Heterodox macroeconomic model for the Greek economy.

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Με τη χρηματοδότηση
της Ευρωπαϊκής Ένωσης
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Contents

Interindustry Linkages and Input-Output Analysis: Historical Perspectives and Empirical Insights on the Greek Economy

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INTRODUCTION

The development of input-output (IO) analysis represents a significant milestone in the evolution of economic thought and empirical research. The study is structured to first provide a historical overview of IO analysis, tracing its conceptual foundations and theoretical advancements, before proceeding to an empirical investigation of its applications in the Greek economy. By integrating theoretical insights with empirical assessment, the study aims to highlight the relevance of IO analysis in understanding structural economic dynamics and informing policy decisions.

The first part starts with origins of IO analysis can be found in early economic theories that sought to explain intersectoral linkages and economic surplus. William Petty and Richard Cantillon were among the first to introduce systematic approaches to understanding economic dependencies, laying the groundwork for François Quesnay's *Tableau Économique*. This early attempt at modeling economic circulation was further expanded by classical economists such as Adam Smith, David Ricardo, and Robert Torrens, who emphasized the role of production and distribution in shaping economic structures. Karl Marx made a critical contribution by formalizing economic reproduction and capital accumulation, distinguishing between simple and extended reproduction schemes—an approach that foreshadowed modern IO models.

During the late 19th and early 20th centuries, economists such as Vladimir K. Dmitriev, Ladislaus von Bortkiewicz, and Georg von Charasoff introduced mathematical rigor into classical value and distribution theories, while Maurice Potron pioneered matrix-based analytical methods that prefigured the modern IO framework. The discipline reached its full empirical maturity with the work of Wassily Leontief, who developed IO tables as a systematic tool for analyzing interindustry relationships, facilitating economic planning and policy assessment. Though Leontief's approach shared some similarities with Walrasian general equilibrium theory, it remained firmly grounded in empirical applications. Piero Sraffa's contributions offered an alternative perspective based on the surplus approach to price and income distribution, further enriching the theoretical landscape of IO analysis.

Leontief's empirical innovations transformed IO analysis into a practical tool for assessing economic structures, sectoral interdependencies, and the propagation of economic shocks. His method provided a quantitative framework for identifying key industries, optimizing resource allocation, and formulating policy interventions. The subsequent development of IO models incorporated refinements such as the introduction of IO systems, supply-driven approaches, and environmental input-output analysis, which expanded the applicability of the methodology beyond traditional economic planning to areas such as sustainability, energy policy, and technological development.

The second part of the study moves from historical and theoretical developments to empirical application, focusing on the structural dynamics of the Greek economy. By employing IO models, the study examines sectoral interdependencies and evaluates economic policy implications. This empirical investigation provides insights into the structural composition of the Greek economy, identifying key industries that sustain economic activity and those that exhibit weak integration into broader production networks. The analysis also explores the role of economic shocks and policy interventions in influencing sectoral dynamics. The study employs traditional IO techniques alongside the Hypothetical Extraction Method (HEM), a counterfactual approach that isolates the role of specific industries by simulating their removal from the economy. This method allows for a more nuanced understanding of sectoral importance, capturing non-linear effects that traditional models often overlook. The interpretation of our results is placed within the broader economic context, considering structural characteristics, historical trends, and policy implications.

1 THE EVOLUTION OF INPUT-OUTPUT ANALYSIS

1.1 Introduction

The study of economic interdependencies has long been a fundamental concern of political economy. From early qualitative insights into production and distribution to the formal mathematical representation of interindustry relationships, the evolution of input-output analysis reflects a continuous refinement of how economists conceptualize economic structure. At its core, input-output analysis provides a framework for understanding the complex web of transactions that sustain economic activity, capturing the interdependencies between industries, sectors, and factors of production. While the modern formulation of input-output analysis is most closely associated with Wassily Leontief, its intellectual foundations extend deep into economic history. The classical political economists—beginning with William Petty and Richard Cantillon—were among the first to systematically analyze economic surplus, intersectoral linkages, and the fundamental drivers of production. Their work influenced François Quesnay and the Physiocrats, who developed the Tableau Économique as a pioneering, though limited, model of economic circulation.

The classical tradition, particularly in the writings of Adam Smith, David Ricardo, and Robert Torrens, further developed the understanding of sectoral interactions, surplus allocation, and income distribution. Karl Marx expanded these ideas with his reproduction schemes, which analyzed how capitalist economies sustain and expand themselves through intersectoral flows of capital and consumer goods. The transition from qualitative reasoning to mathematical formalization was advanced by theorists such as Vladimir K. Dmitriev, Ladislaus von Bortkiewicz, and Georg von Charasoff, who introduced rigorous methods for analyzing value, prices, and distribution in interconnected production systems. Maurice Potron's early use of matrix-based economic models prefigured later developments, but it was Leontief who ultimately transformed input-output analysis into an empirical tool for economic planning and policy.

This part explores the historical evolution of input-output analysis, tracing its development from the foundational contributions of Petty and Cantillon to the classical economists and Marxist reproduction models, before culminating in its mathematical and empirical formalization as a tool for analyzing interindustry relationships. By reviewing these key contributions, the chapter underscores the enduring significance of input-output analysis in economic theory and policy, emphasizing its crucial role in understanding production dynamics, economic growth, and structural change.

1.2 The Procreation: Petty and Cantillon

The contributions of William Petty and Richard Cantillon to classical Political Economy are fundamental, particularly in relation to their methodological approaches and conceptual foundations. Their work laid the groundwork for later economic analysis, influencing the development of input-output systems, the notion of productive interdependence, and the conceptualization of social surplus. Petty, often regarded as one of the founders of classical Political Economy, introduced key economic principles that would later form the basis of systematic economic analysis. His famous dictum—'Labour is the Father and active principle of Wealth, as Lands are the Mother' (Petty, [1662] 1986, p. 68)—encapsulates his belief in the centrality of labor and land in wealth creation. Marx, among others, recognized Petty's significance, acknowledging him as a pioneer of classical economic thought (Marx, [1867] 1954, p. 85, fn. 2).

Petty's seminal work, "Treatise of Taxes and Contributions" (1662), was the first to present a clear concept of social surplus. He quantified agricultural surplus by subtracting necessary inputs from outputs, identifying rent as the remaining surplus (Petty, [1662] 1986, p. 43). Petty further conceptualized surplus in demographic terms, explaining that it represented the additional population that could be sustained by a given level of labor productivity. He distinguished between 'natural value,' determined by production costs, and 'accidental value,' influenced by temporary factors (ibid., pp. 51 and 90). His insights into rent, particularly the idea of differential rent based on land proximity, anticipated later economic theories on land use and cost structures (ibid., p. 48).

Cantillon, building on Petty's insights, introduced a more refined understanding of value and price formation. In his "Essai sur la nature du commerce en général" (1755), he differentiated between market price and intrinsic value, the latter being determined by the land and labor required for production. He wrote that intrinsic value "is the measure of the quantity of Land and of Labour entering into its production, having regard to the fertility or produce of the Land and to the quality of Labour" (Cantillon, [1755] 1931, p. 29; similarly p. 107). He recognized that market prices fluctuate due to imbalances in supply and demand but tend to gravitate towards intrinsic values over time (ibid., p. 31). This notion foreshadowed Adam Smith's later work on market dynamics.

A crucial element of Cantillon's analysis was his tripartite division of economic agents: proprietors of land, farmers and entrepreneurs, and laborers. He argued that all social classes ultimately subsist on agricultural production, implying that surplus value originates primarily in agriculture. However, he also acknowledged that manufacturing could generate surplus through profits (see, for example, ibid., p. 203), suggesting an early awareness of sectoral economic dynamics.

Petty and Cantillon's contributions extend beyond value theory and surplus distribution. Petty's methodological innovations, particularly his use of statistical data and empirical analysis, mark an early attempt at economic quantification. His pioneering work in national accounting and demographic studies paved the way for later economic modeling. Cantillon's insights into entrepreneurial behavior, risk, and capital allocation provided a foundation for modern theories of market equilibrium and business cycles. Although Petty was aligned with Mercantilist thought, advocating for state intervention to enhance national wealth, his analytical approach differed from mainstream Mercantilism. Unlike his contemporaries, who focused on trade balances and bullion accumulation, Petty examined the structural interdependencies within the economy. His recognition of productive linkages anticipated the input-output framework formalized centuries later. Cantillon, diverging from Mercantilist doctrine, emphasized the role of land and agriculture over trade in wealth creation, thereby bridging Mercantilism and Physiocracy.

The early conceptualizations of economic interdependence by Petty and Cantillon highlight their lasting impact. Their work embodies a transition from qualitative economic reasoning to systematic, quantitative analysis. The notions of production as a circular flow, intersectoral linkages, and economic surplus remain central to economic theory, underscoring the enduring relevance of their contributions.

1.3 Quesnay's *Tableau Économique* and the Physiocratic Theory of Surplus

The belief that only agriculture can generate a surplus, or *produit net*, was most clearly articulated by François Quesnay (1694–1774) and the Physiocrats (see e.g. Eltis,1975; INED, 1958). This principle was central to their economic thought and provided the foundation for Quesnay's broader economic analysis, particularly as embodied in his seminal work, the *Tableau Économique*. The *Tableau* sought to explain the mechanisms of production, income distribution, and economic circulation in 18th-century France, portraying the economy as a self-reproducing system in which surplus generation was uniquely tied to agricultural production.

Quesnay's *Tableau*, first published in 1758, was among the earliest systematic representations of an economy's functioning. It was designed to illustrate how production, distribution, and expenditure operated as an interdependent process, with the circulation of commodities and money forming an integral part of economic reproduction. A key objective of this analysis was to uncover the sources of national revenue and identify factors influencing its magnitude, which could then inform economic policies aimed at fostering national prosperity. This emphasis on economic reproduction and policy implications distinguished the *Tableau* as one of the most ambitious economic models of its time. At the heart of Quesnay's framework was the classification of society into three economic classes based on their role in the reproduction process (Quesnay, 1759):

1. The Productive Class (*Classe Productive*) – Comprising primarily those engaged in primary production, particularly agriculture, this class was considered the sole generator of surplus. Agricultural workers were deemed "productive" because the value of their output exceeded the costs incurred in production, including the sustenance of laborers and the replacement of consumed inputs. The surplus

produced by this sector was extracted as rent and distributed to landowners, forming the foundation of national wealth.

2. The Sterile Class (*Classe Stérile*) – This category included those engaged in manufacturing and commerce. The Physiocrats argued that the output of this sector merely covered production costs, including the wages of artisans, merchants, and industrial workers, without generating a surplus. In this view, manufacturing and trade merely transformed existing wealth rather than creating new value, making them "sterile" in terms of net economic contribution.
3. The Proprietor Class (*Classe Propriétaire*) – This group consisted of landowners and those holding natural resources, who did not directly engage in production but benefited from the surplus generated by the agricultural sector. Rent received by this class was spent on both agricultural and manufactured goods, ensuring the continued circulation of income throughout the economy.

The *Tableau* employed a two-sector model, highlighting the interdependencies between agriculture and industry. Although the Physiocrats maintained that only agriculture created surplus, they recognized that neither sector could function in isolation. The model accounted for both intrasectoral (within-sector) and intersectoral (between-sector) flows of goods and money (Quesnay, 1759):

- Agriculture supplied raw materials and subsistence goods (such as food) to the industrial sector.
- Industry provided agriculture with tools, manufactured goods, and other necessary inputs for production.

This interconnected system could be represented mathematically as an indecomposable input-output matrix, where each sector's production contributed to the reproduction of the other. The Physiocrats' depiction of an economy characterized by interdependent sectors was a precursor to later input-output analysis, most notably the work of Wassily Leontief in the 20th century. The *Tableau* also incorporated a detailed analysis of capital, distinguishing among different forms (Quesnay, 1759):

- Avances annuelles – Circulating capital, including raw materials and sustenance for workers, which was used up in the production process and had to be replenished annually.
- Avances primitives – Fixed capital, encompassing tools, buildings, machinery, and livestock, which contributed to production over multiple cycles.
- Avances foncières – Capital embedded in land, including improvements such as irrigation systems, soil enhancement, and infrastructure, which increased agricultural productivity over the long term.

By differentiating capital in this manner, Quesnay provided a structured approach to understanding investment, depreciation, and the role of capital accumulation, even though the *Tableau* itself did not explicitly model economic growth. However, Quesnay recognized the importance of reinvestment and capital expansion for long-term national prosperity, anticipating later classical and neoclassical economic growth theories.

A fundamental feature of the *Tableau* was its asymmetrical treatment of income shares. Wages were taken as an exogenous variable, determined independently of the economic model, while rent was an endogenous outcome, emerging from the surplus product. This formulation underscored the Physiocrats' belief that the primary determinant of national income was the productivity of agriculture. The Physiocrats conceived of surplus as a product of the sphere of production, realized in the sphere of circulation. They assumed that the process of circulation occurred smoothly, facilitated by a system of relative prices supporting economic reproduction. This required a monetary framework compatible with the stock of money available in the economy and prevailing transactional norms. The smooth functioning of circulation was a key assumption underpinning Quesnay's analysis, although later economists would question its realism, particularly in light of issues such as market frictions, imperfect competition, and financial constraints.

The Physiocrats' assertion that only agriculture generated economic value was highly controversial. By dismissing manufacturing and commerce as "sterile" sectors, they effectively negated the role of industrial and commercial expansion in economic development. In modern terms, this would imply that these sectors contributed no "value added," a position that has been thoroughly discredited by subsequent economic analysis. Despite these shortcomings, the *Tableau Économique* introduced a concept of lasting significance: the circular flow of income and output among economic sectors. This insight laid the groundwork for later economic models, particularly in macroeconomics and input-output analysis. The reception of the *Tableau* was mixed. Some economists, including Marx, regarded it as a groundbreaking achievement. Marx famously described it as "an extremely brilliant conception, incontestably the most brilliant for which political economy has up to then been responsible." Others, such as John Gray (1931), dismissed it as a marginal contribution that should be "reduced to an embarrassed footnote." For much of the 19th and early 20th centuries, the *Tableau* was largely ignored, overshadowed by the rise of classical and neoclassical economics.

A key turning point came in the 20th century, when economists sought mathematical formalizations of economic interdependence. Wassily Leontief's input-output analysis—pioneered in his 1936 paper—explicitly referenced Quesnay, describing his approach as an attempt to construct a *Tableau Économique* for the United States in 1919 and 1929. By applying empirical data to a formalized input-output framework, Leontief provided a quantitative validation of Quesnay's fundamental insight into economic circulation.

1.4 Achille-Nicolas Isnard: A Critic of Physiocracy and a Pioneer of Economic Interdependence

Achille-Nicolas Isnard (1749–1803), a French engineer and economist, was one of the earliest and most insightful critics of the Physiocratic doctrine that only agriculture is productive. While the Physiocrats, led by François Quesnay, argued that agriculture alone generates a net surplus (*produit net*), Isnard pointed out fundamental inconsistencies within their framework. He observed that the *Tableau Économique*, which was meant to demonstrate the Physiocratic model of surplus generation, included both agricultural and manufactured products. This, he argued, contradicted the claim that industry and commerce were inherently "sterile" and did not contribute to the economy's net wealth.

More significantly, Isnard challenged the Physiocrats' treatment of economic surplus as an objective phenomenon independent of market exchange. He contended that whether a sector generates income beyond its costs of production cannot be determined in isolation but depends critically on the exchange ratios between commodities, or relative prices. These prices, he argued, reflect not only the real physical costs of production but also the rules governing the distribution of surplus among different economic agents. By emphasizing the role of relative prices in shaping economic outcomes, Isnard introduced a more dynamic and interdependent perspective on production and distribution, one that foreshadowed later developments in classical and general equilibrium economics. Isnard elaborated his analysis in his 1781 work *Traité des richesses*, a two-volume treatise on economic theory. Volume I, in particular, is of great interest, as it systematically examined the circular nature of production and the concept of surplus, which he termed "disposable wealth" (*richesse disponible*). He distinguished between two fundamental components of wealth:

1. Wealth required for production – This portion consists of the inputs necessary for sustaining economic activity, including raw materials, labor sustenance, and capital goods. It represents the means by which production is maintained and renewed over time.
2. Wealth available for enjoyment – This is the surplus that remains after deducting the costs of production. It is the share of wealth that can be freely disposed of by the propertied classes, either for consumption or accumulation. Isnard described this surplus as "the noble part of goods" because it constitutes the wealth that can be enjoyed or reinvested to expand productive capacity.

While recognizing the importance of surplus for economic expansion, Isnard also stressed that its magnitude is determined by technical conditions of production and natural constraints. This view directly challenged the Physiocratic notion that surplus is an inherent feature of agriculture, independent of broader economic forces.

A central aspect of Isnard's critique was his assertion that the Physiocrats' view of surplus generation was inextricably linked to the system of relative prices they assumed in their model. He argued that the *Tableau Économique* implicitly established a price structure in which the entire *produit net* was appropriated by landowners in the form of rent. However, he pointed out that alternative pricing mechanisms could lead to entirely different distributions of surplus, thereby undermining the Physiocrats' claim that industry and commerce were "sterile." Isnard explained that the values of different products determine the shares of total wealth allocated to various producers. These shares, in turn, change depending on the prices of the goods each producer must acquire for production. This insight introduced a more flexible and realistic view of economic distribution, highlighting how relative prices mediate the realization of surplus within an economy.

He argued that if manufacturers were able to sell their goods at higher prices relative to agricultural products, their sector could generate a surplus similar to that of agriculture. Conversely, if agricultural producers faced unfavorable exchange rates, their surplus could shrink or even disappear altogether. In this light, the Physiocratic assumption that surplus is exclusive to agriculture was not an economic law but merely a consequence of their particular price assumptions. Isnard extended his analysis by examining the division of labor and the interdependence of economic sectors. He described a system in which producers specialize in different commodities, using part of their output as inputs for production while exchanging the surplus with other producers to obtain goods they do not produce themselves. This depiction of economic activity as a circular flow of production and exchange represented a significant departure from the Physiocratic model, which treated agriculture as the primary source of wealth.

By emphasizing the mutual dependence of different economic sectors, Isnard anticipated later theories of economic interdependence, including input-output analysis. He highlighted that each sector contributes to the economy's overall surplus by producing goods that enter into the production and consumption processes of other sectors. This holistic view provided a more comprehensive framework for understanding how economies function as interconnected systems rather than as hierarchies with a single productive sector.

Isnard further demonstrated that the distribution of the economy's surplus cannot be determined solely by physical production but depends on the structure of relative prices. He illustrated this through numerical examples, showing how the allocation of surplus between sectors varies with price ratios. For instance, he examined a simple economy consisting of two sectors—agriculture and industry—where each sector requires inputs from the other. He demonstrated that if the price of manufactured goods were set higher relative to agricultural goods, the industrial sector could generate a surplus, contradicting the Physiocrats' claim that only agriculture was productive. Similarly, he showed that different price ratios could redistribute surplus between sectors, making it clear that economic productivity is not an inherent feature of any single industry but is shaped by the interaction of production and market conditions.

Isnard's work was groundbreaking in several respects. His emphasis on relative prices as the mechanism determining surplus challenged the rigid classification of productive and sterile sectors in Physiocratic thought. His recognition of the circular nature of production and exchange prefigured later developments in economic theory, including the classical and neoclassical approaches to distribution and value. Although Isnard's contributions were largely overlooked in his time, his insights foreshadowed important elements of later economic thought (Isnard, 1781):

- Critique of Physiocracy – By demonstrating that surplus is contingent on price relations rather than the inherent nature of a sector, Isnard undermined the Physiocrats' justification for privileging agriculture over industry.
- Recognition of Economic Interdependence – His model of circular production and exchange anticipated later input-output analysis and the general equilibrium framework.
- Role of Prices in Economic Organization – Isnard's approach to price formation and surplus distribution laid the groundwork for later investigations into how markets allocate resources and income among different sectors.

Isnard ultimately concluded that the Physiocrats' claim that industry was "generally not productive" was a misconception arising from their particular assumptions about prices and distribution. His critique provided an early and sophisticated argument for a more integrated understanding of economic productivity—one that recognized the interdependence of agriculture, industry, and commerce.

1.5 The Circular Flow of Production and Surplus in Classical Economics: From Adam Smith to Robert Torrens

The concepts of production as a circular flow and the surplus product resurfaced in the writings of Adam Smith (1723–1790) and became fundamental to classical economic thought. Smith recognized the interdependence of different economic sectors and their role in national wealth formation. His seminal work, *The Wealth of Nations* (1776), particularly in Book V, Chapter V, outlined how production and distribution operate within an interconnected system, where surplus plays a crucial role in shaping economic progress.

