Implications of the Green and Sustainable Transition in Economic Structure: Analyzing the Evolution of the Complexity of the German Economy

Ana Coelho[1]

[1]Economics Institute, UFRJ. Av. Pasteur, 250 - Urca, Rio de Janeiro - RJ, 22290-902, Brazil.

Ana Coelho: analuizamgcoelho@gmail.com

Implications of the Green and Sustainable Transition in Economic Structure: Analyzing the Evolution of the Complexity of the German Economy

Abstract

This paper aims to quantify and analyze the effects of the green and sustainable transition in the German economy. We apply a Markovian model to find the economic steady-state from it to identify the measures more appropriate to study structural changes in the input-output framework. We analyze the German input-output data from OCDE between 1995 and 2018. The results show that among the indicators used, the Average Propagation Length, the Indirect Multipliers, the Selling Complexity Indicator, and the Eigenvector are the most relevant indicators in explaining the evolution of the economic structure. The complexity in the sectors associated with the transition changes, and there is a negative relation between the sector complexity and its impact on the economy.

Keywords: Input-Output Analysis; Markov Chain; Indicators; Policy.

JEL: C67, C53, D57, and Z18.

1. Introduction

The energy transition is a concept that involves promoting important changes in some strategic economic sectors: energy, transport, and IT. In this context, the economic structure of some countries has been subject to policies that react to national, regional e and even international goals. Among the countries that made the most effort to reach these goals are the European countries, particularly Germany. In recent years, policies promoted important changes in its energy sectors. Those changes affect how those sectors are integrated and their importance for the whole German economy and the regional European economy. In other words, structural changes are happening in the German economic structure due to sustainable transition. Those changes would be reflected in this German's input-output tables (Denholm et al., 2010; IRENA (International Renewable Energy Agency), 2017; Schmidt and Sewerin, 2017).

Empirically, measuring structural changes in the input-output framework is a challenge. The input-output table estimations reflect not only structural factors of how the economic sectors are connected but also short-term shocks and fluctuations. The last creates noise in the data, which implies undesirable trends for any measure built directly on such tables. In this case, it becomes tough to analyze the structural information contained in the data (Bullard and Sebald, 1977; Lahr and Dietzenbacher, 2001; Linden and Dietzenbacher, 2000; Miller and Blair, 2009; Sonis et al., 2000; Thakur, 2008).

To deal with that, we propose an approach using Markov Chains; in special, we use the steady-state properties. Markov Chains have been applied to input-output literature to analyze world input-output tables. They consist of a method to compute system risk (sensibility), to identify key sectors for the economic system, the level of fragmentation and specialization of the world economy, and also to analyze the conditions of the equilibrium of the system (Kostoska et al., 2020; Moosavi and Isacchini, 2017; Riane and David, 2022).

Differently from those works, we use Markov Chain methods to investigate the structural changes. Applying it to the input-output tables, we aim to quantify and analyze the effects of the green and sustainable transition in the German economic structure.

We analyze the German economic structure from 1995 to 2018, building stochastic matrixes from the Markov Chain approach. To work with Stochastic Absorbing Markov Chains, we modified input-output tables regarding the import and export column; and added value and final demand columns. In this way, we ensured a closed system and continued with the ability to analyze the external impact caused by changes in German structure or the opposite case. We assume that the steady state of each matrix represents the equilibrium state after n periods when there was no structural change. Therefore changes in economic structure represent changes in the equilibrium state. Measures and indicators are then used computed and used as regressors to elements of the such matrix. In this way, we use the stochastic matrixes to identify the indicators able to explain the behavior of the input-output matrix in its steady state. It implies that the analysis of those measures over time might explain the changes occurring in the German economy's energy sectors. In particular, from it, we can also identify the measures that reflect more structural changes caused by the energetic transition. We use as controls the time series of some macroeconomic variables.

This paper is divided into four more sections. The following section promotes a review of the structural change literature in the input-output framework. The third and fourth sections describe the methodology and the data analyzed, respectively. The results are shown in Section 5. Finally, the sixth section presents the conclusions.

2. Studying changes in economic structure using I-O Framework (500 words)

Economic Structural Changes are defined as qualitative changes in an economy that transform the social and production system, the relationships among the agents, and the results of the whole system (such as income and wage levels and distribution of profits and income). They are the main reason for the development process of countries over time. They are usually associated with de emergence and diffusion of new technologies that, at the same time, are generated and cause transformations in economic systems (Dosi et al., 1990; Schumpeter, 1997).

