more interesting than the forward linked industries (which is in line with Hirschman's idea cited above). For Tunisian economy, Mining support service activities; Mining and quarrying, non-energy producing products; Coke and refined petroleum products and both transportation by water and by air are considered as driven sectors (embodied in the Quadrant IV).

Furthermore, sectors such as rubber and plastics products, while involving manufacturing processes, are often linked to the utilization of natural rubber or synthetic alternatives derived from petrochemical resources, thus maintaining a connection to resource inputs. Basic metals production involves the processing of mineral ores like iron, aluminum, and copper, which are extracted from natural deposits, reinforcing its resource-based nature. In contrast, machinery and equipment manufacturing, nec (not elsewhere classified), tend to be more technological and innovation-driven, although it may still depend on raw materials and components sourced from resource-based sectors.

The sectors characterized by low forward and backward linkages (Quadrant II), such as fishing, aquaculture, certain manufacturing subsectors, and public administration, suggest limited inter-sectoral dependencies, possibly reflecting their specialized or **service-oriented** nature. The analysis also highlights sectors with both low forward and backward linkages, such as mining support services and certain manufacturing activities, indicating their peripheral role within the national economic network. Manufacturing sectors like machinery, equipment, and construction fall also into this quadrant. These sectors may be more specialized or niche, with less influence on the broader economy, or they may suggest being in a developmental stage where their integration into the supply chain is limited. Empirical studies suggest in fact that the machinery and equipment sectors in Tunisia are less integrated into the national and regional supply chains. According to Mouelhi & Ghazali (2018), the machinery sector in Tunisia remains predominantly import-dependent, with limited local manufacturing capabilities and weak linkages with downstream industries such as construction and manufacturing, which restricts overall industrial growth. This reliance on imports constrains the sector's integration into the domestic supply chain, leading to a fragmented industrial ecosystem. Similarly, the construction sector, while vital for infrastructure development, often relies heavily on imported materials and equipment, which hampers its integration with local suppliers and manufacturers.

The machinery sector in Tunisia has historically faced challenges related to technological obsolescence, limited innovation capacity, and insufficient investment in research and development (R&D) [Boujelben & Fadhila, 2010; Rahmouni, 2011; Khelifa, 2022; "TUNISIA: 'Colossal Challenges,'" 2023]. These factors hinder the sector's progression toward higher value-added activities and advanced manufacturing. The construction sector, although more mature than machinery, still grapples with issues such as outdated infrastructure, limited adoption of modern construction technologies, and a lack of skilled labor, which collectively impede its full development potential.

5- Conclusion

This study provides a comprehensive input-output analysis of Tunisia's key economic sectors, utilizing normalized Rasmussen coefficients and the classification adopted by Miller & Blair (2009) to elucidate the intricate web of sectoral linkages that underpin the national economy. The findings reveal a nuanced structural landscape characterized by distinct typologies of forward and backward linkages, which collectively inform strategic policy directions and developmental priorities.

The prominence of demand-driven sectors such as agriculture, wholesale and retail trade, land transport, telecommunications, financial services, and professional activities underscores their vital role in shaping Tunisia's service-oriented economy. These sectors exhibit strong forward linkages, indicating their function as primary consumers within the economic system, yet their weaker backward linkages suggest limited upstream influence. Conversely, resource-dependent sectors—including mining, energy production, and certain manufacturing industries—serve as foundational pillars with high backward linkages, emphasizing their upstream role in supplying essential inputs for broader industrial activity.

The analysis also highlights the pivotal position of the agri-food sector, which demonstrates both high forward and backward linkages, positioning it as a driving force within the economy. Its significant contribution to employment and GDP underscores its strategic importance for sustainable growth and economic diversification. Manufacturing sectors such as textiles, leather, and pharmaceuticals exhibit potential for technological upgrading and integration into global value chains, although current limitations—such as reliance on imports and weak linkages—pose challenges to their development. Furthermore, the study identifies sectors with limited inter-sectoral dependencies, including machinery, equipment, and construction, which appear to be more peripheral within the national economic network. These sectors face structural constraints related to technological obsolescence, limited innovation capacity, and reliance on imports, which hinder their capacity to contribute meaningfully to economic resilience and diversification.