Building on Smith's insights, David Ricardo (1772–1823) further refined the analysis of surplus and economic interdependence in his *Essay on the Influence of a Low Price of Corn on the Profits of Stock* (1815) and *Principles of Political Economy and Taxation* (1817) (see, Ricardo, 1951-73). Ricardo examined how the distribution of income between wages, profits, and rents depends on production conditions, technological progress, and resource constraints. His work provided a systematic account of how the dynamics of land productivity and food supply impact profit rates, capital accumulation, and economic expansion. However, it was Robert Torrens (1780–1864) who explicitly reintroduced these concepts within an input-output framework, shedding new light on the mechanisms governing economic reproduction and growth. In the second edition of his *Essay on the External Corn Trade* (1820), Torrens articulated with great clarity the two central problems of classical political economy:

1. Relative quantities and the rate of growth – How the physical surplus in production determines the potential for economic expansion.
2. Relative prices and the rate of profit – How income distribution among wages, profits, and rents is shaped by production conditions and price relations.

Torrens underscored that the concept of surplus is fundamental to explaining income shares beyond wages and determining the rate of profit. He argued that agricultural profit rates could be measured in physical terms, specifically as the ratio of net corn output to corn input, which included both seed for cultivation and food for workers. He further posited that the relative prices of manufactured goods and agricultural output would adjust to ensure equalized profit rates across sectors. This, he described as a "general principle", acknowledging Ricardo's profound influence in his examination of profit rate determination.

Early classical economists understood that capital in a given sector is heterogeneous, composed of inputs that differ from the sector's final output. Torrens made a crucial departure from earlier assumptions by relaxing the notion that capital within a sector is entirely homogeneous. In his *Essay on the Production of Wealth* (1821), he introduced a two-sector model where both agriculture and industry utilized inputs from both sectors in fixed proportions. This formulation provided a more realistic representation of intersectoral dependencies in production.

Torrens demonstrated that the general rate of profit could be determined without explicit reference to relative prices, provided that surplus output and social capital maintain identical proportions across sectors. He framed profit as the residual that remains after deducting the used-up means of production and the subsistence needs of labor from total output. In this way, he reinforced the idea that surplus, rather than price fluctuations, governs the long-term trajectory of economic growth. Beyond its role in determining profit rates and income distribution, Torrens emphasized the macroeconomic significance of surplus in driving capital accumulation and expansion. He articulated two possible uses for the surplus generated in production:

1. Reinvestment into production – Increasing employment and expanding productive capacity, leading to economic growth.
2. Consumption by the propertied classes – Expenditure on luxury goods, which does not contribute directly to capital formation.

Torrens highlighted that if the entire surplus in each sector were reinvested into production, the economy would expand at a rate equal to the profit rate. This notion of self-sustained growth through reinvestment foreshadowed later formulations of economic expansion, including the Von Neumann growth model. Economist D.G. Champernowne

(1945) later referred to such a state of equi-proportionate growth as a "quasi-stationary state", a precursor to balanced growth models in modern economic theory.

So, the concepts of circular production, surplus, and economic interdependence were continuously refined through the works of Smith, Ricardo, and Torrens. While Smith introduced the basic idea of intersectoral linkages, Ricardo formalized the role of profit and rent distribution in economic expansion. Torrens, however, took a decisive step forward by incorporating an explicit input-output approach, clarifying how surplus determines profit rates and overall growth potential.

1.6 Karl Marx and the Evolution of Reproduction Theory and Value Analysis

Karl Marx (1818–1883) was a profound student of economic history and theory, closely examining the works of the Physiocrats, Adam Smith, and David Ricardo. Among these influences, François Quesnay's *Tableau Économique* played a particularly significant role in shaping Marx's approach to economic reproduction and surplus distribution (Marx, 1956). Marx regarded Quesnay and his followers as "the true fathers of modern political economy" and saw the *Tableau* as a groundbreaking attempt to conceptualize the structure of economic production and distribution in a systematic way. He lamented that English political economists had neglected this crucial analytical framework for nearly a century, failing to recognize its relevance in understanding the capitalist system.

For Marx, the *Tableau Économique* was not merely a historical curiosity but a structural model that could be adapted to his own theory of reproduction and value distribution. His engagement with Quesnay's work led him to develop his own reproduction schemes, which provided the foundation for his analysis of capitalist production, class relations, and economic growth (Marx, 1956). A central tenet of Marx's economic theory was the concept of surplus product, which he defined as all shares of income beyond wages. He argued that surplus is directly linked to the real wage rate, forming an inverse relationship:

- The higher the real wage rate, the smaller the surplus product, reducing the share available for capitalists.

- The lower the real wage rate, the greater the surplus available for reinvestment and accumulation.

This insight built upon the classical tradition, particularly Ricardo's analysis of wages and profits, where the rate of profit was inversely related to labor costs. Marx, however, extended this argument by incorporating it into a more structured theory of capitalist reproduction that differentiated between economic expansion and crisis formation. Marx developed his schemes of reproduction as a way of conceptualizing how the economy sustains itself and grows over time. He built directly on Quesnay's insight that the economy is composed of interdependent sectors, but unlike Quesnay—who divided the economy into "productive" (agriculture) and "sterile" (industry and commerce) sectors—Marx adopted a different classification:

1. Department I – Production of means of production (*e.g., machinery, tools, raw materials*).
2. Department II – Production of means of subsistence (*e.g., food, consumer goods*).

This distinction allowed him to explore how capital flows between investment goods and consumer goods, laying the foundation for a structural analysis of capital accumulation.

- Simple reproduction occurs when the entire surplus is consumed, meaning the economy reproduces itself at a constant level. Capitalists do not reinvest profits but rather use them for personal consumption.
- Extended reproduction takes place when surplus value is partially reinvested, leading to economic growth. This reinvestment increases the productive capacity of Department I (means of production), which in turn enables an expansion of Department II (consumer goods).

Marx's approach highlighted the cyclical and dynamic nature of capitalist production, demonstrating that economic growth requires continuous reinvestment of surplus. His analysis prefigured modern growth models and provided a systematic framework for understanding economic crises, where insufficient demand or over-accumulation could lead to downturns. Moreover, Marx recognized that the Tableau Économique was not only a tool for analyzing sectoral interdependence but also a powerful instrument for understanding profit and value distribution. While Ricardo had established the inverse relationship between profit rates and wages, he had not explicitly shown how the general rate of profit was determined. Marx sought to fill this gap by adapting the Tableau Économique to the classical framework of value and surplus distribution. He identified a key difference between Physiocratic and Classical theories: the Physiocrats attributed surplus exclusively to land rent, seeing landowners as the primary recipients of economic surplus, whereas Classical economists, including Ricardo and Marx, saw surplus distributed between profits and rent, with capitalists as central agents of accumulation.

One of the major innovations in Marx's economic theory was his attempt to systematically determine the general rate of profit and relative prices within a capitalist economy (Marx, 1959). He built on the insights of Ricardo but introduced a more structured framework. The general rate of profit is determined by the relationship between the total surplus value generated in the economy and the total social capital, which consists of constant capital (machinery, inputs) and variable capital (wages). Relative prices emerge from the distribution of surplus value across different industries. Marx proposed a two-step approach: first, determining the rate of surplus value, which depends on labor exploitation and wage levels; and second, allocating this surplus across industries based on their capital intensity, ensuring that profit rates equalize across sectors. Unlike the Physiocrats, who viewed economic flows as a fixed system governed by natural laws, Marx saw prices, wages, and profits as dynamic and shaped by class struggles. His approach emphasized that the rate of profit and price formation cannot be determined independently but must be solved simultaneously, reflecting the structural interdependencies of capitalism. Moreover, he argued that the capitalist system is inherently unstable due to competition, technological change, and shifts in wage bargaining power.

Marx's adaptation of the Physiocratic model into a broader theory of capitalist reproduction and accumulation had a lasting impact on economic thought. His insights paved the way for macroeconomic growth models, as his distinction between simple and extended reproduction influenced later theories of investment cycles and economic expansion. Additionally, his work contributed to theories of crisis and instability, highlighting that capitalist economies are prone to crises due to contradictions in surplus allocation and accumulation. Finally, Marx's reproduction schemes were among the earliest attempts to model economic interdependencies in a structured way, foreshadowing modern input-output analysis, which was later formalized by Wassily Leontief in the 20th century.

1.7 The Contributions of Vladimir K. Dmitriev, Ladislaus von Bortkiewicz, and Georg von Charasoff to the Classical Theory of Value and Distribution

The late 19th and early 20th centuries marked a significant transformation in classical economic theory, particularly concerning the theories of value, surplus, and income distribution. Three key figures—Vladimir K. Dmitriev, Ladislaus von Bortkiewicz, and Georg von Charasoff—played crucial roles in refining and extending both the classical and Marxian frameworks, incorporating more rigorous mathematical methods into economic analysis. Their contributions addressed fundamental theoretical challenges, helping to shape modern economic thought and paving the way for later advancements in input-output analysis.

1.7.1 Vladimir K. Dmitriev

Vladimir K. Dmitriev (1868–1913) was among the first economists to undertake a mathematically rigorous analysis of Ricardo's theory of value and distribution (). His seminal 1898 work (see Dmitriev, 1974), *An Attempt at a Rigorous Analysis* (published in Russian), addressed one of the core questions in classical economics: how to determine the total amount of labour expended in the production of a commodity. A major issue in Ricardo's labour theory of value was the role of indirect labour, meaning the labour embodied in capital goods that are used up in production and contribute to the final commodity. Traditional approaches to this problem suggested an infinite regression of past labour inputs. Dmitriev, however, demonstrated that such a historical tracing of labour inputs was unnecessary. Instead, he showed that labour values could be determined solely based on current production conditions, simplifying the analysis and reinforcing the internal consistency of the labour theory of value.

Beyond labour value, Dmitriev also examined the determination of the rate of profit and the natural prices of commodities. He praised Ricardo's formulation, which established that the profit rate depended on two key factors: the real wage rate, defined as the bundle of goods consumed by workers, and the technical conditions of production in industries producing wage goods. Reformulating Ricardo's arguments in a structured mathematical framework, Dmitriev demonstrated that relative prices are proportional to labour values only under specific conditions—either when the economy operates at a zero profit rate or when production techniques maintain strict proportionality across industries. He further clarified the fundamental inverse relationship between wages and profits, a cornerstone of Ricardian economics. Dmitriev's methodological innovations laid the foundation for a systematic treatment of prices, revealing that the profit rate and natural prices must be determined simultaneously rather than separately. This insight foreshadowed later developments in input-output analysis, as seen in the work of Wassily Leontief, and the linear production models introduced by John von Neumann.

1.7.2 Ladislaus von Bortkiewicz

Ladislaus von Bortkiewicz (1868–1931), a Polish-German economist, played a pivotal role in addressing the mathematical inconsistencies in Marx's theory of value and distribution (see, Bortkiewicz, 1906-7, 1907, 1952). His most influential contribution was his systematic critique of Marx's *transformation problem*, which concerned the conversion of labour values into market prices, or *prices of production*. Marx had attempted to show that the total surplus value in an economy determines the overall profit, but he struggled to reconcile this with the equalization of profit rates across industries. Critics pointed out that his transformation from values to prices was inconsistent, as it failed to account for input prices in production properly. Bortkiewicz corrected this by demonstrating that the classical framework already contained sufficient information to determine both profit rates and prices, without requiring additional assumptions. His analysis showed that prices could be derived directly from technological and wage conditions, without relying on an initial labour-value foundation. Furthermore, he identified inconsistencies in Marx's assumption of an equal profit rate across industries while maintaining his original labour-value calculations.

While Bortkiewicz's critique highlighted weaknesses in Marx's transformation of values into prices, it did not reject the concept of surplus value altogether. Instead, he sought to connect prices and profits to surplus value in a logically consistent manner. His corrections laid the groundwork for a more rigorous understanding of how surplus value is distributed among different industries in a competitive capitalist economy. His work ultimately influenced later theorists, including Piero Sraffa, whose reformulation of classical economics provided a coherent theory of prices and distribution in the mid-20th century.

1.7.3 Georg von Charasoff

Georg von Charasoff (1877–?), a mathematician and economist, advanced a highly abstract yet profoundly insightful reformulation of classical and Marxian economics.[1] His 1910 work, *Das System des Marxismus*, introduced mathematical tools that anticipated modern input-output analysis and highlighted the interdependence of production processes. Charasoff viewed economic production as a circular system, where goods are not only consumed but also serve as inputs for future production. He introduced the concept of *series of production*, a recursive process in which final goods require inputs, which in turn require earlier-stage inputs, extending backward until reaching a set of fundamental commodities indispensable to all production. Through this framework, he identified a core set of commodities, which he termed *basic products*, that form the foundation of economic reproduction. These commodities are essential inputs across all sectors and determine the structural conditions of production. A major theoretical innovation introduced by Charasoff was the concept of *original capital*, a standardized bundle of capital goods whose rate of growth corresponds to the general rate of profit in the economy. His model demonstrated that profit rates emerge naturally from the structure of production and that all industries tend toward a common capital composition over time. His analysis further revealed that the fundamental determinant of profit rates is the growth capacity of basic commodities. This approach closely anticipated the later von Neumann

[1] Due to its dense, abstract reasoning—mathematical yet informal—his work was largely overlooked upon publication and only recently rediscovered (Egidi & Gilibert, 1984).

growth model, where the rate of economic expansion is directly linked to the technical conditions of production.

Hence, the contributions of Dmitriev, Bortkiewicz, and Charasoff represent a crucial turning point in the evolution of classical and Marxian economic thought. Each of these theorists advanced the analytical foundations of economic theory by integrating mathematical formalization into their work, thereby enhancing its precision and applicability ths was more than crucial for the development of input output formalization.

1.8 Maurice Potron's Contribution to Input-Output Analysis

Maurice Potron, a French Jesuit priest and mathematician, made remarkable but long-overlooked contributions to the field of input-output analysis. Working in the early 20th century, he developed fundamental concepts that would later become central to economic modeling, particularly in the analysis of inter-industry relationships. Despite being largely unknown during his lifetime and for decades afterward, his work anticipated key aspects of Leontief's input-output model and introduced the use of mathematical methods to study economic equilibrium. Potron's work in economics was deeply rooted in both his mathematical expertise and his commitment to the Catholic Church's social doctrine. Unlike mainstream economists of his time, who primarily approached economic issues from a theoretical or empirical standpoint, Potron was driven by a moral and ethical perspective. He sought to develop a framework that would ensure fairness in economic transactions, particularly in the determination of wages and prices.

His earliest contributions, dating back to 1911-1912, introduced the idea of using matrices to model economic relationships. In these works, Potron described the economic system as a set of interdependent production processes where inputs from various industries were necessary to produce outputs. This concept, later formalized by Leontief, lies at the heart of modern input-output analysis. One of his major breakthroughs was the introduction of what he termed "technical coefficients." These coefficients represented the amount of input required to produce one unit of output, forming the basis of input-output tables. This was a fundamental step toward quantitatively analyzing how industries depend on one another, a concept that later became a cornerstone of economic planning and industrial policy. One of Potron's most significant innovations was his application of the Perron-Frobenius theorem to economic models. This mathematical theorem, which deals with the properties of non-negative matrices, provided a way to prove the existence of an economic equilibrium. Potron used it to show that under certain conditions, a system of production and wages could reach a stable state, ensuring that all sectors functioned efficiently while maintaining fair remuneration for workers.

At the time, this application of mathematical rigor to economic problems was groundbreaking. Most economists still relied on verbal arguments or simple algebraic formulations, whereas Potron introduced advanced linear algebra techniques into economic analysis. His work demonstrated that economic systems could be studied using precise mathematical methods, paving the way for the formal modeling approaches that became standard in later years.

Unlike later economists who focused primarily on efficiency and optimization, Potron was equally concerned with the ethical implications of economic models. He believed that economic equilibrium should not only ensure the smooth functioning of markets but also guarantee fair wages and just prices. His work aimed to reconcile economic efficiency with social justice, drawing inspiration from Catholic social teaching. Potron argued that wages should at least cover the cost of living, a principle that resonates with modern debates on minimum wage policies and living wage standards. He formulated models in which economic equilibrium would be reached only if workers were paid enough to afford basic necessities, and if production processes were aligned with consumption needs. This approach prefigured later discussions on income distribution and economic inequality, topics that remain central to economic policy today.

Recognizing the complexity of economic interactions, Potron proposed the establishment of a centralized institution responsible for gathering and analyzing economic data. He referred to this as a "computing office," an entity that would collect information on production inputs, consumption patterns, and labor requirements. The purpose of this office would be to monitor economic conditions, ensure the proper allocation of resources, and prevent imbalances in production and wages. This idea was remarkably forward-thinking, as it foreshadowed the role of modern national statistical agencies and the use of economic planning tools. In many ways, Potron's vision anticipated the development of input-output accounting systems used today by governments and international organizations to track economic activity and inform policy decisions. Potron's analysis also identified key conditions necessary for achieving economic stability. He argued that for an economy to function smoothly, production must align with consumption, and wages must be sufficient to cover living expenses. His models highlighted the potential conflicts between these goals, particularly in cases where wage increases led to higher production costs and, consequently, higher prices.

By examining these interactions mathematically, Potron was able to outline the conditions under which an economic system could sustain itself without generating excessive unemployment or inflation. His insights into economic dynamics were decades ahead of their time, predating many of the formal models developed in the mid-20th century to study economic cycles and structural change. Despite the originality and sophistication of his contributions, Potron's work remained largely unknown for much of the 20th century. This was partly due to his position outside mainstream economic circles and partly because he did not actively promote his ideas among professional economists. Additionally, the dominance of classical economic thought during his time meant that his mathematically rigorous approach did not receive the attention it deserved.

It was only in recent decades that scholars revisited Potron's work and recognized its significance. Researchers such as Gilbert Abraham-Frois and Emeric Lendjel (2006) have brought his contributions to light, demonstrating how his ideas prefigured later developments in input-output analysis and economic modeling. Their work has helped to restore Potron's place in the history of economic thought, highlighting his role as an early pioneer of mathematical economics.

1.9 Wassily Wassilyovich Leontief (1906–1999): The Architect of Input-Output Analysis

Wassily Wassilyovich Leontief was born on August 5, 1906, in Munich, Germany, to Russian parents. His father was an economics professor at the University of St.

Petersburg, while his mother was an art historian. Despite his German birthplace, Leontief's early years were deeply shaped by the political and economic turbulence of Russia. Like most children of his time, he received his initial education in a local gymnasium. However, his life took a dramatic turn with the onset of the February Revolution in 1917. His family lost their property, forcing them to relocate.

Between 1917 and 1919, young Wassily was homeschooled before enrolling at the 27th Soviet Union Labor School. He graduated in 1921 at the remarkably young age of 15, earning his diploma (Rose & Miernyk, 1989). That same year, Leontief was admitted to the newly renamed University of Leningrad (formerly the University of St. Petersburg), initially focusing on philosophy and sociology. However, he soon discovered a passion for economics. During this period, he became acutely aware of the socio-political climate in Soviet Russia. His opposition to communist policies and their restrictions on personal freedoms quickly put him under state scrutiny (Rose & Miernyk, 1989). His defiance was not without consequences. At just 15 years old, he was arrested for the first time after being caught nailing anti-communist posters to the wall of a military barrack. He spent several days in solitary confinement. Unshaken, he continued his activism and was arrested multiple times thereafter (Rose & Miernyk, 1989). Despite these challenges, Leontief completed his degree in 1924, earning the title of "Learned Economist"—an academic distinction roughly equivalent to a master's degree today (Rose & Miernyk, 1989).

In 1925, doctors discovered a growth on Leontief's neck, diagnosing it as sarcoma. Realizing the severity of his condition, he applied for permission to travel to Germany for treatment (Samuelson, 2004; Kaliadina & Pavlova, 2006). Soviet authorities, believing he would not survive, granted his request. Fortunately, upon his arrival in Germany, further medical examinations revealed that the growth was benign. Seizing this unexpected second chance, Leontief enrolled at the University of Berlin, where he pursued doctoral studies in economics. His dissertation, *Die Wirtschaft als Kreislauf* (*The Economy as Circular Flow*), was completed in 1928 and officially awarded a PhD in 1929 (Bollard, 2020; Rose & Miernyk, 1989; DeBresson, 2004). While still working on his dissertation, Leontief joined the Institute for the World Economy, where he began his career in economic research. His expertise soon took him beyond Europe—he spent a year assisting the Chinese government in transportation planning, an early indication of his interest in applied economic research (Bollard, 2020; Rose & Miernyk, 1989).

In 1928, Leontief published a section of his dissertation, introducing a two-sector input-output system designed to model the interdependent processes of production, distribution, and consumption within an economy. This work laid the foundation for what would later become his defining contribution to economic science (Bollard, 2020; Rose & Miernyk, 1989). Leontief later reflected that his early work was rooted in classical economic theory, but by the 1930s and 1940s, his input-output model had evolved into a structured adaptation of neoclassical general equilibrium theory. He insisted on a materialist perspective, emphasizing that economic data should derive from directly observable structural relationships. His key insight was that all economic sectors—industries, households, and government—are interconnected through a complex web of buy-sell relationships. By quantifying these relationships in an input-output matrix, economists could analyze how changes in one sector ripple throughout the economy (Bollard, 2020; Kurz & Salvadori, 2010; Rose & Miernyk, 1989). In 1931, Leontief emigrated to the United States, joining the National Bureau of Economic Research. His arrival coincided with the Great Depression, providing a stark backdrop for his investigations into economic interdependence. In 1932, he began teaching at Harvard University, where he received a modest $2,000 research grant and an assistant to support his work (Solow, 1998; Samuelson, 2004). With these resources, he painstakingly constructed input-output tables for 42 industries, covering the years 1919 and 1929. This was an extraordinarily labor-intensive endeavor, as all calculations were performed manually.