In a more quantitative concept, Krüger (2008) defines structural changes as long-term changes in the composition of the economic aggregates. Those changes occur at a micro-level in a very specific way for each agent. Once aggregated, they can (in fact) be significant in the long term, provocating shifts in the growth rate, in the shares of industries, and in the economy as a whole. For the author, technological development is not the only cause of structural changes, but changes in the demand side have their role in directing the change process. By technological development here, it is understood both productivity growth and the emergence of new products, industries, and markets.

By those definitions, we can observe a causality link between economic growth and structural changes. Because of that, some theoretical approaches try to explain structural changes. Many are concerned with explicating the changes in the share of sectors in an economy (usually in terms of value added or employment) (Alves-Passoni, 2019; Baumol et al., 1985; Buera and Kaboski, 2009). However, with the first contribution of Leontief (1951, 1936), economics gained a new framework to study quantitively the structure of an economy: the Input-Output (I-O) Tables. Those tables seem to be a natural path to explore and understand the structural mechanism behind the economies' structure (Passoni, 2019).

In I-O framework, the structural changes are studied by analyzing the matrix of inter-industrial transactions Z. The most important stream working on structural aspects of I-O matrices is Structural Decomposition Analysis (SDA) (Lahr and Dietzenbacher, 2001; Lantner and Lebert, 2013; Levrero et al., 2013; Miller and Blair, 2009; Rose and Chen, 1996). It tries to make a structural decomposition using the I-O tables of two or more years. From a long-term term perspective, SDA decomposes the changes in tables, breaking the changes into parts associated with certain I-O table components. In other words, the changes in the table are separated into parts related to changes in the Leontief matrix (that is, technological changes), final demand, investment, or any other variable or macroeconomic aggregate. Therefore, SDA deals with the problem of identifying changes in the specific parts of the I-O table that cause changes in the I-O table as a whole over the years. In this approach, the changes in the Leontief matrix can be interpreted as changes in the structure of the table – long-term changes that usually are associated with technological changes.

In this paper, we use another approach: key sector identification. It is based on the use of measures or indicators as a basis to identify which sectors are more important in an economy. Under this idea, there is the hypothesis that those measures are proxies of the economic structure; the more important a sector is, the bigger its dynamic influence on changes in the economic structure. As mentioned before, using such measures is the starting point of our analysis. Nevertheless, we recognize its deficiencies, especially because they are biased by the criteria used in their elaboration (Hewings et al., 1989; Kolokontes et al., 2019; Miller and Blair, 2009; Morillas and Díaz, 2008). Thus, we part from the idea that not all indicators bring information about the economic structure, and those that bring only represent pieces of information about the economic structure. Therefore, our methodology tries to identify which measures are relevant to study the economic structure, where the economic structure is given by the steady-state matrices of the Markov Chain process.

3. Methodology

A Markovian model is applied to the german modified input-output matrices in other to estimate the steady-state vector by an interactive process. The state vector shows the probabilities that the system will reach in each state, where the probabilities in the I-O Markovian model are the share of each economic activity in determining the economic outcomes. In other words, it shows the inherent participation of each sector of an equilibrium economy in the case that no structural changes occur.

The state is defined by the economic sectors. We also consider a state that represents the economy of the rest of the world, the factors of production, and the government. In this way, an aggregation of such columns in I-O table is carried out in order to preserve the effects of those activities in the economic system. After this aggregation, we deal with a non-negative squared matrix whose elements represent the flow of money from one state to another. Dividing by the sum of the columns, we have a Markovian matrix of probabilities, where the elements are similar to the elements of the matrix of technical coefficients. Since we have annual matrices, then we have for each year and transaction matrix T_y with $y \in [1995,..., 2018]$ forming a time-homogeneous Markov Chain. The steady vectors for each y is then defined as $\omega = T\omega$.

We used the steady vector to identify the indicators that can be used to analyze the evolution of economic structure. In addition to the indicators already known in the I-O literature, we also define a complex index as Hidalgo and Hausmann (2009). In this way, four indicators are tested: Indirect Multipliers (Backward and Forward), Eigenvector, Average Propagation Length (Backward and Forward), and Complexity Indicators (Buy and Selling).

