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Optimal Productive Structure for Sustainable Development: Environmental Extended Input-Output Analysis

MARKAKI M.[1*] and PAPADAKIS S.[1]

[1]Department of Management Science and Technology, Laboratory of Data Science, Multimedia and Modelling, Hellenic Mediterranean University, 72100 Agios Nikolaos, Crete, Greece.
*corresponding author:
e-mail:mmarkaki@hmu.gr

Abstract

The research aims to apply an integrated methodology for optimizing the productive structure of an economy with a view to sustainable development for the Greek economy. The main purpose of the research project is to constitute at the theoretical and applied level a model of synthesis of all economic, environmental, and social designs to optimize the results they create. The analytical approach at the sectoral level and the implementation of input-output analysis ensure effective planning to achieve an adequate level of development and effective response to modern environmental challenges. The objective of the restricted optimization model is to maximize the economy's growth rate (economic pillar) under air emissions restrictions (environment pillar). The impact of the optimal structure on the workers' skills and the demand for different occupations (pillar society) will be used to assess the results. The optimization model will be resolved using Evolutionary Optimization Algorithms, which are suitable for multimodal, non-curved, intensely nonlinear, with also nonlinear rather than convex limitations problems.

Keywords: Sustainable Development, Input-Output Analysis, Optimization, Economic Structure, Greece

1. Introduction

Understanding the nexus between the three pillars of sustainability, i.e. economic systems, environmental pressure and social conditions, is at the core for successful sustainable policy-making. The majority of the relevant academic research focuses on how energy-saving and emission reduction technologies improve the quality of the environment. In this line of research, the mixture of production is considered an exogenous variable is failing to capture the importance of the industrial structure to environmental risk. Nevertheless, the determination of the optimal balance between energy consumption, pollution, and economic development requires examining not only the green technology innovations but the economic system's structure. In this research, the causality between the sectoral structure of an economy and the air emissions from the production activities is investigated by employing Input-Output analysis.

A restricted optimization model for the Greek economy's case is built for estimating the optimal productive structure under environmental restrictions. Furthermore, the impact of optimal productive structure on the demand for different occupations and skill level is estimated and used to evaluate the social impact of economic restructuring. Thus, the proposed methodology brings together the three pillars of sustainability (social, economic and environmental) through the mathematical modelling of their nexus and determining the necessary trade-off to achieve the maximum level of economic growth.

2. Methodological Framework

The nexus between socioeconomic and environmental macroeconomic data is determined through the environmentally extended input-output analysis (EEIOA). This powerful and robust methodology combines an input-output table with the energy consumption and pollution at a sectoral level. EEIOA is used to identify the environmental impact (direct and indirect) of different final demand patterns and emerge as an important tool of economic restructuring policy-making (Belegri–Roboli et al., 2011; Kitzes, 2013; Markaki et al., 2017, 2013). Furthermore, EEIOA is the only macroeconomic methodology that can link the productive structure of an economic system with its implications to the environment. Thus, EEIOA provides the methodological background for the determination of the optimal productive structure for the achievement of sustainable development. This approach to sustainable development is adopted in the later years by a small but growing amount of literature (De Carvalho et al., 2015; Hristu-Varsakelis et al., 2012; Mi et al., 2015; Papadakis and Markaki, 2019; San Cristóbal, 2010; Zhu and Shan, 2020). All the aforementioned quantitative studies conclude that the difference between the current and the optimal structure is of exceptional importance; thus, industrial policy measures targeting the optimization of an economic systems' structure is a critical tool towards sustainable development.

In this research, the optimization problem aims to minimize the trade balance deficit and the CO_2 emissions intensity of the Greek economy for a specific GDP growth rate for the period 2020-2027. The decision variables of the optimization are i) the value-added structure and ii) the distribution coefficients of the input-output table; thus, in the proposed methodology, sustainable development aim not only to the reallocation of production but also to the strengthness of sectoral linkages, leading to an increased multiplying effect of the economic system. The proposed methodology is based on Markaki and Papadakis (2021) and the objective function $min\frac{CO_2\ emissions}{GDP}$ is added to the model to describe the minimization of the CO2 emissions intensity of the economy. The main peculiarity of the proposed optimization model for the Greek economy is the use of both the value-added structure and the structure of sectoral intermediate linkages as the decision variables. It should be noted that sustainable development that improves the interdependencies of the economic system can be linked with import substitution policies and Global Value Chains upgrading policies (for a similar approach to productive transformation, see Papadakis & Markaki, 2019). The optimized structure of the Greek economy is further evaluated by using additional criteria: The percentage change of the Greenhouse Gas (GHG) emissions intensity and the energy consumption intensity, the percentage change of the backward linkages and the occupations and skills that are more affected.