A breakthrough came in 1935 when he acquired a mechanical computing machine—one of the first ever used by a social scientist. This marked the beginning of Leontief's pioneering integration of computation into economic analysis (Bollard, 2020; Kurz & Salvadori, 2010; Rose & Miernyk, 1989). During World War II, Leontief served as a consultant to the U.S. Office of Strategic Services, advising on industrial production planning while continuing his academic work (Bollard, 2020; Kholi, 2000; 2001). In 1941, he published *Structure of the American Economy, 1919-1929*, further refining his input-output methodology (Phillips, 1955; Steenge & van den Berg, 2007).[2] In 1943, Harvard provided him with the Mark I, one of the earliest large-scale computers. By 1949, he had expanded his analysis to include 500 distinct economic sectors, making him one of the first economists to perform extensive computational modeling (Klein, 2001; Kurz & Salvadori, 2010; Rose & Miernyk, 1989).

By the 1970s, Leontief had become increasingly critical of mainstream economics, arguing that overly complex theoretical models often lacked empirical foundation (Kurz, 2021). In 1973, he was awarded the Nobel Prize in Economics for his development of the input-output method and its application to real-world economic problems. The Nobel committee described him as the "sole and unchallenged creator of the input-output technique" (Nobel Prize, 1973). Dissatisfied with the academic culture at Harvard—where he felt that professors prioritized research over teaching—Leontief left in 1975 and joined New York University. There, he taught both undergraduate and graduate students while continuing to publish influential works such as *Essays in Economics, II* and *The Future of the World Economy* (1977). He retired in 1991 but remained active in research until his passing (Kurz & Salvadori, 2010; Rose & Miernyk, 1989).

Leontief's contributions permanently reshaped economic analysis, bridging the gap between theory and empirical application (Baumol, 2000).[3] His pioneering use of computational methods laid the groundwork for modern economic modeling, ensuring his influence endures to this day. So, Leontief's work was foundational, but he was not the only economist developing similar ideas. Robert Remak (1888–1942) had earlier generalized input-output concepts to an *n*-commodity case (Remak, 1929). Around the same time, Piero Sraffa (1898–1983) was exploring comparable theories in Italy, but his leftist associations may have contributed to the lack of recognition he received (Bjerkholt & Kurz, 2006). Ragnar Frisch (1895–1973), the founder of *Econometrica*, also developed an analytical structure resembling Leontief's closed model in 1934. While he later adopted Leontief's framework, he persistently claimed to have invented input-output

[2] See, also, Leontief et al. (1951).
[3] For further developments of his approach, see Leontief (1966a, 1966b, and 1974).

analysis himself. The two economists never formally collaborated, and Leontief chose not to engage in Frisch’s claims (Bjerkholt & Kurz, 2006; Kurz & Salvadori, 2010).

The following two sections complete the analysis by examining two particularly significant contributions, providing a comprehensive perspective on the evolution of input-output analysis and Leontief’s work (Stone, 1984). The first explores the relationship between Leontief’s framework and the broader tradition of general equilibrium theory. The second contrasts Leontief’s approach with that of Sraffa, shedding light on their distinct methodologies and theoretical implications. Together, these sections offer a well-rounded understanding of the foundations and development of input-output analysis.

1.10 Input-Output Analysis and Walrasian General Equilibrium Theory

The relationship between input-output analysis, as developed by Wassily Leontief, and Walrasian general equilibrium theory has long been a subject of discussion in economic theory. A frequently encountered perspective in the literature suggests that the Leontief system can be understood as an offshoot of the general equilibrium framework originally formulated by Léon Walras in *Eléments d'économie politique pure* ([1874] 1954). Leontief himself, at times, expressed the view that his analysis was compatible with that of Walras. However, upon closer examination, significant methodological and theoretical differences emerge, casting doubt on the extent of their compatibility. A fundamental distinction between the two approaches lies in their methodological foundations. Leontief adopted a 'naturalistic' or 'material' perspective, emphasizing an empirical and directly observable approach to economic structure. He insisted that economic analysis should focus on "directly observable basic structural relationships" (Leontief, 1987, p. 860), in contrast to Walras's general equilibrium theory, which relies on abstract concepts such as utility, demand functions, and subjective preferences—elements that are not directly measurable. This difference highlights Leontief’s practical orientation, favoring empirical data and measurable economic relationships, while Walras constructed a theoretical framework based on axiomatic principles and mathematical formalization.

The perceived similarity between Leontief's and Walras's approaches often stems from the formal resemblance between their respective price equation systems. In Leontief's early work (1928), the system of price equations bears a formal resemblance to Walras's models of pure exchange found in parts II and III of the *Eléments*. However, the resemblance is largely superficial. A key difference lies in the economic context to which their models apply. Walras's pure exchange economy assumes a framework where prices are determined by agents' utility-maximizing behavior, and equilibrium is attained through adjustments in effective demand. In contrast, both Leontief and Isnard focused on economies involving the production and reproduction of both capital and consumption goods. The determination of relative prices in their models relies on technological and institutional parameters rather than subjective preferences. As a result, the underlying determinants of price formation and economic equilibrium in the two approaches diverge significantly.

The contrast between input-output analysis and Walrasian general equilibrium theory becomes particularly stark when considering production. Unlike Walras, who conceptualized the rate of interest as a scarcity index of a given endowment of capital, Leontief's framework does not incorporate interest as an equilibrating variable between capital supply and demand. Instead, Leontief's approach treats production as a technical process governed by inter-industry relationships, in which factor inputs are linked through fixed coefficients and the determination of outputs is largely mechanistic. This distinction has broader implications for how distribution is treated within each framework. In Leontief's system, distribution does not emerge as a function of factor scarcities but is embedded in the technological and institutional parameters defining input-output relationships. Conversely, Walrasian theory seeks to determine factor prices—including wages and profits—through equilibrium conditions based on factor endowments and agents' optimizing behavior.

The historical treatment of Isnard's contributions provides additional insights into the differentiation between Leontief and Walras. Schumpeter (1954) noted that Isnard's work contained an elementary system of equations that anticipated the mathematical formulation of interdependent price systems, resembling Walras's model. However, Isnard's focus—much like Leontief's—was on production-based interdependencies rather than on pure exchange. The association of Isnard with Walras may, therefore, obscure a deeper connection with Leontief's structural analysis, reinforcing the argument that input-output analysis and Walrasian equilibrium theory stem from fundamentally different theoretical traditions.

1.11 A Comparison of Leontief and Sraffa

Wassily Leontief and Piero Sraffa are two of the most significant figures in 20th-century economic thought, both offering alternatives to marginalist theory. Their work shares a common foundation in the classical economic tradition, particularly in the emphasis on objective, measurable economic relationships rather than subjective preferences and utility functions. However, their approaches, objectives, and methodologies diverged significantly, leading them down distinct intellectual paths. Both Leontief and Sraffa rejected the dominant marginalist paradigm of their time, which explained prices and income distribution through supply and demand functions based on subjective utility (Kurz & Salvadori, 2006). Instead, they sought to ground economic analysis in observable, material relationships of production. Their work aligned closely with the classical economists, such as François Quesnay, David Ricardo, and Karl Marx, who viewed economic processes in terms of the circular flow of commodities and the generation and distribution of surplus (Kurz , 20011).

Despite this shared foundation, their ultimate goals were quite different. Leontief was primarily interested in developing a practical and empirical tool for economic planning, leading to his formulation of input-output analysis. In contrast, Sraffa aimed to construct a comprehensive theoretical critique of marginalism, culminating in his work *Production of Commodities by Means of Commodities* (1960), which provided a foundation for surplus-based price theory. Leontief's method was fundamentally empirical. His input-output analysis modeled the economy as a system of interdependent industries, where the outputs of one sector served as inputs for another. This approach allowed economists and policymakers to analyze how changes in one industry affected others, making it highly applicable for economic planning and national accounting. Leontief's input-output tables became a fundamental tool in economic policy, especially in the United States and the Soviet Union.

Sraffa, by contrast, was not concerned with empirical measurement or policy application but with theoretical reconstruction. His approach built on the classical tradition to formulate a model in which prices and distribution were determined exclusively by the technical and social conditions of production, rather than by supply and demand. His work showed that relative prices and the profit rate could be derived independently of subjective preferences, relying solely on objective input-output relationships.

One of the key differences between Leontief and Sraffa lies in their treatment of prices and income distribution. Leontief's price equations assumed given value-added coefficients, meaning that wages and profits were treated as predetermined, rather than being determined within the system. This assumption made his model easier to apply in empirical studies but introduced a theoretical weakness: in reality, wages and profits are endogenous variables that depend on the structure of production and distributional conflict.

Sraffa, on the other hand, explicitly modeled the interdependence of prices, wages, and profits. In his system, prices and the rate of profit were jointly determined by the technical conditions of production and the chosen distributional variable—either the real wage or the profit rate. Unlike Leontief, Sraffa's framework allowed for a theoretical understanding of how changes in income distribution affect prices, which was crucial for the critique of marginalist economics and for Marxian economic analysis. Leontief's work found widespread practical application in economic planning, national income accounting, and policy analysis. His input-output models became integral to government planning agencies, international organizations, and economic forecasting. His empirical methodology was especially influential in macroeconomic policy and development economics, where it provided a systematic way to assess intersectoral dependencies. Sraffa's impact was more theoretical and critical. His work played a key role in reviving the classical approach to political economy and providing a rigorous foundation for post-Keynesian and neo-Ricardian economics. While it did not have direct policy applications like Leontief's, it significantly influenced economic theory by challenging the foundations of neoclassical price and distribution models.

Leontief and Sraffa began with similar objectivist concerns but ultimately pursued different intellectual trajectories. Leontief developed a practical, data-driven tool that transformed economic planning and empirical analysis, while Sraffa created a theoretical framework that reshaped economic thought and provided a rigorous alternative to marginalist theory. Leontief's contribution lies in his ability to model economic interdependencies in a way that could be directly applied to policy and planning, while Sraffa's significance rests in his theoretical rigor and his fundamental critique of marginalist economics. Both, however, remain central figures in the tradition of classical political economy, demonstrating that economic systems can be understood in terms of material flows and objective production relationships rather than subjective preferences and market equilibria.

1.12 Concluding Remarks

The historical development of input-output analysis reflects a continuous refinement of economic thought, from early qualitative insights into economic interdependencies to the formal mathematical modeling of intersectoral relationships. This progression highlights both the theoretical evolution of economic structure and the methodological advancements that have allowed for its empirical application. The foundations of input-output analysis can be traced back to William Petty and Richard Cantillon, who first introduced systematic approaches to economic surplus and intersectoral linkages. These early contributions laid the groundwork for François Quesnay's *Tableau Économique*, which provided one of the first structured representations of economic circulation. Despite its innovative nature, the Physiocratic model was limited by its exclusive emphasis on agriculture as the sole source of surplus. Subsequent classical economists, including Adam Smith, David Ricardo, and Robert Torrens, expanded the understanding of production, distribution, and intersectoral dependencies.

Karl Marx advanced these ideas by formalizing economic reproduction and capital accumulation, differentiating between simple and extended reproduction schemes that foreshadowed later input-output models. In the late 19th and early 20th centuries, theorists such as Vladimir K. Dmitriev, Ladislaus von Bortkiewicz, and Georg von Charasoff introduced mathematical rigor into classical value and distribution analysis, while Maurice Potron pioneered matrix-based approaches that prefigured modern input-output frameworks. The decisive transformation of input-output analysis into a practical and empirical tool came with Wassily Leontief, whose development of input-output tables enabled systematic economic planning and policy analysis. His work formalized interindustry relationships, providing a quantitative framework for assessing structural economic changes. While his approach shared certain similarities with Walrasian general equilibrium theory, it remained firmly rooted in empirical economic modeling. In contrast, Piero Sraffa's theoretical framework offered an alternative surplus-based perspective on price and income distribution.

In the next part, we will build upon this historical and theoretical foundation by presenting an empirical application of input-output analysis to the Greek economy. This application will illustrate how input-output models can be used to examine sectoral interdependencies, assess economic impacts, and inform policy decisions in a real-world context. By integrating historical insights with empirical analysis, we aim to provide a comprehensive understanding of the role of input-output analysis in studying and shaping economic dynamics in Greece.

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2 EMPIRICAL INSIGHTS ON THE GREEK ECONOMY

2.1 Introduction

This part begins with a literature review of some of the most significant contributions to input-output analysis in the Greek context. By tracing key theoretical and empirical advancements, the review aims to contextualize the evolution of the methodology and highlight its role in understanding the interdependencies of the Greek economy.

Following this, the discussion introduces the main notational conventions and fundamental principles of input-output analysis, ensuring a clear and systematic presentation of the framework employed throughout the study. This formal exposition establishes the necessary theoretical foundation for the subsequent empirical investigation. The analysis then proceeds with an in-depth examination of traditional linkage indicators, both from a theoretical and empirical perspective. These indicators, which measure sectoral interconnections, provide valuable insights into the role of individual industries in the production system and their capacity to generate economic spillovers. By applying these measures to Greek input-output data, the study assesses the extent to which specific sectors act as key drivers of economic activity.

Building on this, the focus shifts to the hypothetical extraction method, a more sophisticated approach for evaluating sectoral significance. This method estimates the economy-wide impact of removing a sector, thereby offering a deeper understanding of the structural importance of different industries. The empirical application of this technique to Greece provides an alternative perspective on sectoral interdependencies and complements the insights gained from traditional linkage analysis. Finally, the section concludes with a detailed discussion of the empirical findings.

2.2 The Evolution of Input-Output Tables in Greece: A Historical and Methodological Overview

The development of Input-Output Tables (IOTs) in Greece has played a crucial role in economic research and policy formulation. The first IOT was constructed in 1970 by the Center of Planning and Economic Research (KEPE), marking the beginning of extensive efforts to analyze the structural transformations of the Greek economy. Since then, various institutions, including KEPE, the Hellenic Statistical Authority (ELSTAT), the National Technical University of Athens (NTUA), and Eurostat, have contributed to the construction, refinement, and application of IOTs. These developments have facilitated numerous studies on sectoral interdependencies, production multipliers, employment effects, and regional economic dynamics. The increasing availability of these tables has allowed researchers to conduct more refined analyses, incorporating both short-term fluctuations and long-term structural shifts within the Greek economy.

2.2.1 Historical Development and Contributions

The initial contributions to the field were made in the 1970s. Skountzos (1975) examined the sectoral interdependencies of the Greek economy for 1980, utilizing Leontief's input-output framework. Panayiotopoulos (1976) identified key sectors for economic development, while Fotopoulos (1980) further refined these analyses by focusing on productive sectors. This early work laid the foundation for subsequent research into production linkages and economic efficiency.

A significant milestone was reached in the 1980s with the work of Skountzos (1980), who studied structural changes in the Greek economy from 1959 to 1970. This period also saw advancements in methodology, as Livas (1983) analyzed employment distribution across economic sectors using IOTs. Additionally, Mattas & Shrestha (1989) applied the IO model to assess the contribution of the food sector to economic growth, introducing a new perspective on the importance of agriculture and food industries. These studies provided an empirical basis for understanding sectoral interdependencies and helped inform economic policy decisions regarding investment priorities and regional development strategies.

The 1990s witnessed an expansion in both thematic focus and methodological tools. Tzouvelekas &Mattas (1995) analyzed regional economic structures, revealing internal growth potential through intersectoral linkages. Valma (1993) quantified interregional multipliers, providing a deeper understanding of regional dependencies. Later, Tzouvelekas & Mattas (1999) explored the role of tourism and the agricultural food industry in Crete's economic development and the effects of Greece's accession to the European Union. These contributions were instrumental in refining regional policy approaches, ensuring that investments were strategically placed to maximize economic benefits.

Parallel to these efforts, Livas & Chondronikolas (1994) developed the first and last energy IOTs (1980-1985), investigating the relationship between energy and non-energy sectors. Belegri-Roboli (1994) examined whether the unified procurement program for 1970-1985 had strengthened Greek industry, using the Public Power Corporation (DEI) as a case study. Their work highlighted the critical role of energy consumption patterns in shaping industrial output and economic stability.

2.2.2 Advances in Environmental and Regional Input-Output Analysis

With the rise of environmental concerns, input-output models evolved to incorporate ecological and sustainability dimensions. Mylonas et al. (2000) pioneered the construction of National Accounting Matrix Including Environmental Accounts (NAMEA) tables for Greece. Lapatsiouras et al. (2007) extended this work by conducting a comparative analysis of emission multipliers, using IOTs for selected EU countries between 1990 and 1996. These studies underscored the environmental implications of sectoral production and consumption patterns, facilitating the formulation of more sustainable economic policies.

In the early 2010s, Lalas et al. (2011) assessed the impact of green economic investments on the Greek economy. Their study concluded that investments in sustainable sectors would generate approximately 208,882 to 240,567 full-time jobs annually from 2010 to 2020, with key impacts observed in construction, transportation, and agriculture. Their findings provided a roadmap for policymakers seeking to balance economic growth with environmental sustainability.

Regional studies continued to expand, focusing on the economic dynamics of specific areas. Loizou et al. (2001) analyzed the competitive relationship between regional development goals, while Ciobanu (2003) and Ciobanu et al. (2004, 2010) examined economic transformations in Eastern Macedonia and Thrace. Their work highlighted the region's structural changes and economic dependencies, particularly in agriculture. These studies reinforced the importance of place-based policies that address the unique economic conditions of different Greek regions.

2.2.3 Employment, Income, and Sectoral Interdependencies

The role of IOTs in assessing employment and income distribution has been a key area of research. Skountzos & Strobilos (2004) analyzed production and employment multipliers in Greece, identifying key sectors. Belegri-Roboli et al. (2007) extended this research to Epirus, Peloponnese, and Western Greece, examining regional development potential through IOTs. These studies provided essential insights for labor market policies, especially in times of economic uncertainty.

In a similar vein, Belegri-Roboli et al. (2010) investigated intersectoral relationships and their role in employment and income generation from 1994 to 2007. Their study identified dynamic sectors by analyzing production technology impacts on output, employment, and wages using input-output analysis. The findings were used to inform workforce training programs and investment policies aimed at strengthening employment resilience.

2.2.4 Economic Crisis and Structural Adjustments

During and after the Greek financial crisis, IOTs were used to assess economic disruptions and recovery potential. Mariolis & Soklis (2010) employed the Supply-Use Table to estimate 3,969 commodity multipliers for Greece, providing insights for economic planning. Markaki et al. (2014) examined the labor market impact of the crisis, specifically analyzing the reduction in private consumption due to rising unemployment. These studies were pivotal in shaping post-crisis economic strategies, offering insights into sectoral vulnerabilities and recovery mechanisms.

In the late 2010s, additional studies sought to redefine Greece's economic structure and resilience. Markaki & Economakis (2016) analyzed sectoral restructuring and key industries, while Kolokontes et al. (2018) assessed the attractiveness of Greek economic sectors through input-output linkages. Loizou et al. (2015) applied IOTs to analyze the energy sector's interdependencies, providing policy insights for sustainable energy planning. These contributions played a crucial role in highlighting opportunities for economic diversification and long-term stability.

2.2.5 Recent Developments and Future Prospects

The use of IOTs has continued to evolve, integrating more sophisticated economic theories. Mariolis & Soklis (2015, 2018) explored Sraffian multipliers, offering alternative approaches to economic modeling. Ntemiroglou (2016) identified key commodities for the Greek economy, while Soklis (2017) provided a broader perspective on intersectoral relationships. These advancements signal an ongoing evolution in economic analysis techniques, broadening the scope of IOT applications.

One of the latest contributions that we refer in this study include Kesperi & Mariolis (2022), who examined employment multipliers for 2010-2014, highlighting structural shifts in labor demand. Finaly, we refer also Rodousakis & Soklis (2024) that assesses the intersectoral linkages of the tourism sector of the Greek economy using an extended version of the hypothetical extraction method. the These efforts underscore the continued relevance of input-output models in addressing economic challenges, from crisis response to sustainable development.[4]

2.3 Notation and Fundamental Relationships

An input–output transactions table constitutes a fundamental component of an economy's national accounts framework. It systematically records the flows of goods and services among production sectors, final consumers, and foreign markets, serving as a critical tool for both descriptive analysis and policy evaluation (Miller & Blair, 2009). To better understand the linkages between input-output transactions and the broader system of

[4] Our review, though thorough, is indicative and does not encompass the entirety of published works on input-output analysis in Greece. Complementary to the above, and with an emphasis on intersectoral linkages, see Tsirimokos (2022).

national income and product accounts (NIPA), consider the case of a simplified two-sector economy.