The Indirect Multiplier of the output measures the total impact (direct and indirect) of a specific sector (Leontief, 1951, 1936). The eigenvectors and eigenvalues are calculated based on the matrix of technical coefficients is an infinite iterative procedure that measures and weighs sector backward and forward multipliers. It tends to be more sensitive to structural changes, can be used to find clusters of sectors, and gives a more clean measure of the economic linkages. In the literature, the eigenvector measures the welfare impact of sectoral shocks on the economy (Dietzenbacher, 1992; Morrone, 2021). The Average Propagation Length is defined as the average number of steps for changes in one sector that affects another production (Dietzenbacher and Romero, 2015).

The complex index calculates the complexity of each sector's sales and purchase structures, considering the weight of each transaction and the sector's connectivity inside the economy. It is calculated using the Method of Reflection. An adjacent matrix (MAdj) is built based on the matrix of inter-industry transactions considering only the transactions that are significant for a sector. In this sense, we can define a "Dependence-Scale Comparative Advantage" (DSCA) of a sector j to sell to i, that is, the advantage of the sector j sells to i, given the importance of the sector i in the economy (scale) and how important is sector j's products to the sector i (dependence). If $DSCA_{ij} \geq 1$, then $madj_{ij} = 1$ (that transaction is relevant for sector i). If not, the $madj_{ij} = 0$ (that transaction is not relevant for the sector i), where:

$$DSCA_{ij} = \frac{\frac{x_{ij}}{\sum_{j=1}^{n} x_{ij}}}{\frac{\sum_{i=1}^{n} x_{ij}}{\sum_{j=1}^{n}\sum_{i=1}^{n} x_{ij}}}$$

Using the Method of Reflections, that is an iterative process, we can calculate the average diversification of the industries that have a similar selling structure of sector i (CI_{Sel}), and the average diversification of the industries that have a similar buying structure of sector j (CI_{Buy}). Thus, CI_{Buy} represents the complexity of the buying structure of the sector similar to the buying structure of sector i, and CI_{Sel} represents the complexity of the selling structure of the sector similar to the selling structure of sector i.

We stand out the existence of other indicators; many are calculated based on the first original indicators (Kolokontes et al., 2019; Miller and Blair, 2009). Our analysis focuses on this set of exposed indicators above. Although they have different methodologies, they all try to identify key sectors in the economic system described by I-O tables.

A Lasso Model is used to identify which indicators are relevant to study the economic structure. Lasso is a Shrinkage Method that shrinks the coefficient estimates toward zero making a variable selection. Due to it, it is ideal for our problem. The estimations are a modification of the OLS technique with a different loss function (RSS):

$$RSS_{\lambda}^{Lasso} = \sum_{i=1}^{n} (\widehat{u_i})^2 + \lambda \sum_{f=1}^{n} |\beta_f|$$

$$RSS_{\lambda}^{Lasso} = \sum_{i=1}^{n}(y_i - \beta_0 - \sum_{f=1}^{n}\beta_f^2 X_{if}) + \lambda\sum_{f=1}^{n}|\beta_f|$$

Where $\lambda \geq 0$ is a turning parameter that weights how heavy is the penalty or the constraints. The bigger is λ, the closer to zero, the estimated coefficients are. The Lasso technique does not exclude any predictor irrelevant to predict Y, it only turns those coefficients zero. Thus performing a variable selection.

We use as regressors the indicators and control variables, and as dependent variable (X) the steady vector ω ;

$$\omega_{iy+1} = \alpha + \sum_{i=1}^{7}\beta_i indicators_{iy} + \sum_{j=1}^{n}\gamma_i X_{iy} + \varepsilon_{iy}$$

The hypothesis behind this type of identification is that if an indicator is able to predict the behavior of the economic system, then it brings relevant information about economic structure and can be used to analyze structural changes.