In the recent literature on economic modelling, bio/nature-inspired algorithms are used to solve optimization problems that cannot be approached by linear programming or goal programming. Determining the optimal productive structure using input-output analysis is an important problem in such economic models. The bio/nature-inspired algorithms that are usually applied are: particle swarm optimization (Yu et al., 2016; Papadakis and Markaki, 2019), fuzzy multi-objective algorithm (Tian et. al., 2017), non-dominated sorting genetic algorithm II (Zhu & Sha, 2020). Bio/nature-inspired algorithms are stochastic algorithms capable of dealing with real-world problems, which are usually multimodal. In this research, a particle swarm algorithm is applied since i) it has a relatively easy configuration and ii) the tuning of the balance between exploration-exploitation capacity, which is a crucial concept in optimization, is quite comprehensive.

The proposed methodology is grounded on input-output analysis; thus, the solution of the optimization problem is based on the most recent available data for Greece for the year 2015. CO2 and Greenhouse Gas (GHG) emission data (in CO2 equivalent) come from Eurostat's Air Emissions Accounts (Eurostat Database, 2020). Data on occupation per sector of economic activity derive from the Labour Force Survey for Greece, and the intensity of task per occupation are based on Eurofound (2016). Finally, the macroeconomic projection of the GDP growth and the sectoral growth of the Greek economy for the year 2027 derived from Oxford Economics (2020).

3. Results and discussion

The Greek economy has a weak productive structure, characterized by a small and shrinking industrial sectors, an extent primary sector and a large tertiary sector. It shows relatively low economic linkages and a low level of technological development. As a result, it exhibits a high share of non-tradable goods production and a relatively low international competitiveness (Economakis and Markaki, 2014; Markaki and Economakis, 2020; Papadakis and Markaki, 2019). Furthermore, although the use of natural gas in power plants and the increased capacity of renewable energy resources decreased the CO2 emission intensity of electricity generation and improved the country's carbon footprint (Markaki et al., 2017), Greece could benefit from the development of proper policy measures towards sustainability.

Table 1 summarizes the comparison between the current and the optimal structure of value-added for the Greek economy. The main finding of Table 1 is that the participation of secondary sectors is significantly increased and that the technological structure of manufacturing sectors exhibits improvement.

Table 1. Comparison of the current value-added structure (2019) and the optimal value-added structure for 2027.

	2019	**2027**
Primary Sectors (A)	4.36%	4.52%
Secondary Sectors (B, C, D, E, F)	14.86%	18.16%
Tertiary Sectors (G-T)	80.78%	77.32%
Manufacturing (C)	9.85%	10.86%
High-Tech Sectors	0.97%	1.26%
Medium-High Tech Sectors	1.32%	1.94%
Medium-Low Tech Sectors	3.53%	3,40%
Low Tech Sectors	4.04%	4.29%

Note: The technological level of the manufacturing sectors (NACE Rev. 2) follows the Eurostat's taxonomy(Eurostat, 2014): high-technology (C22, C26), medium-high-technology (20, 27-30), medium-low-technology (19, 22-5) and low-technology (10-18, 31, 32).

The in-depth analysis of the optimal structure would reveal that the main manufacturing sectors participating in the restructuring process are: C10-C12 (Food, beverages and tobacco products), C20 (Chemicals and chemical products), C21 (Basic pharmaceutical products and pharmaceutical preparations), C24 (Other non-metallic mineral products) and C25 (Fabricated metal products, except machinery and equipment). These sectors, in the optimal structure, produce more than 65% of the manufacturing value-added It should be noted that sector C19 (Coke and refined petroleum products), one of the five larger sectors in 2019, shows a decreased participation in the optimal structure deteriorates its importance.

Table 2 depicts the improvement of selected indices due to the economic restructuring of the Greek economy. These indices are: the CO_2 emissions intensity, the GHG emissions intensity and the energy consumption intensity. The optimal structure of the Greek economy can lead to a 4.09% reduction of the CO_2 intensity. The decline is even higher in secondary sectors, where it reaches out 6.54% and lower in primary sectors. Furthermore, the GHG emissions intensity is also decreased by 2.24% for the whole economy and by 4.79% in secondary sectors. The energy consumption intensity is reduced by 4.39% for the entire economy and by 7.06% in secondary sectors.

Table 2. Percentage change of environmental indices between the current (2019) and the optimal (2021) economic structure.