Overall, the input-output framework underscores the importance of targeted policy interventions aimed at strengthening backward linkages in resource-based sectors and fostering innovation-driven growth in manufacturing. Enhancing the integration of peripheral sectors and promoting technological upgrading are essential for achieving a more balanced and resilient economic structure. Future research should focus on dynamic modeling approaches to capture temporal shifts in sectoral linkages and to evaluate the impact of policy measures on the evolution of Tunisia's economic network.

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Appendix

Table 3: Coefficients of backward and forward linkages from I-O Tunisian table of 2018

Code		Backward Linkages	Backward Normalized Linkages	Forward Linkages	Forward Normalized Linkages
D01T02	Agriculture, hunting, forestry	1,274	0,892	1,994	1,396
D03	Fishing and aquaculture	1,189	0,833	1,233	0,864
D05T06	Mining and quarrying, energy producing products	1,615	1,131	2,620	1,835
D07T08	Mining and quarrying, non-energy producing products	1,631	1,143	1,347	0,944
D07	Mining support service activities	1,635	1,145	1,418	0,993
D10T12	Food products, beverages, and tobacco	1,824	1,278	1,677	1,175
D13T15	Textiles, textile products, leather, and footwear	1,524	1,067	1,506	1,055
D16	Wood and products of wood and cork	1,648	1,154	1,477	1,034
D17T18	Paper products and printing	1,521	1,065	1,480	1,037
D19	Coke and refined petroleum products	1,673	1,171	1,280	0,896
D20	Chemical and chemical products	1,668	1,169	1,940	1,359
D21	Pharmaceuticals, medicinal chemical and botanical products	1,617	1,133	1,431	1,002
D22	Rubber and plastics products	1,434	1,004	1,054	0,738
D23	Other non-metallic mineral products	1,738	1,217	1,472	1,031
D24	Basic metals	1,520	1,064	1,132	0,793
D25	Fabricated metal products	1,464	1,025	1,656	1,160
D26	Computer, electronic and optical equipment	1,406	0,984	1,033	0,724
D27	Electrical equipment	1,425	0,998	1,044	0,732
D28	Machinery and equipment, nec	1,442	1,010	1,295	0,907
D29	Motor vehicles, trailers, and semi-trailers	1,369	0,959	1,037	0,727
D30	Other transport equipment	1,387	0,971	1,005	0,704
D31T33	Manufacturing nec; repair and installation of machinery and equipment	1,453	1,018	1,137	0,797
D35	Electricity, gas, steam, and air conditioning supply	1,599	1,120	1,924	1,347
D36T39	Water supply; sewerage, waste management and remediation activities	1,531	1,073	1,063	0,744
D41T43	Construction	1,644	1,152	1,342	0,940
D45T47	Wholesale and retail trade; repair of motor vehicles	1,226	0,859	2,849	1,996
D49	Land transport and transport via pipelines	1,340	0,939	2,470	1,730
D50	Water transport	1,481	1,037	1,086	0,760
D51	Air transport	1,623	1,137	1,031	0,722
D52	Warehousing and support activities for transportation	1,322	0,926	2,170	1,520
D53	Postal and courier activities	1,176	0,823	1,178	0,825
D55T56	Accommodation and food service activities	1,421	0,996	1,182	0,828
D58T60	Publishing, audiovisual and broadcasting activities	1,564	1,095	1,211	0,848
D61	Telecommunications	1,118	0,783	1,441	1,009
D62T63	IT and other information services	1,302	0,912	1,238	0,867
D64T66	Financial and insurance activities	1,168	0,818	2,283	1,599
D68	Real estate activities	1,195	0,837	1,222	0,856
D69T75	Professional, scientific, and technical activities	1,363	0,954	1,765	1,236

D77T82	Administrative and support services	1,322	0,926	1,447	1,014
D84	Public administration and defence; compulsory social security	1,102	0,772	1,033	0,723
D85	Education	1,149	0,805	1,007	0,705
D86T88	Human health and social work activities	1,282	0,898	1,009	0,707
D90T93	Arts, entertainment, and recreation	1,512	1,059	1,009	0,707
D94T96	Other service activities	1,351	0,946	1,020	0,715
D97T98	Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use	1,000	0,700	1,000	0,700
	Average index	1,428		1,428	

Source: Our calculations from OCDE IO table 2018.

Word Counter Statement

This article comprises a total of 9,601 words, with the word count including the title page.