4. Data

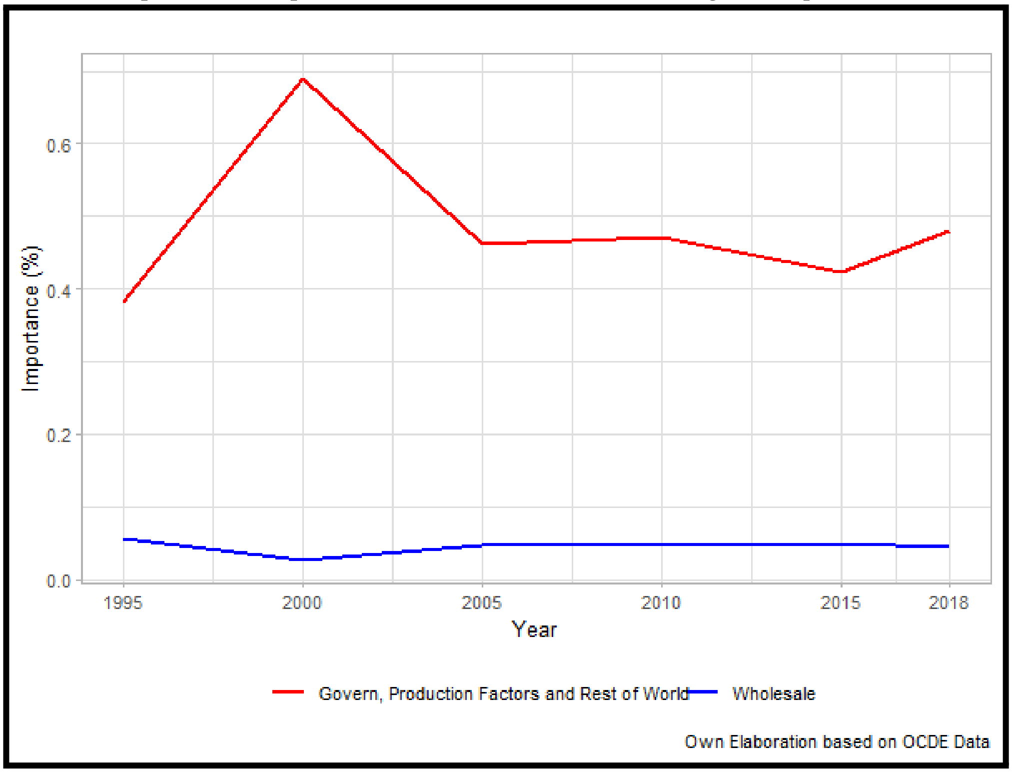
For this work, we use the data available by OCDE. The tables are available for Germany, between 1995 and 2018. We consider 45 sectors. The data unit is a million dollars. In this table, we have the description of matrix Z and the information about each sector's output, importation, exportation, added value, gross capital formation, government expenditures, household expenditures, and taxes. We also used the Research and Development expenditures of the business enterprises by sector for the years 1995 to 2018 in dollars, the number of employees (person, in thousands), Labour Costs in millions of dollars, and Patents by local inventors and sectors. The Patent data are available by IPC code. To find the data by sector, the EPO compatibility table was applied. Further, we also use transition statistics available by International Energy Agency about the German Public Budget to promote the energy transition, in particular, the adoption of renewable energy.

5. Results

Among the economic activities that most impact the results in the steady-state are the activities of Govern, Production Factors, and the Rest of the World (Importation and Exportation), Wholesale. Graphic 1 shows how important was to consider, as a state of our

Markovian model, the activities of Govern, Production Factors, and the Rest of the World. They are the activities that most impact the results in equilibrium, representing almost fifty percent of the expected long-term relative transactions. In second place are the Wholesale activities whose impact in long-term equilibrium is less than ten percent.