	% change in CO2 emissions intensity	% change in GHG emissions intensity	% change in energy consumption intensity
Primary Sectors (A)	-0,58%	-0,37%	-0,51%
Secondary Sectors (B, C, D, F)	-6,54%	-4,79%	-7,06%
Tertiary Sectors (G-T)	-1,36%	-1,05%	-1,90%
Manufacturing (C)	-2,04%	-0,97%	-5,52%
High-Tech Sectors	-1,14%	-0,71%	-0,83%
Medium-High Tech Sectors	-2,76%	-2,76%	-1,38%
Medium-Low Tech Sectors	-2,43%	-2,26%	-4,61%
Low Tech Sectors	-0,07%	-0,15%	-0,12%
Total Economy	-4,09%	-2,24%	-4,39%

As Figure 2 indicates, the optimization process could significantly improve the backward linkages of the greek economy in all sectors of economic activity. The most significant increase of backward linkages (more than 15%) is located in the following sectors: C22 (Rubber and plastic products), C13-C15 (Textiles, wearing apparel, leather and related products), C17 (Paper and paper products) and C26 (Computer, electronic and optical products). Following, sectors C24 (Printing and recording services), C25 (Fabricated metal products, except machinery and equipment), C27 (Electrical equipment), and C28 (Machinery and equipment n.e.c) show an increase in backward linkages between 10% and 15%. The percentage change is positive, but lower than 10% in the rest of the sectors.

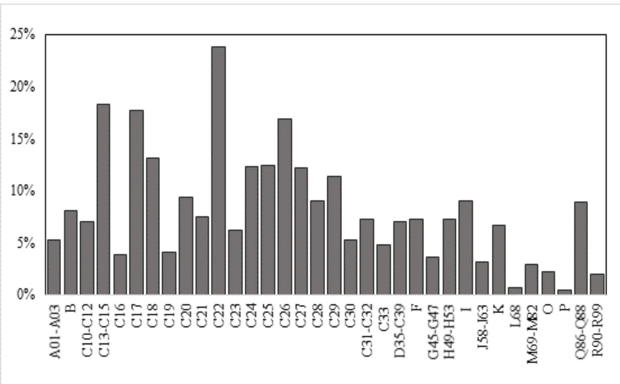

Figure 1. Percentage change of backward linkages, 2015-2027

The reduction of the examined indices and the strength of the backward linkages results from both the reallocation of production within sectors and the import distribution in intermediate demand. On the one hand, the reallocation of production diversifies the economic system's internal structure, as the distribution of intermediate demand (and supply) within the sectors also changes. As a result of the optimization process, the expansion of activities that cause lower pressure to the environment is selected; thus the arising environmental indices are lower. On the one hand, import substitution develops a more robust network of linkages, as domestic sectors satisfy a much larger part of the intermediate demand for products and services. Therefore, the effect of structural transformation is diffused throughout the economy, improving the interconnectedness of the whole system.

Moreover, the restructuring process will also alter the labour demand. Table 3 lists the occupations with the higher demand increase, accord to the ISCO08 classification. The occupations with the higher effect are linked with the increased participation of manufacturing sectors at the optimal economic structure. A large share of these occupations is connected, according to Eurofound (2016), with the operation of ICT (Information and Communication Technologies) and non-ICT mechanical machinery and tools.

Table 3. Occupation with the higher demand increase

25	Information and Communications Technology Professionals
31	Science and Engineering Associate Professionals
33	Business and Administration Associate Professionals
35	Information and Communications Technicians
61	Market-oriented Skilled Agricultural Workers
71	Building and Related Trades Workers (excluding Electricians)
72	Metal, Machinery and Related Trades Workers
74	Electrical and Electronic Trades Workers
81	Stationary Plant and Machine Operators
82	Assemblers
83	Drivers and Mobile Plant Operators
83	Drivers and Mobile Plant Operators
91	Cleaners and Helpers
92	Agricultural, Forestry and Fishery Labourers
93	Labourers in Mining, Construction, Manufacturing and Transport
94	Food Preparation Assistants

4. Conclusions

The findings of this research show that the structural transformation of the Greek economy could lead to an important level of GDP growth while reducing the environmental pressure of economic activities and alter the labour market toward more skilled employment.

The optimal structure of the Greek economy is characterized by an upgraded role of manufacturing, which plays a more critical role in the economic development in connection to the rest of the sectors. Furthermore, the distinction between technologically advanced and non-technologically advanced sectors is critical to sustainable development, given that the promotion of technologically advanced sectors can reduce CO2 emissions. Furthermore, the significant increase in the backward linkages and the economic leakages highlight the importance of improving the interdependencies of the economy as a base for a restructuring plan.

The importance of both macroeconomic and sectoral-specific policy interventions for the achievement of sustainable development is necessary for economic restructuring. Therefore, a mix of different policy measures is required to reach the optimal economic structure targets.

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