The final demand vector (f) captures the exogenous demand for sectoral outputs and consists of several key elements:

- Household (private consumption) expenditures (C), representing purchases made by domestic consumers.
- Private investment (I), encompassing expenditures on capital goods and inventories.
- Government purchases (G), including federal, state, and local government procurement of goods and services.
- Exports (E), representing goods and services sold to foreign entities.

Thus, for any sector i, final demand can be decomposed as follows:

$$f_i = c_i + i_i + g_i + e_i$$

where c_i, i_i, g_i, e_i denote the respective components of final demand for sector i. This decomposition aligns with the standard expenditure-based approach to measuring GDP, which aggregates domestic consumption, investment, government spending, and net exports.

Simultaneously, the payments sector accounts for the primary inputs required in production. These payments include:

- Employee compensation (L), representing wages and salaries paid to labor.
- Other value-added payments (N), covering capital costs, land rents, indirect business taxes, and entrepreneurial income.
- Imports (M), capturing purchases of foreign-produced goods and services.

For any given sector j, total payments to primary inputs and imported goods can be expressed as:

$$v_j = l_j + n_j$$

where l_j denotes labor compensation and n_j aggregates non-labor value-added components.

An expanded input-output transactions table, incorporating both interindustry transactions and final payments, is structured as follows (Table 1).

Table 1: *An expanded Input-Output Table*

	Sector 1	Sector 2	Consumption (C)	Investment (I)	Government (G)	Exports (E)	Total Output (x)
Sector 1	z_{11}	z_{12}	c_1	i_1	g_1	e_1	x_1
Sector 2	z_{21}	z_{22}	c_2	i_2	g_2	e_2	x_2
Payments Sector	$l_1 + n_1$	$l_2 + n_2$	$l_C + n_C$	$l_I + n_I$	$l_G + n_G$	$l_E + n_E$	$L + N$
Imports	m_1	m_2	m_C	m_I	m_G	m_E	M
Total Output (x)	x_1	x_2	C	I	G	E	X

This double-entry accounting structure ensures that total sectoral outlays (sum of inputs) equal total sectoral revenues (sum of outputs), reflecting the fundamental identity of input-output balance.

By summing the total output column, we obtain the aggregate gross output (X):

$$X = x_1 + x_2 + L + N + M$$

This same value can be derived from summing across the total outlays row:

$$X = x_1 + x_2 + C + I + G + E$$

These two equivalent summations reflect the core circular flow identity in national accounting.

In national income and product accounting (NIPA), the principal interest lies in measuring gross domestic product (GDP), which represents the total market value of all final goods and services produced within an economy. Equating the two expressions for X and subtracting intermediate inputs (x_1, x_2) from both sides yields:

$$L + N + M = C + I + G + E$$

or, in a more familiar form:

$$L + N = C + I + G + (E - M)$$

Here, the left-hand side represents gross national income (GNI)—the sum of all payments to labor and capital—while the right-hand side represents gross domestic product (GDP)—the total expenditure on final goods and services.

In practical applications, imports (M) are often netted out from exports (E) to compute net exports (NX), reflecting the contribution of international trade:

$$GDP = C + I + G + NX, \text{ where} NX = E - M$$

2.4 Production Relations and the Input–Output Model

The input–output model provides a structured representation of an economy's production system by capturing the interdependencies between different sectors. Each sector both produces outputs that are sold to other sectors and requires inputs sourced from other sectors. The fundamental premise of this framework is that these interindustry transactions occur in fixed proportions, meaning that the production of a given sector requires specific amounts of inputs from other sectors that do not change over time.

This assumption allows us to model economic activity using a system of linear equations, which describes how the total output of each sector is allocated among intermediate and final uses. The ability to quantify these interdependencies makes the input–output model an essential tool for economic analysis, industrial planning, and policy evaluation.

Each sector in the economy depends on the production of other sectors, either directly or indirectly. For example, the automobile industry requires inputs such as steel, rubber, plastics, and electronic components, which are produced by other industries. In turn, the steel industry depends on iron ore, coal, and electricity, while the rubber industry relies on chemicals and synthetic compounds. These relationships form an interconnected system of production, where changes in one sector have cascading effects across multiple industries.

To formally represent these relationships, we define interindustry transactions as the flows of goods and services between sectors over a given period (typically one year). The fundamental data structure of input–output analysis is the input–output transactions table, which records the monetary values of these intersectoral exchanges. This table provides a detailed accounting of how each sector sources its inputs and distributes its outputs.

The transactions between sectors are commonly expressed in monetary terms because industries often produce multiple goods, making physical units (e.g., tons, liters) difficult to standardize. However, the monetary representation introduces potential price distortions, as changes in prices do not necessarily reflect changes in physical production. Despite this limitation, the use of monetary values remains the standard approach due to its practicality in national accounts.

A key concept in input–output analysis is the technical coefficient, which describes the relationship between inputs and outputs in the production process. Each sector requires a certain amount of inputs from other sectors to produce one unit of output. This relationship is formalized using technical coefficients, denoted as a_{ij}:

$$a_{ij} = \frac{z_{ij}}{x_j}$$

where:

- z_{ij} is the value of inputs purchased by sector j from sector i.
- x_j is the total output of sector j.
- a_{ij} represents the fixed proportion of sector i's output required per unit of sector j's output.

For example, if an automobile manufacturer purchases 300 euro worth of steel from the steel industry to produce 15,000 euro worth of cars, the technical coefficient is:

$$a_{14} = \frac{300}{15{,}000} = 0.02$$

This means that for every dollar of automobile production, 2 cents' worth of steel is required.

A defining characteristic of input–output analysis is the assumption that these technical coefficients remain fixed. If automobile production triples from 15,000 to 45,000 euro, the required steel input will also triple:

$$z_{14} = (0.02) \times (45{,}000) = 900$$

This assumption of fixed input proportions implies that production operates under constant returns to scale, meaning that doubling the output of a sector requires precisely double the amount of inputs. It also means that no input substitution is allowed, which contrasts with neoclassical economic models where firms adjust input combinations based on relative prices and marginal productivity.

Each sector's total output is either:

- Used as an intermediate input by other industries, or
- Sold as a final good to households, government, or foreign markets.

This can be expressed mathematically as:

$$x_i = \sum_{j=1}^{n} z_{ij} + f_i$$

where:

- x_i is the total output of sector i.
- z_{ij} represents intermediate sales to other sectors.
- f_i represents the final demand for sector i's output.

Substituting the technical coefficients, we obtain:

$$x_i = a_{i1}x_1 + a_{i2}x_2 + \cdots + a_{in}x_n + f_i$$

This forms a system of n simultaneous equations, which describes how each sector's output depends on the outputs of all other sectors and the level of final demand.

To express this system more concisely, we use matrix notation:

$$\mathrm{x} = A\mathrm{x} + \mathrm{f}$$

where:

- x is the $n \times 1$ vector of total sectoral outputs.
- A is the $n \times n$ technical coefficients matrix, summarizing intersectoral dependencies.
- f is the $n \times 1$ vector of final demand.

Rearranging:

$$(I - A)\mathrm{x} = f$$

where I is the identity matrix.

If $(I - A)$ is invertible, the solution for total output is:

$$\mathrm{x} = (I - A)^{-1}\mathrm{f}$$

where $(I - A)^{-1}$ is the Leontief inverse matrix, denoted as L.

Each element l_{ij} of this matrix captures the total (direct and indirect) output required from sector i to meet a one-unit increase in final demand in sector j. This allows us to measure the total production requirements of an economy in response to changes in demand.

The Leontief inverse enables a detailed assessment of sectoral interdependencies, making it a valuable tool for economic impact analysis. Some key applications include:

- Policy Analysis – Evaluating the impact of government spending on different industries.
- Supply Chain Effects – Identifying how disruptions in one sector (e.g., semiconductor shortages) propagate through the economy.
- Environmental and Resource Analysis – Estimating carbon emissions or energy consumption linked to economic production.
- Employment Analysis – Determining the labor requirements associated with different levels of economic activity.

For example, if the government invests in infrastructure, this increases final demand for construction services, which in turn raises demand for cement, steel, transportation, and machinery. The Leontief inverse quantifies these ripple effects throughout the economy.

While input–output models provide valuable insights into economic structure, they also have limitations:

- Fixed technical coefficients: Assumes no input substitution, which may not hold in dynamic industries.
- Constant returns to scale: Ignores economies of scale and technological advancements.
- Static nature: Does not account for long-term structural changes.
- Neglect of price effects: Treats transactions in monetary terms without considering price changes.

Despite these limitations, input–output analysis remains a widely used framework in both academic research and policymaking.

2.5 Supply-Side Input–Output Models

The supply-side input–output model, introduced by Ghosh (1958), presents an alternative perspective on economic interdependencies. While the traditional demand-driven model, developed by Leontief (1941, 1986), focuses on how changes in final demand propagate through an economic system, the supply-side model shifts attention to primary inputs—such as labor, capital, and raw materials—as the driving force of economic activity.

At the core of Ghosh's formulation is the idea that sectoral gross production is determined by the availability and distribution of primary inputs rather than by changes in final demand. This alternative interpretation offers valuable insights into how constraints on the supply of inputs (e.g., labor strikes, resource depletion, capital shortages) influence economic output across industries.

The Leontief model is fundamentally demand-driven, meaning that changes in output are dictated by variations in final demand. In contrast, the Ghosh model adopts a supply-side perspective, focusing on the distribution of sectoral production across industries rather than on how sectors respond to changes in final demand. Instead of assuming fixed input coefficients (as in the demand-driven model), the supply-side approach assumes fixed output coefficients, meaning that the distribution of a sector's output to its purchasing industries remains stable over time.

To operationalize this concept, Ghosh suggested "rotating" or transposing the traditional input–output model. Instead of dividing each column of the transactions matrix (Z) by total sectoral output (which gives input coefficients), we divide each row of Z by total sectoral output, yielding output coefficients. This results in a new matrix, B, known as the direct-output coefficients matrix, or the allocation coefficients matrix.

The technical transformation from a demand-driven to a supply-driven system is achieved by defining the allocation coefficients b_{ij}, where:

$$b_{ij} = \frac{z_{ij}}{x_i}$$

Here:

- z_{ij} represents the monetary value of sector i's output sold to sector j.
- x_i is the total output of sector i.
- b_{ij} measures the proportion of sector i's total output that is allocated to sector j.

This formulation is structurally similar to the technical coefficients matrix (A) in the demand-driven model, but while A captures input dependence, B captures output distribution.

Using matrix notation, the supply-side model is defined as:

$$\mathrm{x} = B\mathrm{x} + \mathrm{v}$$

where:

- B is the direct-output coefficients matrix.
- v is the vector of primary inputs (e.g., labor, capital, imported materials).
- x is the vector of total sectoral outputs.

Rearranging:

$$(I - B)\mathrm{x} = \mathrm{v}$$

If $(I - B)$ is invertible, we obtain the solution:

$$\mathrm{x} = (I - B)^{-1}\mathrm{v} = G\mathrm{v}$$

where:

- $G = (I - B)^{-1}$ is the Ghosh inverse, or output inverse.
- Each element g_{ij} represents the total value of production that results in sector j per unit of primary input in sector i.

This equation mirrors the Leontief inverse formulation but operates under supply-driven assumptions rather than demand-driven ones.

The Ghosh inverse matrix provides a framework for analyzing how supply-side changes affect economic output. Each element g_{ij} can be interpreted as:

$$\frac{\partial x_j}{\partial v_i} = g_{ij}$$

which represents the change in sector j output due to a one-unit increase in primary inputs for sector i.

For example, if $g_{ij} = 0.67$, this means that a one-euro reduction in labor availability in sector i would lead to a 0.67 euro decrease in sector j output. This reflects the propagation of supply constraints through the economic system.

In Leontief's demand model, the output multipliers are given by column sums of the Leontief inverse matrix:

$$\sum_{i=1}^{n} l_{ij}$$

which measures the total increase in economy-wide output from a one-dollar increase in final demand for sector j.

In Ghosh's supply model, the input multipliers (also called supply multipliers) are given by row sums of the Ghosh inverse:

$$\sum_{j=1}^{n} g_{ij}$$

which represents the total increase in economy-wide output resulting from a one-dollar increase in primary inputs to sector i.

While the Leontief model is useful for analyzing demand-side policies (e.g., fiscal stimulus, consumption-driven growth), the Ghosh model is more suited for studying supply constraints (e.g., labor shortages, capital investment decisions, raw material disruptions).

The supply-side input–output model is particularly useful in the following contexts:

- Labor and Capital Constraints: Evaluating the impact of a shortage in labor or investment capital on sectoral outputs.
- Natural Resource Depletion: Assessing how a reduction in raw material availability (e.g., oil, minerals) affects production across industries.
- Disruptions in Supply Chains: Examining the effects of supply shocks such as factory closures, trade restrictions, or geopolitical tensions.
- Infrastructure and Investment Analysis: Measuring how changes in infrastructure investment alter sectoral production and economic growth.
- Policy Design for Economic Resilience: Understanding how economies react to supply-side shocks to design appropriate mitigation strategies.

For instance, if an oil supply disruption occurs, the Ghosh model can quantify its downstream effects on industries reliant on petroleum-based inputs (e.g., plastics, transportation, chemicals). Similarly, if an economy invests in new energy infrastructure, the model can estimate how this increased availability of energy resources influences industrial output.

Despite its analytical power, the Ghosh model has been subject to various criticisms:

- Assumption of Fixed Output Coefficients: Just as the Leontief model assumes fixed input proportions, the Ghosh model assumes fixed output allocation proportions, which may not hold in dynamic economies.
- Implausibility of Backward-Causation: Some argue that treating primary inputs as the sole drivers of production ignores demand-driven market mechanisms.
- Limited Empirical Validation: The Ghosh model has been less extensively validated in real-world economic systems compared to the Leontief model.

However, despite these limitations, the supply-side approach remains a valuable complement to demand-driven analysis, particularly in resource economics, supply chain management, and investment planning.

2.6 Relationships Between the Demand-Side and Supply-Side Models: Connections Between $\boldsymbol{A}$, $\boldsymbol{B}$, $\boldsymbol{L}$, and $\boldsymbol{G}$

As we show above, the input–output model can be interpreted from both demand-side (Leontief) and supply-side (Ghosh) perspectives, each offering different insights into economic interdependencies. The Leontief model examines how final demand changes influence total sectoral output, while the Ghosh model explores how variations in primary inputs affect economic activity. Despite their distinct interpretations, the two models share a structural similarity, which can be mathematically formalized through relationships between the direct input coefficients matrix A and the direct output coefficients matrix B, as well as between the Leontief inverse L and the Ghosh inverse G.

The direct input coefficients matrix in the demand-side model is defined as:

$$A = Zx^{-1}$$

where:

- Z is the interindustry transactions matrix, capturing the flows of goods and services among sectors.
- x^{-1} is the inverse of the diagonal matrix of total sectoral outputs.

Similarly, in the supply-side model, the direct output coefficients matrix is given by:

$$B = x^{-1}Z$$

where each element b_{ij} represents the share of sector i's output that is sold to sector j.

Substituting $Z = xB$ into the definition of A, we obtain:

$$A = xBx^{-1}$$

which shows that A and B are similar matrices, denoted as:

$$A \sim B$$

This mathematical similarity implies that all economic relationships captured by A can also be derived from B, provided that total output (x) is known. Conversely, supply-driven measures based on B can be computed using A and x.

This structural connection between the two coefficient matrices is significant because it allows us to reinterpret demand-side multipliers (e.g., backward linkages, total output multipliers) in terms of supply-side analysis (e.g., forward linkages, input multipliers).

From the Leontief and Ghosh model, we established that:

$$(I - A) = x(I - B)x^{-1}$$

it follows that:

$$(I - A)^{-1} = x(I - B)^{-1}x^{-1}$$

which implies:

$$L = xGx^{-1}$$

or equivalently:

$$G = x^{-1}Lx$$

This result shows that the Leontief inverse and the Ghosh inverse are also similar matrices, meaning that multipliers computed under one model can be converted into the equivalent supply-side multipliers under the other.

This relationship provides a fundamental bridge between the two perspectives of input–output analysis: one driven by demand and the other driven by supply.

The Leontief inverse and Ghosh inverse have important interpretations, as we will see in the next chapter, in terms of elasticities and linkages:

- Leontief model: The elements of L measure the total percentage change in sector i's output due to a one-percent increase in final demand for sector j. This is referred to as the output-to-output elasticity.

- Ghosh model: The elements of G measure the total percentage change in sector j's output due to a one-percent increase in the availability of primary inputs to sector i. This is known as the input-to-output elasticity.

Thus, column sums of L correspond to traditional demand-side output multipliers, while row sums of G provide analogous supply-side multipliers. For instance: Backward linkages (demand-driven) can be measured as column sums of L, indicating how a sector's expansion affects its upstream suppliers, while the Forward linkages (supply-driven) can be measured as row sums of G, reflecting how a sector's increased production influences its downstream buyers.

2.7 Extraction of Matrices A and B of the Greek Economy

Suppose an economy in which two commodities (commodity 1 and commodity 2) are produced through single production processes. The simplest possible form of the Symmetric Input-Output Table (SIOT) of this economy is that shown in Table 2:

Table 2: *Simplified Symmetric Input-Output Table*

	Commodity 1	Commodity 2	**y**	**x**
Commodity 1	Z_{11}	Z_{12}	Y_1	X_1
Commodity 2	Z_{21}	Z_{22}	Y_2	X_2
t	T_1	T_2		

x	X_1	X_2

where Z_{ij} is the quantity of good i used in the production of commodity j , Y_i is the final demand for commodity i, T_j is the value added corresponding to the production of commodity j, X_i the gross outflow of commodity i (all figures are in monetary units). Therefore, it follows that the construction of a SIOT constitutes an attempt to systematically represent all the economic activities of a given economic system. However, the SIOT described by Table 3 is extremely simplified. The tables corresponding to real economies may describe several dozen commodities, while the final demand and value added data may be seperated into many subcategories. In Table 2 we present an SIOT, in the format published by Elstat. The input-output tables published by Eurostat describe 65 commodities, i.e. the intermediate consumption matrix is 65×65. For the sake of simplicity, it is assumed that the matrix describes only two commodities.

Table 3: *Simplified Eurostat Symmetric Input-Output Table*

[Insert here, File 1]

where TX_j is taxes minus subsidies on commodity j, TZ_j is total intermediate consumption in the production of good j , W_j the compensation of employees in the production of the commodity j , NT_j other net taxes on the production of the good j , CFC_j the consumption of fixed capital in the production of commodity j , NS_j the net operating surplus in the production of commodity j, GS_j the gross operating surplus in the production of the commodity j, EIM_j imports from European Union countries in commodity j, NIM_j imports from countries outside the European Union in goods j, IM_j is total imports in commodity j, TS_j is total supply of the economy in commodity j, HC_i the final consumption of households in merchandise i, NC_i the final consumption of Non-Profit Organizations serving households in commodity i, GC_i the final consumption of government in commodity i, FC_i the total final consumption in commodity i, FCF_i the gross fixed capital formation capital in commodity i, CV_i the changes in assets in commodity i, CI_i the changes in stocks in commodity i, CIV_i the changes in assets and stocks in goods i, CF_i the gross capital formation in commodity i, EEX_i exports within the EU in commodity i, NEX_i exports outside the EU in commodity i, EX_i the total exports in commodity i, FU_i the final uses in commodity i and TU_i the total uses in commodity i.