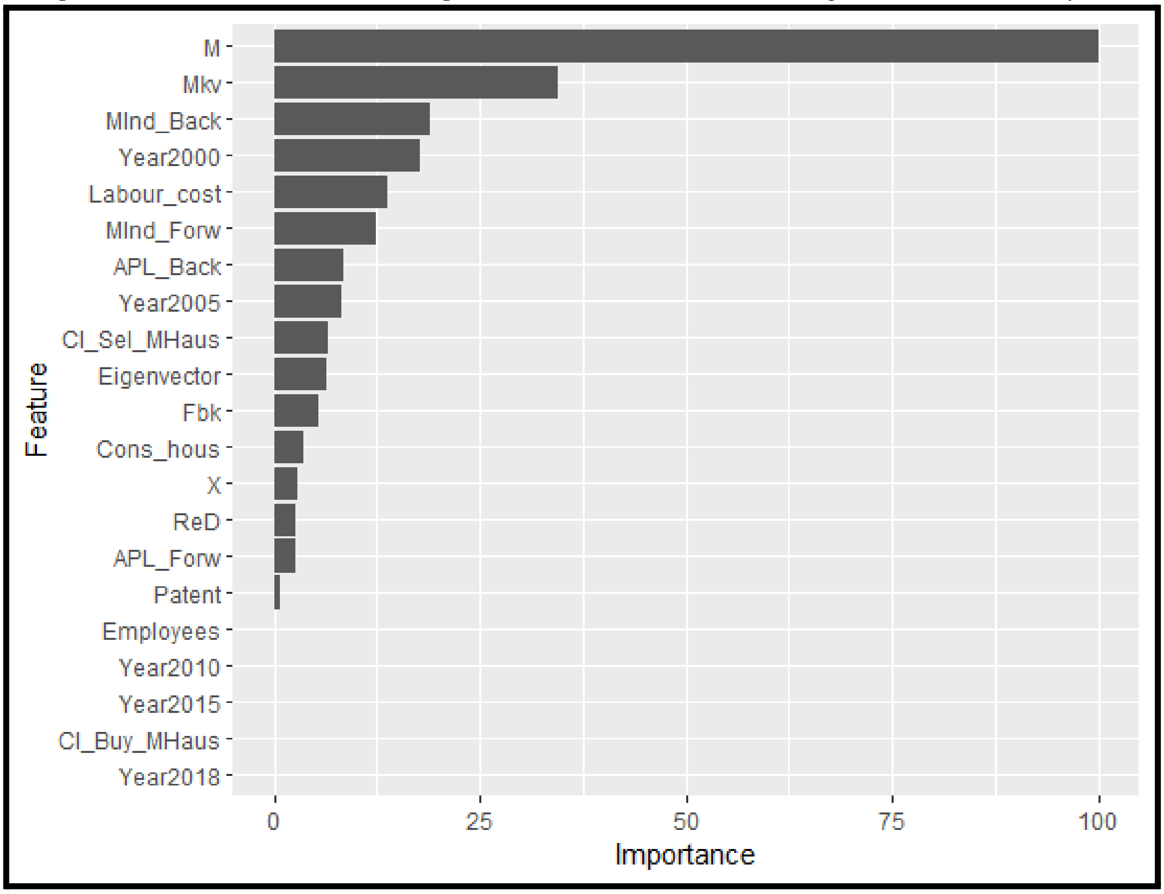
Graphic 1: Participation of economic activities in the long-term equilibrium



The results of the Lasso model are summarised in Graphic 2. As mentioned before, the Lasso model shrinks the coefficient estimates toward zero, then in the graphic below, we see the importance of the variables to predict the Markovian steady-state relative to the size of the values of the coefficients. From the control variable, imports (M), labour cost, year, and the state of equilibrium of the previous period (Mkv) are important in the model. The importance of importation confirms the results of Graphic 1. The big importance of the previous state of equilibrium shows a path-dependence trend, which is common in economies.

Regarding the Indicators, the Indirect Multipliers (Backward and Forward), the Average Propagation Length (Backward and Forward), the Selling Complexity Indicator, and the Eigenvector are relevant to predict the behavior of the economic system.

Graphic 2: Results of Lasso Model - Importance of Variables for Forecasting the Markovian Steady-State



Further, we stress that our model has Root Mean Squared Error in the test data of 0.002 and R- Squared of 0.959, representing a good fitting of the model to the test data.

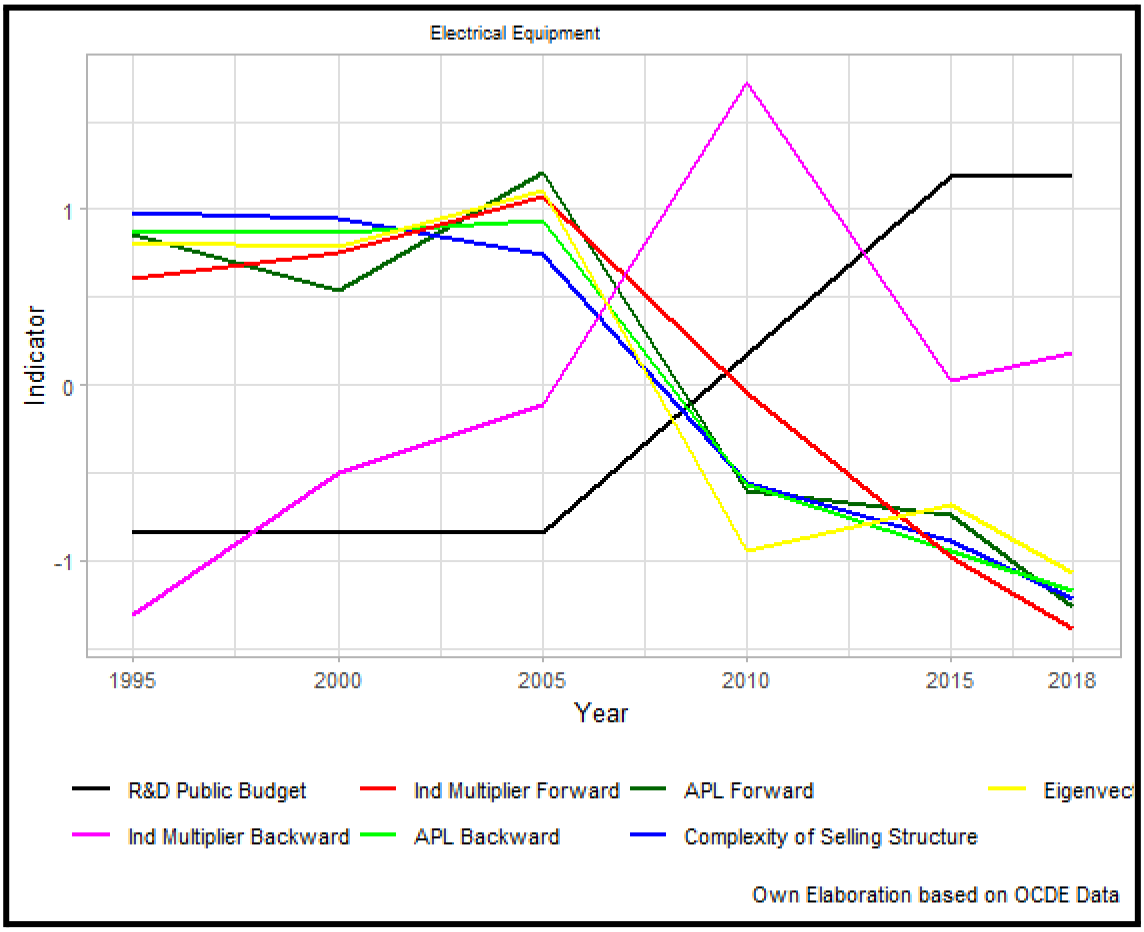
Considering the results above, we can now understand the effects of the green and sustainable transition in the German economy using the selected indicators. We focus our analysis on two sectors directly related to energy transactions: Electrical Equipment and Electricity, Gas, Steam, and Air Conditioning Supply. The sectors' aggregation did not seem relevant in the analysis.

Moreover, to compare the results of the indicators, we also plot in black the German Public Budget to promote the energy transition. This way, we can observe more clearly when such policies began to be implemented.

In 2005, we see a rupture of the Budget trend that started to increase drastically after it. At the same time, we also observe ruptures in the different indicators for both activities (graphic 3 e graphic 4). The increase in the complexity of the selling structure of the sectors also means a lower distance between the sector and the other sectors (Average Propagation

Length). However, it also means lower impacts of the sector on economic activity (Indirect Multipliers and Eigenvector).