The following identities hold:

$Z_{1j} + Z_{2j} + TX_j \equiv TZ_j$

$CFC_j + NS_j \equiv GS_j$

$GS_j + W_j + NT_j \equiv T_j$

$TZ_j + T_j \equiv X_j$

$EIM_j + NIM_j \equiv IM_j$

$X_j + IM_j \equiv TS_j$

$HC_i + NC_i + GC_i \equiv FC_i$

$CV_i + C_{Ii} \equiv CIV_i$

$FCF_i + CIV_i \equiv CF_i$

$EEX_i + NEX_i \equiv EX_i$

$FC_i + CF_i + EX_i \equiv FU_i$

$Z_{i1} + Z_{i2} + FU_i \equiv TU_i$

$TU_1 \equiv TS_1$

$TU_2 \equiv TS_2$

$\sum_{i=1}^{2} TU_i \equiv \sum_{i=1}^{2} TS_j$

$TU_1 - IM_1 \equiv X_1$

$TU_2 - IM_2 \equiv X_2$

$\sum_{i=1}^{2} TU_i - \sum_{i=1}^{2} IM_j \equiv \sum_{i=1}^{2} X_j$

So based on the above and setting that the matrix of intermediate consumption, Z, and the vector of the gross output, χ of a 2×2 SIOT can be written as follows

$$Z = \begin{pmatrix} p_1 a_{11} x_1 & p_1 a_{12} x_2 \\ p_2 a_{21} x_1 & p_2 a_{22} x_2 \end{pmatrix}$$

$$\chi = \begin{pmatrix} p_1 x_1 \\ p_{12} x_2 \end{pmatrix}$$

where p_i is the price of commodity i and χ_i is the gross out ii commodity i. If we assume that $p_1 = p_2 = 1$, which means that as physical unit of each commodity is considered to be that quantity of commodity worth 1 monetary unit (see, e.g., Miller and Blair, 1985, p. 356), from the above we obtain, respectively

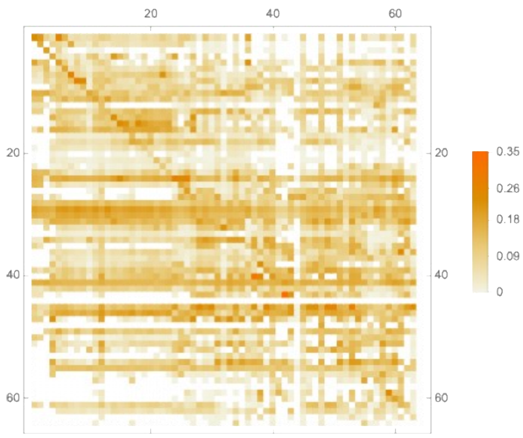
$$Z = \begin{pmatrix} a_{11} x_1 & a_{12} x_2 \\ a_{21} x_1 & a_{22} x_2 \end{pmatrix}$$

$$\chi = \begin{pmatrix} x_1 \\ x_2 \end{pmatrix}$$

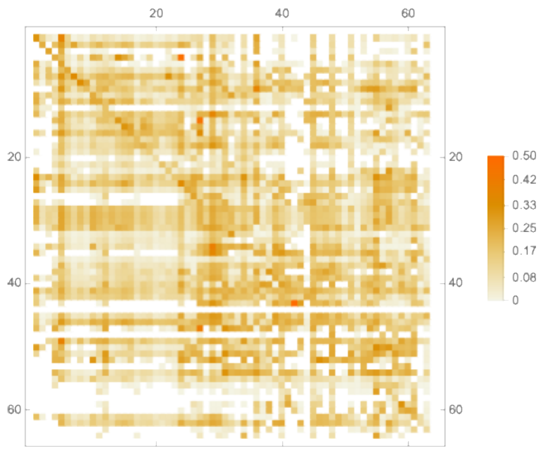
Finally, we create the matrix

$$x = \begin{pmatrix} x_1 & 0 \\ 0 & x_2 \end{pmatrix}$$

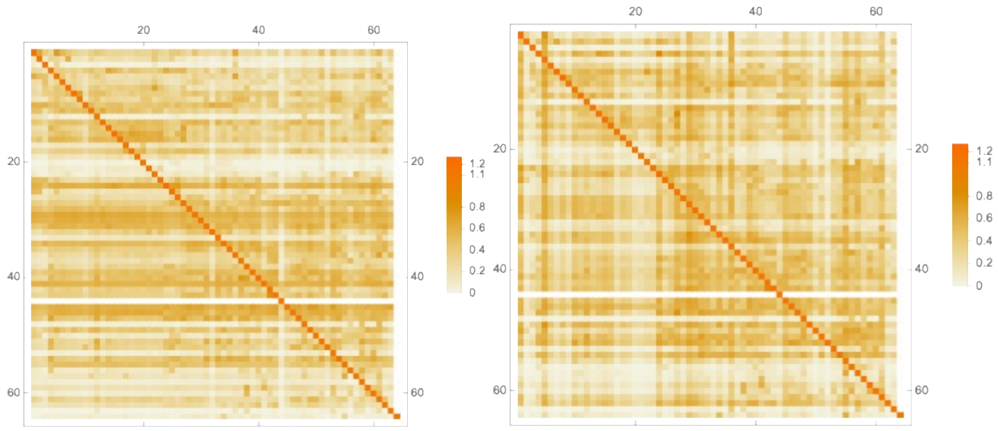
and, therefore, utilizing the latest available data from Eurostat (2020), constructing the A and B and then L and G for the Greek economy is a straightforward process.



(a)



(b)



(c) (d)

Figure 1.1: *Plot of the domestic matrices (a) A, (b) L, (c) B, (d) G of the Greek economy*

The data we use in our analysis is of dimensions 64×64. The 64 rows and columns of the matrix refer to the 64 commodities/sectors described in the input-output table, for which we can make the following general distinction: (a) commodities/sectors 1–4 belong to the primary production; (b) commodities/sectors 5–27 belong to industry; and (c) commodities/sectors 28–64 belong to services.

The plot of the extended matrix of the Greek economy is presented in Figure 1. In the matrix plot, in place of each element are represented, instead of numbers, cells with shades of red. The brighter a cell is, the larger the number it represents; the closer a cell is to white, the closer the number is to zero, while the diagram shows the range and level of the matrix values.

In this study, we focus on the domestic components of the input-output matrix, as they provide the most suitable foundation for analyzing the forward and backward linkages that follow. Beyond their analytical relevance, these data also offer an initial visual insight into the structural differences between the A, B, L, and G matrices, allowing for a first impression of their distinct characteristics. A more detailed examination of these differences will be undertaken in the next where the traditional approaches to measuring forward and backward linkages will be systematically explored.

2.8 Linkages in Input–Output Models

2.8.1 The Traditional Methods

The concept of linkages in input–output analysis has been a fundamental tool for understanding the interdependencies between different sectors of an economy. Since the pioneering work of Hirschman (1958) and Rasmussen (1957), economists have sought to quantify how production in one sector stimulates economic activity in others, either through the demand for inputs (backward linkages) or the supply of intermediate goods (forward linkages). These measures have played a critical role in identifying key sectors, informing industrial policy, and assessing economic development strategies.

The distinction between backward and forward linkages is essential for understanding how economies function. When a sector expands its output, it increases its demand for inputs from upstream suppliers—a relationship that characterizes backward linkages. Conversely, as production increases, the sector provides more outputs to downstream industries, forming forward linkages. The traditional input–output model, as formulated by Leontief (1936, 1941, 1987), has been the foundation for measuring these linkages, with refinements emerging in subsequent decades.

The formalization of backward linkages as a measure of demand-driven economic interdependence can be traced to Rasmussen (1957), who proposed a method based on the Leontief inverse matrix. This approach allowed researchers to quantify how an increase in final demand for a sector's output propagates through the economy, increasing production in related industries. At the same time, Hirschman (1958) emphasized the role of sectoral interdependencies in economic development, arguing that economies with strong backward linkages could stimulate industrialization by creating demand for domestically produced inputs.

In parallel, Chenery & Watanabe (1958) introduced measures of forward linkages, shifting the focus to the supply-side effects of production. Their work examined how different sectors supply intermediate goods to others, forming the basis for evaluating how economic growth in one sector supports productive activity in its downstream industries. This approach gained traction in later studies by Yotopoulos & Nugent (1973), Laumas (1975), and Jones (1976), who extended the framework to compare sectoral interdependencies across different economies.

As interest in linkage measures grew, so did debates regarding their proper definition and interpretation. The Quarterly Journal of Economics (May 1976) featured a series of papers discussing the theoretical underpinnings of linkage analysis, with contributions from Diamond (1976), Schultz & Schumacher (1976), and Laumas (1976a, 1976b). These discussions focused on the appropriate ways to normalize and interpret linkage coefficients, an issue that remains relevant in contemporary research.

The ability to quantify intersectoral dependencies has made linkage analysis a valuable tool for economic policy and regional development planning. By comparing the relative strength of backward and forward linkages, policymakers can identify key sectors—those that, if expanded, would generate the largest overall impact on the economy. This approach has been particularly influential in development economics, where identifying strategic sectors for investment is a crucial part of industrialization strategies.

For instance, McGilvray (1977) and Hewings (1982) examined how linkage measures could be applied to development planning, raising questions about whether key sector identification should be a primary focus of industrial policy. Their analyses highlighted the complexities of using input–output linkages to guide economic decision-making, particularly in economies undergoing structural transformation.

As globalization increased the complexity of production networks, researchers began applying linkage analysis to international comparisons of economic structures. Studies such as those by Augustinovics (1970) and Oosterhaven (1980, 1988, 1989) explored how different economies exhibit varying patterns of intersectoral dependence, particularly in the context of trade and industrial specialization.

2.8.2 Backward Linkage: Definition, Measurement, and Normalization

The concept of backward linkage is fundamental in input–output analysis as it quantifies the extent to which a sector's production relies on inputs sourced from other industries. This measure is essential for understanding intersectoral dependencies, identifying key sectors, and designing industrial policies that stimulate broad-based economic growth.

The simplest measure of backward linkage focuses on direct interindustry dependencies—the extent to which a sector requires intermediate inputs from other sectors. This is derived from the Leontief technical coefficients matrix (A), where each element a_{ij} represents the proportion of sector j's total output that is sourced from sector i.

The direct backward linkage for sector j is given by the sum of all elements in the jth column of A:

$$BL(d)_j = \sum_{i=1}^{n} a_{ij}$$

This measure, first proposed by Chenery & Watanabe (1958), provides a sector-specific metric of how dependent a given industry is on interindustry inputs. Higher values indicate greater reliance on other sectors, suggesting that expansion in this sector would strongly stimulate demand for inputs from upstream industries.

Alternatively, using the transactions matrix (Z) instead of A, the direct backward linkage can also be expressed as the total value of intermediate inputs purchased by sector j, normalized by its total output x_j:

$$BL(d)_j = \frac{\sum_{i=1}^{n} z_{ij}}{x_j}$$

which captures backward dependence in absolute terms.

In vector notation, the set of direct backward linkages across all sectors is expressed as:

$$b(d) = iA$$

where i is a row summation vector (a row of ones), which ensures that each sector's total dependency on upstream industries is captured.

While direct backward linkages capture first-order dependencies, they do not account for indirect effects, such as secondary demand increases in upstream suppliers. To incorporate these indirect effects, Rasmussen (1957) proposed using the Leontief inverse matrix (L):

$$L = (I - A)^{-1}$$

where $L = [l_{ij}]$ represents the total requirements matrix, capturing the direct and indirect production effects across the economy.

The total backward linkage for sector j is then computed as:

$$BL(t)_j = \sum_{i=1}^{n} l_{ij}$$

This formulation ensures that both direct input needs and indirect production effects are incorporated, providing a comprehensive measure of sectoral influence on upstream industries.

Expressed in vector form, the total backward linkages across all sectors are:

$$b(t) = iL$$

where, again, the row summation vector ensures that total backward dependence is aggregated.

However, it should be noted that key methodological debate in the literature concerns whether the diagonal elements of A and L should be included or excluded from the summation when calculating backward linkages. This issue was highlighted by Harrigan & McGilvray (1988) in their discussion of input–output methodologies.

- Inclusion of diagonal elements: If self-dependency is considered an integral part of an industry's total economic impact, the diagonal elements should be retained. This approach aligns with Hirschman's (1958, p.100) argument that internal linkages contribute to derived demand effects.
- Exclusion of diagonal elements: If the focus is solely on intersectoral dependencies, then self-reliance should be removed from the calculations.

The decision to include or exclude these elements depends on the analytical focus of the study. If the objective is to assess total sectoral dependence, diagonal elements are included; if the goal is to measure intersectoral connectedness, they are omitted. Table 4 presents direct backward linkages and total backward linkages for various industries of the Greek economy.

Table 4: *The direct and total backward linkages of the Greek economy*

	b(*d*)	*b*(*t*)
Products of agriculture, hunting and related services	0,351119	1,53661
Products of forestry, logging and related services	0,234208	1,34352
Fish and other fishing products; aquaculture products; support services to fishing	0,208308	1,28791
Mining and quarrying	0,347644	1,52761
Food, beverages and tobacco products	0,509706	1,79026
Textiles, wearing apparel, leather and related products	0,362154	1,54631
Wood and of products of wood and cork, except furniture; articles of straw and plaiting materials	0,429819	1,67531
Paper and paper products	0,430255	1,68177
Printing and recording services	0,314975	1,49194
Coke and refined petroleum products	0,183619	1,26487
Chemicals and chemical products	0,304442	1,45544

Basic pharmaceutical products and pharmaceutical preparations	0,47959	1,70587
Rubber and plastic products	0,324534	1,48777
Other non-metallic mineral products	0,471995	1,74209
Basic metals	0,461757	1,7375
Fabricated metal products, except machinery and equipment	0,384509	1,60136
Computer, electronic and optical products	0,352881	1,52714
Electrical equipment	0,372541	1,59571
Machinery and equipment n.e.c.	0,363052	1,56163
Motor vehicles, trailers and semi-trailers	0,36086	1,54985
Other transport equipment	0,262419	1,39993
Furniture and other manufactured goods	0,350156	1,54722
Repair and installation services of machinery and equipment	0,321099	1,48928
Electricity, gas, steam and air conditioning	0,429829	1,65861
Natural water; water treatment and supply services	0,318823	1,50099
Sewerage services; sewage sludge; waste collection, treatment and disposal services; materials recovery services; remediation services and other waste management services	0,38521	1,6102
Constructions and construction works	0,498247	1,77351
Wholesale and retail trade and repair services of motor vehicles and motorcycles	0,413418	1,58435
Wholesale trade services, except of motor vehicles and motorcycles	0,369691	1,53979
Retail trade services, except of motor vehicles and motorcycles	0,319047	1,44594
Land transport services and transport services via pipelines	0,375817	1,57126
Water transport services	0,211503	1,28189
Air transport services	0,468916	1,70206
Warehousing and support services for transportation	0,383386	1,56791
Postal and courier services	0,334439	1,5008
Accommodation and food services	0,325665	1,51911
Publishing services	0,538312	1,78279
Motion picture, video and television programme production services, sound recording and music publishing; programming and broadcasting services	0,495551	1,77231
Telecommunications services	0,423049	1,59063
Computer programming, consultancy and related services; Information services	0,336153	1,48998
Financial services, except insurance and pension funding	0,123046	1,17277
Insurance, reinsurance and pension funding services, except compulsory social security	0,514147	1,80982
Services auxiliary to financial services and insurance services	0,460871	1,68207
Imputed rents of owner-occupied dwellings	0,028549	1,04576
Real estate services excluding imputed rents	0,148584	1,22158
Legal and accounting services; services of head offices; management consultancy services	0,269202	1,368
Architectural and engineering services; technical testing and analysis services	0,387951	1,55736
Scientific research and development services	0,252355	1,37733
Advertising and market research services	0,538973	1,76465
Other professional, scientific and technical services and veterinary services	0,417369	1,56001
Rental and leasing services	0,357306	1,52888

Employment services	0,086777	1,11997
Travel agency, tour operator and other reservation services and related services	0,657375	1,93474
Security and investigation services; services to buildings and landscape; office administrative, office support and other business support services	0,327918	1,48493
Public administration and defence services; compulsory social security services	0,195598	1,27914
Education services	0,074132	1,11542
Human health services	0,201844	1,30927
Residential care services; social work services without accommodation	0,292741	1,43848
Creative, arts, entertainment, library, archive, museum, other cultural services; gambling and betting services	0,325783	1,48245
Sporting services and amusement and recreation services	0,468175	1,72113
Services furnished by membership organisations	0,458496	1,70108
Repair services of computers and personal and household goods	0,300632	1,44013
Other personal services	0,233764	1,30242
Services of households as employers; undifferentiated goods and services produced by households for own use	0	1

From Table 4 we observe that industries with high direct and total backward linkages significantly contribute to economic interconnectivity by demanding substantial inputs from upstream industries. The top industries with the highest total backward linkages include Travel agency, tour operator, and other reservation services, which has the highest overall impact. Insurance, reinsurance, and pension funding services (1.80982) strongly influence financial services. Food, beverages, and tobacco products (1.79026) are highly interconnected with agriculture and manufacturing. Publishing services (1.78279) have strong economic interactions with the printing and media industries. Some industries exhibit the lowest direct backward linkages, indicating minimal dependence on other industries. Services of households as employers have no intersectoral dependencies. Imputed rents of owner-occupied dwellings (0.0285) require minimal demand for intermediate inputs. Education services 0.0741) are relatively self-contained. Manufacturing sectors such as chemicals, basic metals, machinery, and textiles exhibit moderate to high total backward linkages, reinforcing their role as key economic drivers. Service industries like financial services, telecommunications, and advertising play significant roles due to their high total backward linkages, indicating strong ripple effects throughout the economy.

To enable comparisons across sectors, backward linkage measures are often normalized. A common method is to divide each sector's backward linkage by the average across all sectors:

$$\bar{BL}(d)_j = \frac{BL(d)_j}{\frac{1}{n}\sum_{j=1}^{n} B\,L(d)_j}$$

which ensures that:

- Values greater than 1 indicate above-average backward linkages, meaning that expanding this sector stimulates a larger-than-average increase in input demand.
- Values less than 1 indicate below-average backward linkages, suggesting that expanding this sector has a weaker than average upstream impact.

Using vector notation, the normalized direct backward linkage index is given by:

$$\bar{b}(d) = \frac{niA}{iA}$$

Similarly, the normalized total backward linkage index (proposed by Rasmussen (1957) as the Index of the Power of Dispersion) is given by:

$$\bar{b}(t) = \frac{niL}{iL}$$

In both cases, the normalization procedure standardizes sectoral influence, making it easier to compare relative backward dependencies across industries.

The analysis of normalized backward linkages provides insights into how different industries in the Greek economy interact with their upstream sectors after adjusting for sectoral size (Table 5). Industries with higher-than-average backward linkages have a stronger impact on input demand, meaning that their growth stimulates significant activity in supplier industries. Conversely, industries with lower backward linkages rely less on intermediate inputs, making them less interconnected with the broader economy.

Table 5: *Normalized Backward Linkages of the Greek economy*

	Normalized *b*(*d*)	Normalized b(*t*)
Products of agriculture, hunting and related services	1,024684	1,015349
Products of forestry, logging and related services	0,683498	0,88776
Fish and other fishing products; aquaculture products; support services to fishing	0,607913	0,851015
Mining and quarrying	1,014543	1,009402
Food, beverages and tobacco products	1,487495	1,182953
Textiles, wearing apparel, leather and related products	1,056888	1,021758
Wood and of products of wood and cork, except furniture; articles of straw and plaiting materials	1,254357	1,106998
Paper and paper products	1,25563	1,111266
Printing and recording services	0,919204	0,985832
Coke and refined petroleum products	0,535862	0,835791

Chemicals and chemical products	0,888465	0,961714
Basic pharmaceutical products and pharmaceutical preparations	1,399606	1,127191
Rubber and plastic products	0,9471	0,983077
Other non-metallic mineral products	1,377441	1,151124
Basic metals	1,347563	1,148091
Fabricated metal products, except machinery and equipment	1,122127	1,058134
Computer, electronic and optical products	1,029826	1,009091
Electrical equipment	1,087201	1,0544
Machinery and equipment n.e.c.	1,059509	1,031881
Motor vehicles, trailers and semi-trailers	1,053112	1,024097
Other transport equipment	0,765827	0,925034
Furniture and other manufactured goods	1,021874	1,022359
Repair and installation services of machinery and equipment	0,937076	0,984074
Electricity, gas, steam and air conditioning	1,254387	1,095963
Natural water; water treatment and supply services	0,930433	0,991812
Sewerage services; sewage sludge; waste collection, treatment and disposal services; materials recovery services; remediation services and other waste management services	1,124173	1,063975
Constructions and construction works	1,454053	1,171886
Wholesale and retail trade and repair services of motor vehicles and motorcycles	1,206494	1,046894
Wholesale trade services, except of motor vehicles and motorcycles	1,078883	1,01745
Retail trade services, except of motor vehicles and motorcycles	0,931087	0,955437
Land transport services and transport services via pipelines	1,096761	1,038244
Water transport services	0,617237	0,847037
Air transport services	1,368456	1,124673
Warehousing and support services for transportation	1,11885	1,036031
Postal and courier services	0,976006	0,991686
Accommodation and food services	0,950401	1,003785
Publishing services	1,570977	1,178018
Motion picture, video and television programme production services, sound recording and music publishing; programming and broadcasting services	1,446186	1,171093
Telecommunications services	1,2346	1,051044
Computer programming, consultancy and related services; Information services	0,981008	0,984537
Financial services, except insurance and pension funding	0,35909	0,774933
Insurance, reinsurance and pension funding services, except compulsory social security	1,500455	1,195878
Services auxiliary to financial services and insurance services	1,344978	1,111465
Imputed rents of owner-occupied dwellings	0,083314	0,691009
Real estate services excluding imputed rents	0,433618	0,807186
Legal and accounting services; services of head offices; management consultancy services	0,785623	0,903936
Architectural and engineering services; technical testing and analysis services	1,132172	1,02906
Scientific research and development services	0,736457	0,910101
Advertising and market research services	1,572906	1,166031
Other professional, scientific and technical services and veterinary services	1,218024	1,030811
Rental and leasing services	1,04274	1,010241
Employment services	0,253246	0,740045