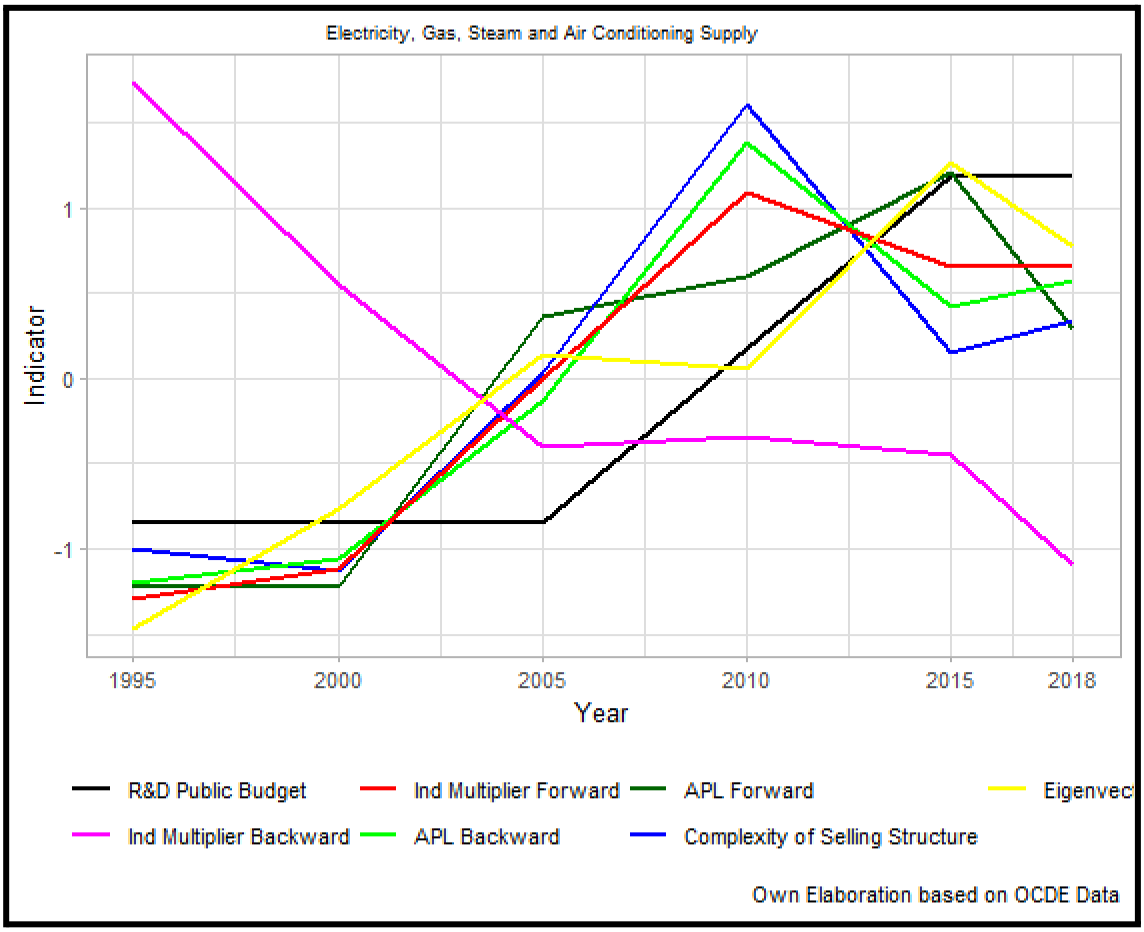
Graphic 3: Results for Electrical Equipment



In the context of the debate between specialization and diversification, we observe that energy transition policies that promote diversification (increasing complexity) have a cost in terms of the impact of that sector on economic activity. In this scenario, the sectorial policy also loses its intensity, needing to be more systemic in order to be able to leverage the economy as a whole.

For Electrical Equipment, as the Budget increased, the complexity of the selling structure of the sector also increased, while for the rest of the indicators, the trend is negative. For Electricity, Gas, Steam, and Air Conditioning Supply, the effects are the opposite. That means while Electrical Equipment, increase its complexity of selling and its integration with other sectors, the Electricity, Gas, Steam, and Air Conditioning Supply decrease its integration in the economic system. Since the German green and sustainable transition is marked by the increase in residential generation and by the electrification process, the results are corroborated: we observe an expansion of the activities of the sector directly linked with the electrification process, and a decrease in the activities of the sector directly linked with the end-customer decisions (Schmidt and Sewerin, 2017).

Graphic 4: Results for Electricity, Gas, Steam, and Air Conditioning Supply



6. Conclusions

Studying the effects of the green and sustainable transition on the economic structure using the Input-Output framework is a challenge. To do that, in the first place, we need ways to quantify structural change. The use of Machine Learning can be used to deal with the problems that are inherent to the data. There is a set of measures capable of providing insights into the economic structure. Each measure carries a piece of information about the economic structure. When put together, these pieces of information show that the German transition is associated with changes in its structure: while some sectors linked to the development of new technologies are increasing their complexity, others are becoming simpler (case of the electricity services). Connections have been emerging and falling apart. This also ends up impacting the importance of sectors in terms of their economic impact.

7. References

Alves-Passoni, P., 2019. DEINDUSTRIALIZATION AND REGRESSIVE SPECIALIZATION IN THE BRAZILIAN ECONOMY BETWEEN 2000 AND 2014: A CRITICAL ASSESSMENT BASED ON THE INPUT-OUTPUT ANALYSIS (PhD Thesis). https://doi.org/10.13140/RG.2.2.19286.06725

Baumol, W., Blackman, A., Wolff, E., 1985. Unbalanced Growth Revisited: Asymptotic Stagnancy and New Evidence. Am. Econ. Rev. 75.

Buera, F., Kaboski, J., 2009. Can Traditional Theories of Structural Change Fit The Data? J. Eur. Econ. Assoc. 7.

Bullard, C., SebaldSource:, A., 1977. Effects of Parametric Uncertainty and Technological Change on Input-Output Models. Rev. Econ. Stat. 59.

Denholm, P., Jorgenson, J., Hummon, M., Jenkin, T., Palchak, D., 2010. The Role of Energy Storage with Renewable Electricity Generation. NREL.

Dietzenbacher, E., 1992. The measurement of interindustry linkages: Key sectors in the Netherlands. Econ. Model. 9.

Dietzenbacher, E., Romero, I., 2015. Using Average Propagation Lengths to Identify Production Chains in the Andalusian Economy. Estud. Econ. Apl. 23, 23–48.

Dosi, G., Pavitt, K., Soete, L., 1990. The economic of technical change and international trade. Wheatsheaf Press, Harvester.

Hewings, G., Fonseca, M., Guilhoto, J., Sonis, M., 1989. Key sectors and structural change in the Brazilian economy: A comparison of alternative approaches and their policy implications. J. Policiy Model. 11.

IRENA (International Renewable Energy Agency), 2017. Adapting Market Design To High Shares Of Variable Renewable Energy.

Kolokontes, A., Kontogeorgos, A., Loizou, E., Chatzitheodoridis, F., 2019. Input-Output Models and Derived Indicators: A Critical Review. Sci. Ann. Econ. Bus. 66, 267–308. https://doi.org/10.2478/saeb-2019-0026

Kostoska, O., Stojkoski, V., Kocarev, L., 2020. On the Structure of the World Economy: An Absorbing Markov Chain Approach. Entropy 22.

Krüger, J., 2008. Productivity And Structural Change: A Review Of The Literature. J. Econ. Surv. 22.

Lahr, M., Dietzenbacher, E., 2001. Input-Output Analysis: Frontiers and Extensions. Palgrave, London.

Lantner, R., Lebert, D., 2013. Dominance, dependence and interdependence in linear structures. A theoretical model and an application to the international trade flows. Doc. Trav. Cent. D'Economie Sorbonne 43.

Leontief, W., 1951. Input-output Economics. Sci. Am. 185.

Leontief, W., 1936. Quantitative Input and Output Relations in the Economic Systems of the United States. Rev. Econ. Stat. 18.

Levrero, E., Palumbo, A., Stirati, A., 2013. Sraffa and the Reconstruction of Economic Theory: Volume Two (Aggregate Demand, Policy Analysis and Growth). Palgrave Macmillan, London.

Linden, J., Dietzenbacher, E., 2000. The determinants of structural change in the European Union: a new application of RAS. Environ. Plan. 32.

Miller, R., Blair, R., 2009. Input–Output Analysis Foundations and Extensions, 2nd ed. Cambridge University Press.

Moosavi, V., Isacchini, G., 2017. A Markovian model of evolving world input-output network. PLOS ONE 12, 1–18. https://doi.org/10.1371/journal.pone.0186746

Morillas, A., Díaz, B., 2008. Key Sectors, Industrial Clustering and Multivariate Outliers. Econ. Syst. Res. 20, 57–73.

Morrone, H., 2021. Qualitative Input-Output Analysis of the Brazilian Structural Transformation, 2005 - 2014. Rev Econ Contemp 25.

Passoni, P., 2019. Deindustrialization and regressive specialization in the brazilian economy between 2000 and 2014: a critical assessment based on the input-output analysis (Thesis). Universidade Federal do Rio de Janeiro, Rio de Janeiro.

Riane, N., David, C., 2022. Input-Output Analysis: New Results From Markov Chain Theory. Économie Appliquée 1.

Rose, A., Chen, C., 1996. Input–output structural decomposition analysis: a critical appraisal. Econ. Syst. Res. 8.

Schmidt, T.S., Sewerin, S., 2017. Technology as a driver of climate and energy politics. Nat. Energy 2, 17084.

https://doi.org/10.1038/nenergy.2017.84
Schumpeter, S., 1997. Teoria do desenvolvimento econômico: Uma investigação sobre lucros, capital, crédito, juro e o ciclo econômico. Nova Cultural.
Sonis, M., Hewings, J., GUO, J., 2000. A New Image of Classical Key Sector Analysis: Minimum Information Decomposition of the Leontief Inverse. Econ. Syst. Res. 12, 401-423,.
Thakur, S., 2008. Identification of Temporal Fundamental Economic Struc-ture (FES) of India: An Input-Output and Cross-Entropy AnalysisEntropy Analysis. Struc-Tural Change Econ. Dyn. 19.