Travel agency, tour operator and other reservation services and related services	1,918443	1,278422
Security and investigation services; services to buildings and landscape; office administrative, office support and other business support services	0,956976	0,9812
Public administration and defence services; compulsory social security services	0,570821	0,84522
Education services	0,216343	0,737038
Human health services	0,589049	0,865129
Residential care services; social work services without accommodation	0,854317	0,950507
Creative, arts, entertainment, library, archive, museum, other cultural services; gambling and betting services	0,950745	0,979561
Sporting services and amusement and recreation services	1,366293	1,137274
Services furnished by membership organisations	1,338047	1,124026
Repair services of computers and personal and household goods	0,877346	0,951597
Other personal services	0,682202	0,860603
Services of households as employers; undifferentiated goods and services produced by households for own use	0	0,660772

Several industries with high backward linkages stand out due to their strong ties to suppliers and extensive economic interactions. Among these, food, beverages, and tobacco exhibit one of the highest backward linkages, given their dependence on agriculture, packaging, and retail distribution. Pharmaceuticals also maintain strong linkages, as they require significant inputs from the chemical industry and research sectors. Basic metals and non-metallic minerals play an essential role in industrial supply chains, providing materials for construction and manufacturing. Similarly, wood and paper products have strong connections with printing, packaging, and other industrial applications. In the service sector, several industries demonstrate strong backward linkages, indicating their wide-reaching economic influence. Publishing services are heavily integrated with printing, media, and education, reinforcing their role in information dissemination. Insurance and pension services exhibit strong backward linkages due to their involvement in financial markets and corporate operations. Advertising and market research services contribute to various industries by supporting business expansion and consumer engagement. Telecommunications serve as an essential backbone for modern economies, facilitating digital commerce, automation, and communication across multiple industries. Wholesale trade services play a key role in supply chain efficiency by linking producers with retailers and managing large-scale product distribution. Construction and infrastructure also feature high backward linkages, as they require raw materials, engineering services, and investment. Tourism-related industries, such as travel agencies and accommodation services, stand out as the most interconnected sectors in Greece, given their dependence on transportation, hospitality, retail, and food services. Some industries show moderate backward linkages, meaning that their economic impact is closer to the national average. Agriculture and hunting remain fundamental to the economy, but their backward linkages are slightly lower because they rely on natural resources rather than extensive industrial inputs. Land transport services play a crucial role in logistics and mobility, yet their supply-chain influence is not as pronounced as in wholesale or warehousing. Professional and scientific services, such as legal consulting and business support, show moderate backward linkages since they primarily facilitate business operations. Real estate services, while significant for investment, display lower backward linkages due to their limited dependence on industrial production. Industries with low backward linkages have a weaker-than-average effect on upstream industries. Education services rely mainly on labor rather than industrial goods, leading to lower backward linkages. Healthcare services also have a limited supply-chain impact, as their primary inputs consist of specialized labor and equipment rather than broad industrial products. Employment services focus on human resources rather than material inputs, making them less integrated with supplier industries. Financial services, excluding insurance, exhibit moderate backward linkages since they provide capital flow rather than direct economic stimulation. Postal and courier services, though essential for logistics, have declining economic influence due to digitalization. Some industries operate with minimal reliance on intermediate inputs. Household services have no structured supply-chain dependencies, as they consist of domestic labor and informal employment. Personal and social services, including social work and creative industries, primarily deliver labor-intensive outputs with fewer industrial inputs. Real estate transactions, despite being a major sector in terms of investment, display lower backward linkages because they do not require substantial upstream production.

2.8.3 Forward Linkage: Definition, Measurement, and Normalization

In input–output analysis, forward linkage measures the extent to which a sector supplies intermediate goods to other industries. It is a counterpart to backward linkage, which focuses on a sector's reliance on inputs. A high forward linkage value indicates that a sector plays a key role as a supplier in the production network, making it critical for downstream industries. Understanding forward linkages helps policymakers and analysts assess the impact of supply-side shocks, trade policies, and infrastructure investments.

The historical development of forward linkage measures follows similar lines to backward linkage analysis, with early work by Chenery and Watanabe (1958), Rasmussen (1957), and

Hirschman (1958) providing the initial framework. Later refinements, particularly through the Ghosh model, offered an improved method for assessing forward dependencies.

The earliest measures of forward linkages were based on the Leontief input–output model, specifically using the technical coefficients matrix A and the total requirements matrix L. The row sums of these matrices were proposed as indicators of forward linkages:

- Direct forward linkage (Leontief-based) is computed as the sum of the elements in the ith row of the direct input coefficients matrix A:

$$FL(d)_i = \sum_{j=1}^{n} a_{ij}$$

This measure captures how much sector i contributes to the production of other sectors in direct terms.

- Total forward linkage (Leontief-based) is derived from the Leontief inverse matrix (L), which captures both direct and indirect effects:

$$FL(t)_i = \sum_{j=1}^{n} l_{ij}$$

This accounts for both first-order and higher-order supply-side dependencies. However, these measures faced criticism because they were based on an artificial stimulus—a simultaneous increase in all sectoral outputs (A) or final demands (L). This does not reflect real-world supply-side adjustments, leading to concerns about their validity as forward linkage indicators (Beyers, 1976; Jones, 1976). Given the limitations of the Leontief-based approach, alternative supply-driven linkage measures were developed based on the Ghosh model. This framework, which focuses on the distribution of a sector's output across purchasing industries, was deemed more appropriate for measuring forward linkages (Beyers, 1976; Jones, 1976).

- Direct forward linkage (Ghosh-based) is based on the direct output coefficients matrix B, the direct forward linkage for sector i is given by:

$$FL(d)_i = \sum_{j=1}^{n} b_{ij}$$

This measure represents how much sector i distributes to other sectors as a proportion of its total output. In transactions terms (using Z instead of B), it can be written as:

$$FL(d)_i = \frac{\sum_{j=1}^{n} z_{ij}}{x_i}$$

This was first proposed by Chenery and Watanabe (1958) and provides a sector-specific measure of how much it contributes to intermediate demand.

- Total Forward Linkage (Ghosh-based) incorporates both direct and indirect effects, this measure is based on the Ghosh inverse matrix G ($G = (I - B)^{-1}$):

$$FL(t)_i = \sum_{j=1}^{n} g_{ij}$$

The Ghosh inverse captures how an increase in primary inputs propagates through supply chains, providing a comprehensive measure of forward linkages. Like the Leontief-based measures, there is debate over whether diagonal elements should be included or excluded, depending on whether self-supply is considered an integral part of forward dependencies. In matrix notation, the vector representations of forward linkages are:

$$f(d) = Bi$$

$$f(t) = Gi$$

where i is a column summation vector (a column of ones), ensuring that the total forward dependency of each sector is accounted for.

The Forward Linkages table provides insights into how different sectors in the Greek economy contribute to intermediate demand and influence supply chains. The Direct Forward Linkage (f(d)) measures the extent to which a sector distributes its output to other industries as a proportion of its total production, while the Total Forward Linkage (f(t)) incorporates both direct and indirect effects, reflecting the sector's overall role in supply propagation. In the case of Greek economy the direct and total forward linkages are given in Tabel 6**.**

Table 6: *The direct and total forward linkages of the Greek economy*

	f(d)	f(t)
Products of agriculture, hunting and related services	0,483637	1,64234
Products of forestry, logging and related services	0,289179	1,44683
Fish and other fishing products; aquaculture products; support services to fishing	0,112419	1,12822
Mining and quarrying	0,835389	2,58164
Food, beverages and tobacco products	0,168833	1,20664

Textiles, wearing apparel, leather and related products	0,146838	1,21796
Wood and of products of wood and cork, except furniture; articles of straw and plaiting materials	0,722584	2,13215
Paper and paper products	0,483159	1,85061
Printing and recording services	0,954844	2,29529
Coke and refined petroleum products	0,169326	1,23564
Chemicals and chemical products	0,305735	1,45298
Basic pharmaceutical products and pharmaceutical preparations	0,099127	1,11044
Rubber and plastic products	0,632115	2,01101
Other non-metallic mineral products	0,709403	2,01234
Basic metals	0,334381	1,51959
Fabricated metal products, except machinery and equipment	0,617106	1,84041
Computer, electronic and optical products	0,109868	1,17055
Electrical equipment	0,391161	1,62678
Machinery and equipment n.e.c.	0,042801	1,06729
Motor vehicles, trailers and semi-trailers	0,011964	1,01936
Other transport equipment	0,026265	1,03791
Furniture and other manufactured goods	0,147687	1,17266
Repair and installation services of machinery and equipment	0,87627	2,29264
Electricity, gas, steam and air conditioning	0,594428	1,98635
Natural water; water treatment and supply services	0,315468	1,4459
Sewerage services; sewage sludge; waste collection, treatment and disposal services; materials recovery services; remediation services and other waste management services	0,188453	1,27322
Constructions and construction works	0,173601	1,26475
Wholesale and retail trade and repair services of motor vehicles and motorcycles	0,359227	1,52179
Wholesale trade services, except of motor vehicles and motorcycles	0,359505	1,50996
Retail trade services, except of motor vehicles and motorcycles	0,38637	1,53225
Land transport services and transport services via pipelines	0,461925	1,74275
Water transport services	0,124284	1,15414
Air transport services	0,079071	1,10376
Warehousing and support services for transportation	0,726764	2,14423
Postal and courier services	0,872193	2,38846
Accommodation and food services	0,057919	1,07434
Publishing services	0,296988	1,40663
Motion picture, video and television programme production services, sound recording and music publishing; programming and broadcasting services	0,400436	1,69365
Telecommunications services	0,220329	1,36512
Computer programming, consultancy and related services; Information services	0,471725	1,7573
Financial services, except insurance and pension funding	0,565681	1,85484
Insurance, reinsurance and pension funding services, except compulsory social security	0,178432	1,27469
Services auxiliary to financial services and insurance services	0,978371	2,49023
Imputed rents of owner-occupied dwellings	0	1
Real estate services excluding imputed rents	0,658385	2,07495
Legal and accounting services; services of head offices; management consultancy services	0,848394	2,31301
Architectural and engineering services; technical testing and analysis services	0,951661	2,49158

Scientific research and development services	0,046601	1,05093
Advertising and market research services	0,832975	2,23888
Other professional, scientific and technical services and veterinary services	0,602012	1,7323
Rental and leasing services	0,819828	2,20577
Employment services	0,998943	2,76671
Travel agency, tour operator and other reservation services and related services	0,071837	1,09155
Security and investigation services; services to buildings and landscape; office administrative, office support and other business support services	0,856267	2,27053
Public administration and defence services; compulsory social security services	0,038792	1,05961
Education services	0,017723	1,02117
Human health services	0,09256	1,09986
Residential care services; social work services without accommodation	0,017482	1,02841
Creative, arts, entertainment, library, archive, museum, other cultural services; gambling and betting services	0,213711	1,30222
Sporting services and amusement and recreation services	0,130088	1,16155
Services furnished by membership organisations	0,122133	1,19307
Repair services of computers and personal and household goods	0,40306	1,64583
Other personal services	0,010229	1,01192
Services of households as employers; undifferentiated goods and services produced by households for own use	0,068193	1,08499

Some industries exhibit strong forward linkages, indicating that their outputs are widely used as intermediate inputs by other sectors. Mining and quarrying has one of the highest total forward linkages, suggesting that its extracted raw materials serve as fundamental inputs for various industries, including construction, energy, and manufacturing. Repair and installation services of machinery and equipment also show high forward linkages, demonstrating their importance in maintaining and supporting production processes across multiple industries. Architectural and engineering services, as well as legal and accounting services, exhibit strong total forward linkages, reflecting their role as essential business services that facilitate operations in construction, infrastructure development, and corporate management. Wholesale trade services also have significant forward linkages, indicating their critical function in distributing goods across different economic sectors. The manufacturing sector shows variation in forward linkages depending on the industry. Basic metals and non-metallic mineral products have substantial forward linkages, as their outputs are crucial for industries such as construction, machinery, and manufacturing. Rubber and plastic products and chemicals and chemical products also display relatively high forward linkages, as their materials are widely used in industrial processes. Wood and paper products contribute significantly to supply chains by providing essential materials for packaging, printing, and construction. Several service industries play a key role in distributing outputs across the economy. Telecommunications services have an important forward linkage, as they support multiple business operations, financial services, and digital commerce. Financial services, particularly auxiliary financial services, show high forward linkages, as they provide the necessary infrastructure for investment and economic transactions. Employment services have one of the highest total forward linkages, indicating that they support a wide range of industries by supplying labor resources. Advertising and market research services also contribute significantly, as they provide essential services that facilitate business expansion, branding, and consumer engagement. Some industries exhibit lower forward linkages, meaning their output is primarily consumed directly rather than being used as an input for other industries. Education services, human health services, and residential care services have relatively low forward linkages, as their services are mainly final consumption goods rather than inputs for further production. Retail trade services also show moderate forward linkages, as their primary function is to distribute goods to final consumers rather than serving as an intermediary for industrial processes. Accommodation and food services also fall into this category, as they cater primarily to direct consumers rather than business supply chains. Fromm all the above, the sectors with the highest forward linkages are those that provide essential raw materials, intermediary services, and business support, such as mining, wholesale trade, financial services, and professional consulting. In contrast, industries focused on direct consumption, such as healthcare, education, and retail services, exhibit lower forward linkages. This distinction highlights the importance of certain sectors in sustaining supply chains and supporting overall economic activity.

As with backward linkages, forward linkage values are often normalized to facilitate sectoral comparisons. The normalized direct forward linkage index is defined as:

$$\bar{FL}(d)_i = \frac{FL(d)_i}{\frac{1}{n}\sum_{i=1}^{n} F\,L(d)_i}$$

This ensures that:

- Values greater than 1 indicate above-average forward linkages, meaning a sector supplies more intermediate goods than the typical industry.
- Values less than 1 indicate below-average forward linkages, suggesting a weaker than average supplier role.

In vector notation, the normalized forward linkage indices are:

$$\bar{f}(d) = \frac{nBi}{Bi}$$

$$\bar{f}(t) = \frac{nGi}{Gi}$$

where the average value of the index is set to 1, making it easier to identify sectors with strong supply-side linkages.

The normalized forward linkages table (Table 7) presents a standardized comparison of sectoral forward linkages within the Greek economy. By normalizing direct and total forward linkages, it allows for a clearer assessment of industries that play an above-average role as suppliers of intermediate goods.

Table 7: *Normalized Forward Linkages of the Greek economy*

	Normalized f(d)	Normalized f(t)
Products of agriculture, hunting and related services	1,274714	1,041717
Products of forestry, logging and related services	0,762184	0,917707
Fish and other fishing products; aquaculture products; support services to fishing	0,296301	0,715617
Mining and quarrying	2,20182	1,637504
Food, beverages and tobacco products	0,44499	0,765358
Textiles, wearing apparel, leather and related products	0,387018	0,772538
Wood and of products of wood and cork, except furniture; articles of straw and plaiting materials	1,904502	1,352398
Paper and paper products	1,273454	1,17382
Printing and recording services	2,516666	1,455876
Coke and refined petroleum products	0,44629	0,783752
Chemicals and chemical products	0,80582	0,921608
Basic pharmaceutical products and pharmaceutical preparations	0,261267	0,704339
Rubber and plastic products	1,666055	1,27556
Other non-metallic mineral products	1,869761	1,276404
Basic metals	0,881322	0,963858
Fabricated metal products, except machinery and equipment	1,626496	1,167351
Computer, electronic and optical products	0,289577	0,742466
Electrical equipment	1,030976	1,031848
Machinery and equipment n.e.c.	0,11281	0,67697
Motor vehicles, trailers and semi-trailers	0,031534	0,646568
Other transport equipment	0,069225	0,658334
Furniture and other manufactured goods	0,389256	0,743805
Repair and installation services of machinery and equipment	2,30957	1,454195
Electricity, gas, steam and air conditioning	1,566724	1,259919

Natural water; water treatment and supply services	0,831474	0,917118
Sewerage services; sewage sludge; waste collection, treatment and disposal services; materials recovery services; remediation services and other waste management services	0,496702	0,807589
Constructions and construction works	0,457557	0,802216
Wholesale and retail trade and repair services of motor vehicles and motorcycles	0,946808	0,965254
Wholesale trade services, except of motor vehicles and motorcycles	0,947541	0,95775
Retail trade services, except of motor vehicles and motorcycles	1,018349	0,971888
Land transport services and transport services via pipelines	1,217488	1,105406
Water transport services	0,327573	0,732058
Air transport services	0,208405	0,700102
Warehousing and support services for transportation	1,915519	1,36006
Postal and courier services	2,298824	1,514972
Accommodation and food services	0,152656	0,681441
Publishing services	0,782766	0,892209
Motion picture, video and television programme production services, sound recording and music publishing; programming and broadcasting services	1,055422	1,074262
Telecommunications services	0,580717	0,86588
Computer programming, consultancy and related services; Information services	1,243317	1,114635
Financial services, except insurance and pension funding	1,490956	1,176503
Insurance, reinsurance and pension funding services, except compulsory social security	0,47029	0,808521
Services auxiliary to financial services and insurance services	2,578675	1,579524
Imputed rents of owner-occupied dwellings	0	0,634288
Real estate services excluding imputed rents	1,735294	1,316117
Legal and accounting services; services of head offices; management consultancy services	2,236097	1,467115
Architectural and engineering services; technical testing and analysis services	2,508276	1,58038
Scientific research and development services	0,122827	0,666593
Advertising and market research services	2,195458	1,420096
Other professional, scientific and technical services and veterinary services	1,586713	1,098778
Rental and leasing services	2,160806	1,399094
Employment services	2,632897	1,754892
Travel agency, tour operator and other reservation services and related services	0,189338	0,692357
Security and investigation services; services to buildings and landscape; office administrative, office support and other business support services	2,256848	1,440171
Public administration and defence services; compulsory social security services	0,102244	0,672098
Education services	0,046712	0,647716
Human health services	0,24396	0,697628
Residential care services; social work services without accommodation	0,046076	0,652308
Creative, arts, entertainment, library, archive, museum, other cultural services; gambling and betting services	0,563274	0,825983
Sporting services and amusement and recreation services	0,342871	0,736758
Services furnished by membership organisations	0,321904	0,75675
Repair services of computers and personal and household goods	1,062338	1,043931
Other personal services	0,026959	0,641849
Services of households as employers; undifferentiated goods and services produced by households for own use	0,179736	0,688197

From Table 2.4 we observe that certain industries exhibit high normalized forward linkages, indicating that they distribute significantly more of their output as intermediate inputs compared to the average sector. Mining and quarrying has one of the highest normalized values, with a direct forward linkage of 2.2018 and a total forward linkage of 1.6375, emphasizing its essential role in supplying raw materials to industries such as energy, manufacturing, and construction. Printing and recording services and repair and installation of machinery and equipment also demonstrate strong supply-side linkages, as they provide crucial intermediate services that support production across multiple industries. Services auxiliary to financial services and insurance, as well as legal and accounting services, have some of the highest normalized forward linkages, reflecting their role in facilitating business operations and investment. The manufacturing sector presents varied results depending on the industry. Rubber and plastic products, non-metallic mineral products, and fabricated metal products all have above-average forward linkages, indicating that their outputs are widely used in construction, industrial production, and other secondary manufacturing processes. Wood and paper products also rank highly in terms of forward linkages, reinforcing their importance in packaging, printing, and construction supply chains. On the other hand, motor vehicles and transport equipment show lower forward linkages, suggesting that these industries supply primarily final goods rather than intermediate products. The service sector includes both high and low forward linkage industries. Financial services, particularly employment services, advertising, and market research, have some of the strongest forward linkages, as they provide critical business support functions. Telecommunications and IT services also contribute significantly, serving as foundational industries for digital commerce and communication networks. In contrast, education, healthcare, and residential care services exhibit lower-than-average forward linkages, as their services are consumed directly rather than being used in further production processes. Retail trade services have a normalized forward linkage close to one, reflecting their balanced role between distribution and final consumption. Some sectors have below-average forward linkages, indicating that they play a weaker role as suppliers of intermediate goods. Fish and fishing products, accommodation and food services, and air transport services rank among the lowest, meaning that their outputs are primarily directed toward final consumption rather than feeding into other industries. Real estate services, while significant in economic terms, also exhibit moderate forward linkages due to their limited interaction with industrial supply chains. To sum up, the industries with the strongest forward linkages are those that act as fundamental suppliers of raw materials, intermediary services, and business support, such as mining, printing, financial services, and manufacturing-related industries. Meanwhile, sectors that focus primarily on final consumption, such as education, healthcare, and personal services, tend to have lower forward linkages.

2.8.4 Classifying Backward and Forward Linkage Results: Identifying Key Sectors in Economic Analysis

The classification of backward and forward linkages is an essential step in identifying key sectors within an economy. By analyzing these linkages, researchers and policymakers can determine which industries drive intersectoral demand and supply relationships, offering valuable insights for industrial planning, economic development, and policy formulation.

Most studies aiming to identify key sectors rely on normalized backward and forward linkage measures, ensuring that comparisons are not biased by differences in sectoral scale. In normalized form, a linkage value greater than one indicates that a sector exhibits above-average interdependence with other sectors, while a value less than one suggests below-average interconnectivity.

A sector is typically classified as key if it ranks high in both backward and forward linkages, meaning it is both a major consumer of intermediate inputs and a crucial supplier of intermediate goods. However, not all sectors fit this dual classification. To provide a more detailed perspective, a four-way classification system is often used.

A commonly used classification framework distributes sectors into four categories, depending on whether their backward and forward linkages are above or below the economy-wide average. This method allows for a systematic assessment of sectoral interdependencies.

The classification follows a 2 × 2 matrix is given in Table 8.

Table 8: *Identifying Key Sectors*

	Direct or Total Forward Linkage	
Direct or Total Backward Linkage	Low (<1)	High (>1)
Low (<1)	(I) Generally Independent	(II) Dependent on Interindustry Demand
High (>1)	(IV) Dependent on Interindustry Supply	(III) Generally Dependent

Each category represents a different role in the economy:

(I) Generally Independent Sectors (low backward and low forward linkage)

- These sectors have limited intersectoral connections and do not play a significant role in input-output interactions.
- They neither demand many intermediate goods from other sectors nor supply many intermediate goods for production in other industries.
- Economic Implication: Expanding these sectors may have a limited ripple effect across the economy.

(II) Sectors Dependent on Interindustry Demand (low backward and high forward linkage)

- These sectors are strong suppliers of intermediate goods but have relatively low dependency on interindustry inputs.
- They provide critical raw materials or intermediate goods for other sectors but do not rely heavily on inputs from other industries.
- Economic Implication: Growth in these sectors is highly influenced by demand from downstream industries, making them sensitive to fluctuations in manufacturing and industrial production.

(III) Generally Dependent Sectors (high backward and high forward linkage)

- These sectors are highly interconnected and serve as both major consumers of intermediate goods and key suppliers of inputs for other industries.
- Their growth stimulates multiple sectors simultaneously, making them key industries for economic development.
- Economic Implication: These sectors act as engines of economic growth, meaning that targeted policies to support their expansion can create strong multiplier effects throughout the economy.

(IV) Sectors Dependent on Interindustry Supply (high backward and low forward linkage)

- These sectors heavily rely on interindustry inputs but do not act as major suppliers of intermediate goods.
- They primarily convert inputs into final goods or operate in areas where their output is mostly consumed directly rather than used as an input for further production.
- Economic Implication: Their performance depends on the availability and cost of upstream inputs, making them vulnerable to supply chain disruptions.

The classification of industries based on their backward and forward linkages provides a structured way to understand their roles in the economy. Industries fall into four categories depending on whether their direct and total backward linkages and direct and total forward linkagesare above or below the average value of 1. Some industries exhibit strong backward and forward linkages, indicating that they both rely heavily on inputs from other sectors and supply significant intermediate goods. These industries are considered generally dependent on the economy and play a central role in production networks. Mining and quarrying is a clear example, with backward linkages slightly above 1, while its forward linkages are significantly above average, particularly with a direct forward linkage of 2.2018, indicating its crucial role in supplying raw materials. Similarly, wood and paper products, printing services, and repair and installation of machinery demonstrate high values in both linkage measures, meaning they both depend on upstream industries and supply essential intermediate goods to other sectors. Industries that have high backward linkages but low forward linkages are dependent on interindustry demand, meaning they rely significantly on inputs from other sectors but do not contribute as much to supplying other industries. Food, beverages, and tobacco products fall into this category, with strong backward linkages ($\bar{b}(d) = 1.487$, $\bar{b}(t) = 1.183$) but weaker forward linkages ($\bar{f}(d) = 0.445$, $\bar{f}(t) = 0.765$), reflecting the fact that food processing is highly dependent on agricultural inputs but mainly supplies products for final consumption rather than intermediate production. Other manufacturing sectors such as textiles, pharmaceuticals, and motor vehicles also fall into this category, as they require substantial inputs but mostly produce consumer or capital goods rather than intermediate inputs. Conversely, industries with low backward linkages but high forward linkages are dependent on interindustry supply, meaning they do not rely as much on inputs from other sectors but serve as key suppliers to the economy. Financial and business services, including legal and accounting services, advertising and market research, and telecommunications, fit this profile. These industries provide essential services that facilitate business operations, finance, and communication but do not require extensive intermediate inputs themselves. Wholesale and retail trade services also fall into this category, acting as major distributors of goods across the economy while sourcing relatively fewer inputs. Industries that have both low backward and forward linkages are generally independent, meaning they have weaker interactions with other sectors and tend to focus on final consumption rather than interindustry transactions. Education, healthcare, and residential care services fit this classification, as they provide essential public and social services but do not significantly influence supply chains. Real estate services, accommodation and food services, and household services also exhibit this pattern, as they primarily serve end consumers rather than industrial supply networks. So, the classification of sectors based on backward and forward linkages highlights their varying roles in economic interdependencies. Some industries act as key intermediaries by both consuming and supplying large volumes of inputs, while others are highly specialized, either as demand-driven sectors that rely on extensive inputs or as supply-driven industries that provide essential goods and services to the rest of the economy. Understanding these relationships is crucial for identifying key drivers of economic activity and ensuring a balanced, interconnected industrial structure.

Next we ranking the industries bases on their linkage effects (Table 9). So, we can now quickly identify industries with strong or weak backward and forward linkage effects, helpful for targeting industrial or investment policies. This means that industries with consistently high ranks across multiple columns (e.g., "Food and beverages," "Wholesale trade," "Electricity and gas") are key economic drivers, while with consistently low rankings could be examined for potential policy support or restructuring.

Table 9: *Ranking the Linkages of the Greek economy; based on the traditional methods*

	Normalized b(d)	Normalized b(t)	Normalized f(d)	Normalized f(t)
Products of agriculture, hunting and related services	19	19	9	11
Products of forestry, logging and related services	29	29	19	18
Fish and other fishing products; aquaculture products; support services to fishing	30	30	26	27
Mining and quarrying	21	20	3	1
Food, beverages and tobacco products	1	1	23	24
Textiles, wearing apparel, leather and related products	16	17	25	23
Wood and of products of wood and cork, except furniture; articles of straw and plaiting materials	8	7	4	4
Paper and paper products	6	6	10	8
Printing and recording services	26	23	1	2
Coke and refined petroleum products	31	31	22	22
Chemicals and chemical products	27	26	18	17
Basic pharmaceutical products and pharmaceutical preparations	3	5	28	28
Rubber and plastic products	22	25	6	6
Other non-metallic mineral products	4	3	5	5
Basic metals	5	4	16	15
Fabricated metal products, except machinery and equipment	11	10	7	9
Computer, electronic and optical products	18	21	27	26
Electrical equipment	13	11	12	12
Machinery and equipment n.e.c.	15	14	29	29
Motor vehicles, trailers and semi-trailers	17	15	31	31

Other transport equipment	28	28	30	30
Furniture and other manufactured goods	20	16	24	25
Repair and installation services of machinery and equipment	23	24	2	3
Electricity, gas, steam and air conditioning	7	8	8	7
Natural water; water treatment and supply services	25	22	17	19
Sewerage services; sewage sludge; waste collection, treatment and disposal services; materials recovery services; remediation services and other waste management services	10	9	20	20
Constructions and construction works	2	2	21	21
Wholesale and retail trade and repair services of motor vehicles and motorcycles	9	12	15	14
Wholesale trade services, except of motor vehicles and motorcycles	14	18	14	16
Retail trade services, except of motor vehicles and motorcycles	24	27	13	13
Land transport services and transport services via pipelines	12	13	11	10

The analysis of normalized backward and forward linkages reveals distinct sectoral patterns. In terms of normalized backward linkages in domestic output (b(d)), the highest-ranked sectors include "Food, beverages, and tobacco," "Constructions," and "Pharmaceutical products," indicating strong domestic interdependencies. In contrast, sectors such as "Petroleum products" and "Forestry" rank lowest, reflecting weaker domestic backward linkages. When considering total normalized backward linkages (b(t)), the strongest effects are observed in sectors like "Food, beverages, and tobacco," "Constructions," and "Non-metallic mineral products," while "Forestry" and "Fish products" exhibit the weakest backward linkages. For normalized forward linkages in domestic output (f(d)), the highest values are recorded in sectors such as "Printing services," "Repair services," and "Mining and quarrying," signifying their strong role as suppliers within the economy. Conversely, sectors like "Motor vehicles," "Education," and "Transport equipment" rank low, indicating limited forward linkages. When examining total normalized forward linkages (f(t)), sectors such as "Repair and installation services," "Printing services," and "Machinery installation" display the strongest total forward linkage effects, while "Motor vehicles" and similar sectors continue to exhibit the weakest forward linkages.

2.9 Hypothetical Extraction

2.9.1 Measuring Sectoral Importance in Input–Output Models

Traditional backward and forward linkage measures, while useful, rely on direct and indirect dependency coefficients within the input-output system. However, these measures do not fully capture the extent to which a sector supports or depends on the rest of the economy. However, the Hypothetical Extraction Method (HEM) is a powerful analytical tool that offers several advantages over traditional backward and forward linkage measures. One of its key strengths lies in its ability to capture both direct and indirect effects. Traditional linkage measures, which rely on summing input coefficients (A) or output coefficients (B), provide useful insights into intersectoral dependencies but fail to account for the nonlinear feedback loops within an economy. In contrast, the hypothetical extraction method removes an entire sector and assesses the full system-wide effect of its absence, including indirect feedback effects that conventional measures might overlook.

Another major advantage of HEM is its ability to assess the true role of a sector within the economy. A sector with high backward and forward linkages does not necessarily mean it is critical for economic stability or growth. The hypothetical extraction method directly quantifies the reduction in total output caused by the removal of a sector, offering a more precise measure of its systemic importance. This makes it particularly valuable for policy analysis, as it can help identify sectors whose decline or collapse would cause significant economic disruption.

Unlike traditional linkage measures that often depend on arbitrary normalization techniques, such as dividing by sectoral averages, the hypothetical extraction method provides an absolute measure of sectoral importance. This eliminates potential biases introduced by normalization and allows for more meaningful cross-country or cross-sectoral comparisons.

HEM also extends naturally to spatial and international contexts, making it a valuable tool for analyzing global value chains and regional economic dependencies. By assessing how the removal of a sector—or even an entire region—affects the broader economic system, this approach provides insights into vulnerabilities within trade networks and interregional dependencies.

From a policy and industrial strategy perspective, the hypothetical extraction method offers crucial advantages. Traditional linkage measures may overlook sectors that, despite not having extreme linkage values, hold high systemic importance in maintaining economic stability. By revealing the broader economic vulnerability to sectoral disruptions, HEM provides valuable input for resilience planning, economic diversification strategies, and industrial policy design. Its ability to highlight key sectors that sustain economic structures makes it an essential tool for policymakers aiming to safeguard economic stability and long-term growth.

So, while traditional linkage measures provide valuable insights into sectoral interdependencies, the hypothetical extraction method is a more robust approach for assessing the true economic significance of a sector. It allows policymakers and researchers to quantify the consequences of a sector's absence, offering a more realistic picture of economic structure and resilience. Thus, if the objective is to prioritize sectors based on their importance, the hypothetical extraction method can be seen as superior to traditional backward and forward linkage measures.

2.9.2 Conceptual Framework of Hypothetical Extraction

The hypothetical extraction approach is a widely used method in input–output analysis for quantifying the economic impact of removing a specific sector from an economy. This technique assesses how much total output would decrease if a particular sector were eliminated or ceased production, providing a robust measure of the sector's total linkage within the economic system.

First introduced in Paelinck et al. (1965) and Strassert (1968) and later formalized in Schultz (1976, 1977), the approach offers a comprehensive way to evaluate the relative importance of sectors in terms of their contribution to intersectoral trade and economic output.

The core idea behind hypothetical extraction is to simulate the removal of a sector from the input–output system and observe how the remaining sectors adjust. This is achieved by modifying the input–output matrix in a way that excludes the transactions associated with the extracted sector.

For an economy with n sectors, the total economic output (x) is determined using the standard Leontief model. When a sector j is removed, the modified economy operates with a reduced input–output matrix A^*, which excludes sector j. The new output vector for the modified economy is:

$$x^*(j) = [I - A^*(j)]^{-1} f^*(j)$$

where:

- $A^*(j)$ is the (n−1) × (n−1) input–output matrix without sector j
- $f^*(j)$ is the reduced final demand vector that excludes demand for sector j

The difference between total output in the full economy and total output after extraction provides an estimate of the economic loss due to the sector's removal:

$$T_j = ix - ix^*(j)$$

where T_j represents the total linkage of sector j, reflecting the extent to which the economy depends on sector j for production and demand interactions.

For a normalized interpretation, the impact is often expressed as a percentage reduction in total output:

$$T_j^* = 100 \times \frac{\left(ix - ix^*(j)\right)}{ix}$$

This normalization allows for comparisons across sectors, making it easier to identify key industries with significant economic influence.

2.9.3 Backward and Forward Linkage Decomposition Using Hypothetical Extraction

The hypothetical extraction approach can also be used separately to measure the backward and forward linkages of a sector.

Backward linkages quantify the extent to which a sector depends on inputs from other industries. To simulate the removal of these linkages, column j of the input coefficients matrix A is replaced with zeros, effectively ensuring that sector j no longer demands any intermediate goods from other sectors. This modification isolates the sector's role as a consumer within the production system and allows for the assessment of its reliance on upstream suppliers.

Following this adjustment, the new economic output is computed using the equation:

$$x^*\left(c_j\right) = \left[I - A^*\left(c_j\right)\right]^{-1} f$$

where $A^*\left(c_j\right)$ represents the input-output matrix with column j replaced by zeros. This transformed system yields a revised set of economic outputs, reflecting the consequences of removing sector j's demand for intermediate inputs.

The backward linkage contribution of sector j is then determined by:

$$B(t)_j = ix - ix^*\left(c_j\right)$$

which measures the extent to which sector j depends on its suppliers and, by extension, its significance for upstream industries. This approach provides a direct quantification of how critical a sector is in sustaining the demand for intermediate goods across the economy.

To enable cross-sectoral comparisons, a normalized version of this measure is given by:

$$B^*(t)_j = 100 \times \frac{\left(ix - ix^*(c_j)\right)}{ix}$$

This normalization standardizes the impact, allowing for meaningful comparisons of backward linkages across different sectors, regardless of their absolute economic size. Using now the empirical data of Greek economy for 2000, we can easily estimate the $B(t)_j$ and $B^*(t)_j$, see Table 10.

Table 10: *Backward linkages; hypothetical extraction approach*

	B(t)	B*(t)
Products of agriculture, hunting and related services	4947,22	1,87204
Products of forestry, logging and related services	69,7237	0,026384
Fish and other fishing products; aquaculture products; support services to fishing	244,842	0,092649
Mining and quarrying	422,981	0,160057
Food, beverages and tobacco products	12125,6	4,58838
Textiles, wearing apparel, leather and related products	683,749	0,258733
Wood and of products of wood and cork, except furniture; articles of straw and plaiting materials	223,481	0,084566
Paper and paper products	781,975	0,295902
Printing and recording services	241,116	0,091239
Coke and refined petroleum products	2473,73	0,936065
Chemicals and chemical products	961,986	0,364019
Basic pharmaceutical products and pharmaceutical preparations	1508,8	0,570933
Rubber and plastic products	858,844	0,324989
Other non-metallic mineral products	1180,74	0,446796
Basic metals	2681,78	1,01479
Fabricated metal products, except machinery and equipment	1600,68	0,605701
Computer, electronic and optical products	190,892	0,072234
Electrical equipment	837,21	0,316803
Machinery and equipment n.e.c.	506,346	0,191603
Motor vehicles, trailers and semi-trailers	122,579	0,046384
Other transport equipment	141,349	0,053487
Furniture and other manufactured goods	358,38	0,135612
Repair and installation services of machinery and equipment	272,361	0,103062
Electricity, gas, steam and air conditioning	5200,95	1,96805
Natural water; water treatment and supply services	502,196	0,190032

Sewerage services; sewage sludge; waste collection, treatment and disposal services; materials recovery services; remediation services and other waste management services	1234,67	0,467202
Constructions and construction works	6265,47	2,37087
Wholesale and retail trade and repair services of motor vehicles and motorcycles	1379,9	0,522158
Wholesale trade services, except of motor vehicles and motorcycles	10267,6	3,88528
Retail trade services, except of motor vehicles and motorcycles	4328,07	1,63776
Land transport services and transport services via pipelines	2874,06	1,08755
Water transport services	3475,13	1,315
Air transport services	536,993	0,2032
Warehousing and support services for transportation	2388,83	0,90394
Postal and courier services	507,403	0,192003
Accommodation and food services	5841,55	2,21046
Publishing services	668,137	0,252825
Motion picture, video and television programme production services, sound recording and music publishing; programming and broadcasting services	703,529	0,266218
Telecommunications services	3512,78	1,32925
Computer programming, consultancy and related services; Information services	1412,64	0,534549
Financial services, except insurance and pension funding	1225,47	0,463722
Insurance, reinsurance and pension funding services, except compulsory social security	1362,81	0,51569
Services auxiliary to financial services and insurance services	733,319	0,27749
Imputed rents of owner-occupied dwellings	691,214	0,261558
Real estate services excluding imputed rents	2746,41	1,03925
Legal and accounting services; services of head offices; management consultancy services	1617,41	0,612033
Architectural and engineering services; technical testing and analysis services	1465,96	0,554724
Scientific research and development services	1121,26	0,424287
Advertising and market research services	963,626	0,364639
Other professional, scientific and technical services and veterinary services	182,443	0,069037
Rental and leasing services	458,838	0,173626
Employment services	44,3857	0,016796
Travel agency, tour operator and other reservation services and related services	667,01	0,252399
Security and investigation services; services to buildings and landscape; office administrative, office support and other business support services	900,77	0,340854
Public administration and defence services; compulsory social security services	5691,6	2,15372
Education services	1013,3	0,383436
Human health services	2927,61	1,10782
Residential care services; social work services without accommodation	471,272	0,178331
Creative, arts, entertainment, library, archive, museum, other cultural services; gambling and betting services	1023,34	0,387237
Sporting services and amusement and recreation services	594,236	0,224861
Services furnished by membership organisations	1632,56	0,617767
Repair services of computers and personal and household goods	134,629	0,050944
Other personal services	342,247	0,129507
Services of households as employers; undifferentiated goods and services produced by households for own use	0,423552	0,00016

The industries analyzed using the hypothetical extraction approach reveal varying degrees of dependency on their suppliers. Among the most dependent sectors are food, beverages and tobacco products, wholesale trade, and construction, which exhibit strong interlinkages with upstream industries. These sectors play a crucial role in economic activity, relying heavily on intermediate inputs from multiple sources. Other sectors with significant backward linkages include electricity and gas, agriculture, and accommodation and food services, all of which contribute substantially to supply chains by requiring inputs from various industries. In contrast, industries such as employment services, forestry and logging, and household services display minimal reliance on upstream sectors. Other professional and technical services, as well as repair services, also exhibit lower backward linkages, indicating a reduced level of integration with intermediate suppliers.

Forward linkages measure the extent to which a sector supplies its output to other industries. Unlike backward linkages, which focus on input dependencies, forward linkages assess a sector's role as a supplier within the economy. To simulate the removal of a sector's forward linkages, the approach modifies the output coefficients matrix (B) instead of the input coefficients matrix (A). The output coefficients matrix describes how sectoral outputs are allocated across industries.

In this process, row j in B is replaced with zeros, effectively eliminating sector j's role as a supplier within the economy. This adjustment allows for an assessment of the downstream effects of removing sector j, capturing its significance in sustaining production in other industries. The new economic system is then expressed as:

$$x^*(r_j) = v\left(I - B^*(r_j)\right)^{-1}$$

where $B^*(r_j)$ represents the Ghosh-based output coefficients matrix with row j replaced by zeros. This modified framework recalculates economic outputs under the assumption that sector j no longer supplies any inputs to other industries.

The forward linkage contribution of sector j is then determined by:

$$F(t)_j = x - x^*(r_j)$$

which quantifies the extent to which sector j contributes to the functioning of downstream industries. This measure captures the systemic impact of a sector's removal, reflecting its importance in supplying inputs to other parts of the economy.

To facilitate cross-sectoral comparisons, a normalized version of this measure is given by:

$$F^*(t)_j = 100 \times \frac{\left(x - x^*(r_j)\right)}{x}$$

This normalization standardizes the impact, allowing for meaningful comparisons across sectors by expressing their forward linkages as relative proportions of total economic activity. Using the empirical data of Greek economy for 2000, we can easily estimate the $F(t)_j$ and $F^*(t)_j$, see Table 11.

Table 11: *Forward linkages; hypothetical extraction approach*

	F(t)	F*(T)
Products of agriculture, hunting and related services	5921,97	2,24089
Products of forestry, logging and related services	90,6407	0,034299
Fish and other fishing products; aquaculture products; support services to fishing	109,339	0,041374
Mining and quarrying	1267,2	0,479513
Food, beverages and tobacco products	3170,94	1,19989
Textiles, wearing apparel, leather and related products	273,111	0,103346
Wood and of products of wood and cork, except furniture; articles of straw and plaiting materials	374,463	0,141698
Paper and paper products	975,549	0,369151
Printing and recording services	634,259	0,240006
Coke and refined petroleum products	2200,86	0,832811
Chemicals and chemical products	956,85	0,362075
Basic pharmaceutical products and pharmaceutical preparations	236,474	0,089483
Rubber and plastic products	1779,77	0,673471
Other non-metallic mineral products	1610,66	0,60948
Basic metals	1889,59	0,715026
Fabricated metal products, except machinery and equipment	2236,87	0,84644
Computer, electronic and optical products	62,1111	0,023503
Electrical equipment	880,911	0,33334
Machinery and equipment n.e.c.	61,0987	0,02312
Motor vehicles, trailers and semi-trailers	4,7871	0,001811
Other transport equipment	3,8449	0,005239
Furniture and other manufactured goods	113,427	0,042921
Repair and installation services of machinery and equipment	718,941	0,27205
Electricity, gas, steam and air conditioning	7788,92	2,94735
Natural water; water treatment and supply services	447,077	0,169175
Sewerage services; sewage sludge; waste collection, treatment and disposal services; materials recovery services; remediation services and other waste management services	553,108	0,209298
Constructions and construction works	2144,82	0,811605
Wholesale and retail trade and repair services of motor vehicles and motorcycles	1232,27	0,466294
Wholesale trade services, except of motor vehicles and motorcycles	9700,12	3,67055
Retail trade services, except of motor vehicles and motorcycles	5165,68	1,95471
Land transport services and transport services via pipelines	3736,71	1,41398
Water transport services	1900,43	0,71913

Air transport services	79,783	0,03019
Warehousing and support services for transportation	4812,63	1,82111
Postal and courier services	1406,08	0,532064
Accommodation and food services	836,962	0,316709
Publishing services	347,331	0,131431
Motion picture, video and television programme production services, sound recording and music publishing; programming and broadcasting services	631,99	1,95471
Telecommunications services	2171,76	0,821801
Computer programming, consultancy and related services; Information services	2183,19	0,826125
Financial services, except insurance and pension funding	6062	2,29388
Insurance, reinsurance and pension funding services, except compulsory social security	462,612	0,175054
Services auxiliary to financial services and insurance services	1601,79	0,606121
Imputed rents of owner-occupied dwellings	0,48544	0,000184
Real estate services excluding imputed rents	13321,8	5,04102
Legal and accounting services; services of head offices; management consultancy services	5769,8	2,18331
Architectural and engineering services; technical testing and analysis services	3922,46	1,48427
Scientific research and development services	151,776	0,057433
Advertising and market research services	1561,06	0,590712
Other professional, scientific and technical services and veterinary services	238,484	0,090243
Rental and leasing services	1045,67	0,395684
Employment services	647,941	0,245183
Travel agency, tour operator and other reservation services and related services	65,7731	0,024889
Security and investigation services; services to buildings and landscape; office administrative, office support and other business support services	2359,41	0,892808
Public administration and defence services; compulsory social security services	1215,82	0,46007
Education services	186,303	0,070498
Human health services	945,67	0,357845
Residential care services; social work services without accommodation	30,991	0,011727
Creative, arts, entertainment, library, archive, museum, other cultural services; gambling and betting services	641,256	0,242653
Sporting services and amusement and recreation services	133,516	0,050523
Services furnished by membership organisations	449,955	0,170264
Repair services of computers and personal and household goods	97,409	0,0747
Other personal services	13,9599	0,005282
Services of households as employers; undifferentiated goods and services produced by households for own use	57,7522	0,021854

Real estate services stand out as the most significant, reflecting its deep connections across various economic activities. Wholesale trade and electricity supply also show a strong impact, reinforcing their essential role in maintaining economic flows. Industries like financial services and legal consultancy demonstrate a moderate influence, indicating their importance in business operations but not as direct drivers of industrial production. Land transport services are another key player, as logistics and supply chains depend heavily on efficient movement of goods. On the other end, industries like motor vehicle production and air transport exhibit minimal forward linkages, suggesting that their removal would not disrupt the broader economy as much. This may be due to their specialized nature or limited integration with other sectors. Interestingly, agriculture and food production maintain a notable impact, likely due to their role in supply chains. Telecommunications and IT services also show strong linkages, reflecting the increasing reliance on digital infrastructure. Hence, this analysis underscores the critical role of trade, utilities, and essential services in sustaining economic activity, while specialized industries may have a more isolated influence.

In Table 12, the linkage measures are normalized based on the sectoral average, allowing for a relative comparison of backward and forward linkages across industries. This normalization ensures that the values reflect the degree of interdependence in relation to the overall economic structure, facilitating meaningful cross-sectoral comparisons.

Table 12: *Average Backward and Forward linkages; hypothetical extraction approach*

	Average B*(t)	Average F*(t)
Products of agriculture, hunting and related services	2,813405	3,258055
Products of forestry, logging and related services	0,039651	0,049867
Fish and other fishing products; aquaculture products; support services to fishing	0,139238	0,060154
Mining and quarrying	0,240543	0,697169
Food, beverages and tobacco products	6,895672	1,744533
Textiles, wearing apparel, leather and related products	0,388838	0,150256
Wood and of products of wood and cork, except furniture; articles of straw and plaiting materials	0,12709	0,206016
Paper and paper products	0,444698	0,536713
Printing and recording services	0,137119	0,348947
Coke and refined petroleum products	1,40677	1,210833
Chemicals and chemical products	0,547068	0,526425
Basic pharmaceutical products and pharmaceutical preparations	0,85803	0,1301
Rubber and plastic products	0,488411	0,979167
Other non-metallic mineral products	0,67147	0,88613
Basic metals	1,525083	1,039584
Fabricated metal products, except machinery and equipment	0,910281	1,230648
Computer, electronic and optical products	0,108558	0,034171
Electrical equipment	0,476109	0,484647
Machinery and equipment n.e.c.	0,287952	0,033614
Motor vehicles, trailers and semi-trailers	0,069709	0,002634
Other transport equipment	0,080383	0,007617
Furniture and other manufactured goods	0,203805	0,062403
Repair and installation services of machinery and equipment	0,154887	0,395536
Electricity, gas, steam and air conditioning	2,957695	4,285185
Natural water; water treatment and supply services	0,285591	0,245965
Sewerage services; sewage sludge; waste collection, treatment and disposal services; materials recovery services; remediation services and other waste management services	0,702137	0,304301

Constructions and construction works	3,563075	1,180001
Wholesale and retail trade and repair services of motor vehicles and motorcycles	0,784728	0,67795
Wholesale trade services, except of motor vehicles and motorcycles	5,839014	5,336653
Retail trade services, except of motor vehicles and motorcycles	2,461317	2,841974
Land transport services and transport services via pipelines	1,63443	2,055801
Water transport services	1,976255	1,045551
Air transport services	0,30538	0,043894
Warehousing and support services for transportation	1,358491	2,647732
Postal and courier services	0,288553	0,773574
Accommodation and food services	3,322002	0,460467
Publishing services	0,379959	0,191089
Motion picture, video and television programme production services, sound recording and music publishing; programming and broadcasting services	0,400087	2,841974
Telecommunications services	1,997671	1,194826
Computer programming, consultancy and related services; Information services	0,80335	1,201112
Financial services, except insurance and pension funding	0,696907	3,335097
Insurance, reinsurance and pension funding services, except compulsory social security	0,775008	0,254513
Services auxiliary to financial services and insurance services	0,417027	0,881246
Imputed rents of owner-occupied dwellings	0,393084	0,000267
Real estate services excluding imputed rents	1,561843	7,329195
Legal and accounting services; services of head offices; management consultancy services	0,919797	3,174338
Architectural and engineering services; technical testing and analysis services	0,83367	2,157997
Scientific research and development services	0,637642	0,083502
Advertising and market research services	0,548	0,858843
Other professional, scientific and technical services and veterinary services	0,103752	0,131205
Rental and leasing services	0,260935	0,575289
Employment services	0,025242	0,356474
Travel agency, tour operator and other reservation services and related services	0,379319	0,036186
Security and investigation services; services to buildings and landscape; office administrative, office support and other business support services	0,512254	1,298063
Public administration and defence services; compulsory social security services	3,23673	0,668901
Education services	0,576249	0,102497
Human health services	1,664893	0,520275
Residential care services; social work services without accommodation	0,268006	0,01705
Creative, arts, entertainment, library, archive, museum, other cultural services; gambling and betting services	0,581961	0,352796
Sporting services and amusement and recreation services	0,337934	0,073456
Services furnished by membership organisations	0,928414	0,247549
Repair services of computers and personal and household goods	0,076562	0,108607
Other personal services	0,19463	0,00768
Services of households as employers; undifferentiated goods and services produced by households for own use	0,000241	0,031773

Based on the above we can define four categories of industries:

High Backward Linkages (>1) & High Forward Linkages (>1)

- If a sector exhibits high values in both backward and forward linkage extraction measures, it indicates strong interdependence with the rest of the economy.
- Example applications have been conducted in Dietzenbacher and van der Linden (1997) using European Community data.
- These industries are key economic intermediaries, playing both a major consumer and supplier role within the economy.
- Includes sectors such as agriculture, food processing, petroleum refining, metals, utilities, construction, wholesale/retail trade, transport, telecommunications, and real estate services.
- Their strong interconnections suggest that policy interventions or shocks in these sectors will have broad spillover effects across the economy.

High Backward Linkages (>1) & Low Forward Linkages (<1)

- Industries in this category consume many inputs but do not significantly supply intermediate goods or services to other industries.
- Includes accommodation and food services, public administration, and healthcare.
- These sectors drive demand but do not serve as core suppliers, meaning policies affecting their demand will have substantial upstream effects but limited downstream impacts.

Low Backward Linkages (<1) & High Forward Linkages (>1)

- These industries supply other sectors significantly but have low demand for inputs from the domestic economy.
- Includes fabricated metal products, media, IT services, financial services, consultancy, and business services.
- They are key providers of essential services to multiple industries, meaning their performance affects economic efficiency and competitiveness.

Low Backward Linkages (<1) & Low Forward Linkages (<1)

- These industries are less integrated into the domestic economy, having minimal interdependencies.

- Includes mining, textiles, chemicals, pharmaceuticals, electronics, machinery, vehicles, education, scientific research, air transport, publishing, creative industries, and personal services.
- Their lower integration suggests that changes in these sectors have more localized or isolated effects, making them less central to economic propagation mechanisms.

An analytical categorization of the industries of the Greek economy is given in Table 13.

Table 13: *Classification of hypothetical approach results*

Backward Linkage Category	Forward Linkage Category	
High (>1)	High (>1)	'Products of agriculture, hunting and related services', 'Food, beverages and tobacco products', 'Coke and refined petroleum products', 'Basic metals', 'Electricity, gas, steam and air conditioning', 'Constructions and construction works', 'Wholesale trade services, except of motor vehicles and motorcycles', 'Retail trade services, except of motor vehicles and motorcycles', 'Land transport services and transport services via pipelines', 'Water transport services', 'Warehousing and support services for transportation', 'Telecommunications services', 'Real estate services excluding imputed rents'
High (>1)	Low (<1)	'Accommodation and food services', 'Public administration and defence services; compulsory social security services', 'Human health services'
Low (<1)	High (>1)	'Fabricated metal products, except machinery and equipment', 'Motion picture, video and television programme production services, sound recording and music publishing; programming and broadcasting services', 'Computer programming, consultancy and related services; Information services', 'Financial services, except insurance and pension funding', 'Legal and accounting services; services of head offices; management consultancy services', 'Architectural and engineering services; technical testing and analysis services', 'Security and investigation services; services to buildings and landscape; office administrative, office support and other business support services'
Low (<1)	Low (<1)	'Products of forestry, logging and related services', 'Fish and other fishing products; aquaculture products; support services to fishing', 'Mining and quarrying', 'Textiles, wearing apparel, leather and related products', 'Wood and of products of wood and cork, except furniture; articles of straw and plaiting materials', 'Paper and paper products', 'Printing and recording services', 'Chemicals and chemical products', 'Basic pharmaceutical products and pharmaceutical preparations', 'Rubber and plastic products', 'Other non-metallic mineral products', 'Computer, electronic and optical products', 'Electrical equipment', 'Machinery and equipment n.e.c.', 'Motor vehicles, trailers and semi-trailers', 'Other transport equipment', 'Furniture and other manufactured goods', 'Repair and installation services of machinery and equipment', 'Natural water; water treatment and supply services', 'Sewerage services; sewage sludge; waste collection, treatment and disposal services; materials recovery services; remediation services and other waste management services', 'Wholesale and retail trade and repair services of motor vehicles and motorcycles', 'Air transport services', 'Postal and courier services', 'Publishing services', 'Insurance, reinsurance and pension funding services, except compulsory social security', 'Services auxiliary to financial services and insurance services', 'Imputed rents of owner-occupied dwellings', 'Scientific research and development services', 'Advertising and market research services', 'Other professional, scientific and technical services and veterinary services', 'Rental and leasing services', 'Employment services', 'Travel agency, tour operator and other reservation services and related services', 'Education services', 'Residential care services; social work services without accommodation', 'Creative, arts, entertainment, library, archive, museum, other cultural services; gambling and betting services', 'Sporting services and amusement and recreation services', 'Services furnished by membership organisations', 'Repair services of computers and personal and household goods', 'Other personal services', 'Services of households as employers; undifferentiated goods and services produced by households for own use'

The ranking of industries based on their backward and forward linkages provides valuable insights into the structure of intersectoral dependencies within the economy (Table 2.11).

Table 2.11: *Ranking of hypothetical approach results*

Industry	Rank B*(t)	Rank F*(t)
Products of agriculture, hunting and related services	7	5

Products of forestry, logging and related services	62	53
Fish and other fishing products; aquaculture products; support services to fishing	54	52
Mining and quarrying	50	25
Food, beverages and tobacco products	1	11
Textiles, wearing apparel, leather and related products	40	44
Wood and of products of wood and cork, except furniture; articles of straw and plaiting materials	56	42
Paper and paper products	36	29
Printing and recording services	55	37
Coke and refined petroleum products	15	14
Chemicals and chemical products	32	30
Basic pharmaceutical products and pharmaceutical preparations	20	46
Rubber and plastic products	34	20
Other non-metallic mineral products	27	21
Basic metals	14	19
Fabricated metal products, except machinery and equipment	19	13
Computer, electronic and optical products	57	56
Electrical equipment	35	32
Machinery and equipment n.e.c.	46	57
Motor vehicles, trailers and semi-trailers	61	61
Other transport equipment	59	60
Furniture and other manufactured goods	51	51
Repair and installation services of machinery and equipment	53	34
Electricity, gas, steam and air conditioning	6	3
Natural water; water treatment and supply services	47	41
Sewerage services; sewage sludge; waste collection, treatment and disposal services; materials recovery services; remediation services and other waste management services	25	38
Constructions and construction works	3	17
Wholesale and retail trade and repair services of motor vehicles and motorcycles	23	26
Wholesale trade services, except of motor vehicles and motorcycles	2	2
Retail trade services, except of motor vehicles and motorcycles	8	7
Land transport services and transport services via pipelines	12	10
Water transport services	10	18
Air transport services	44	54
Warehousing and support services for transportation	16	8
Postal and courier services	45	24
Accommodation and food services	4	33
Publishing services	41	43
Motion picture, video and television programme production services, sound recording and music publishing; programming and broadcasting services	38	7
Telecommunications services	9	16
Computer programming, consultancy and related services; Information services	22	15
Financial services, except insurance and pension funding	26	4
Insurance, reinsurance and pension funding services, except compulsory social security	24	39
Services auxiliary to financial services and insurance services	37	22
Imputed rents of owner-occupied dwellings	39	62
Real estate services excluding imputed rents	13	1
Legal and accounting services; services of head offices; management consultancy services	18	6
Architectural and engineering services; technical testing and analysis services	21	9

Scientific research and development services	28	49
Advertising and market research services	31	23
Other professional, scientific and technical services and veterinary services	58	45
Rental and leasing services	49	28
Employment services	63	35
Travel agency, tour operator and other reservation services and related services	42	55
Security and investigation services; services to buildings and landscape; office administrative, office support and other business support services	33	12
Public administration and defence services; compulsory social security services	5	27
Education services	30	48
Human health services	11	31
Residential care services; social work services without accommodation	48	58
Creative, arts, entertainment, library, archive, museum, other cultural services; gambling and betting services	29	36
Sporting services and amusement and recreation services	43	50
Services furnished by membership organisations	17	40
Repair services of computers and personal and household goods	60	47
Other personal services	52	59

Industries with high backward linkages values, such as "Food, beverages and tobacco products," "Wholesale trade services, except of motor vehicles and motorcycles," and "Electricity, gas, steam, and air conditioning," are characterized by strong backward linkages, meaning they have a significant impact on the supply chain by generating demand for inputs from various other industries. Their high rankings suggest that these sectors serve as crucial drivers of economic activity, influencing production processes across multiple levels. In contrast, industries positioned lower in the backward linkages ranking, such as "Products of forestry, logging and related services" and "Employment services," exhibit relatively weak backward linkages. These industries do not generate substantial upstream demand for other sectors, indicating a lower level of economic propagation through intermediate input usage. Their role in the production structure appears more self-contained or dependent on a limited set of upstream linkages. The ranking of industries based on forward linkages reveals a different perspective, capturing the extent to which each sector contributes to final demand. "Real estate services excluding imputed rents" ranks the highest, highlighting its strong presence in final consumption and investment expenditures. This suggests that a significant portion of economic activity in this sector is driven by direct demand rather than inter-industry dependencies. Similarly, industries such as "Public administration and defence services; compulsory social security services" and "Financial services, except insurance and pension funding" rank prominently in forward linkages, reinforcing their crucial role in supporting overall economic stability and consumer-related expenditures. The comparison of rankings between backward linkages and forward linkages underscores notable structural differences.

Some industries exhibit a relatively balanced ranking across both indicators, indicating their dual role in driving both production and final demand. For example, "Wholesale trade services, except of motor vehicles and motorcycles" ranks highly in both categories, reflecting its importance as both a facilitator of supply chains and a major component of consumer and business demand. Conversely, certain industries display a pronounced divergence in rankings. "Electricity, gas, steam, and air conditioning" ranks high in backward linkages but lower in forward linkages, indicating its strong role in production processes while being less directly consumed in final demand. On the other hand, "Accommodation and food services" ranks relatively high in forward linkages but lower in backward linkages, underscoring its reliance on direct consumption rather than extensive production linkages. The presence of tied rankings in forward linkages suggests that some industries exert comparable influence on final demand, potentially due to similarities in market size, consumption patterns, or regulatory factors. This may indicate clustering effects where multiple industries contribute equally to economic expansion through direct consumption channels. Overall, the ranking distribution reveals a complex economic landscape where industries differ significantly in their contributions to production and demand. High-ranking industries in both backward linkages and forward linkages act as economic hubs, influencing multiple sectors either through input-output relationships or final consumption. Understanding these dynamics provides a clearer perspective on industrial interdependencies, highlighting key sectors that policymakers and businesses may need to focus on for economic planning and investment decisions.

2.10 Concluding Remarks

The Greek economy, shaped by its historical reliance on tourism, services, and real estate, exhibits a structural composition that has often hindered productivity growth and industrial diversification. Understanding the sectoral dynamics through input-output linkages provides valuable insights into how industries interact and how economic shocks or policy interventions propagate throughout the system. Backward linkages reflect an industry’s capacity to generate demand for inputs from other sectors, while forward linkages measure its contribution to final demand and its role in supplying inputs to other industries. By analyzing these interdependencies, it becomes evident which industries function as critical economic hubs and which sectors operate in relative isolation, with limited spillover effects.

In this study, we have employed traditional methods to evaluate sectoral interdependencies. However, our primary focus has been on the Hypothetical Extraction Method (HEM) due to its ability to provide more precise and policy-relevant insights. The HEM allows for a counterfactual assessment of sectoral importance by simulating the effects of removing an industry from the economy. Unlike traditional measures, which assume proportional relationships and static coefficients, the HEM captures non-linear effects and provides a clearer picture of how sectoral disruptions propagate through the economic system. Given the structural complexities of the Greek economy, this method enables a more accurate identification of key industries whose presence is crucial for economic stability and growth.

The analysis reveals a stark contrast between industries that drive production through extensive supply chain integration and those that dominate final demand with minimal upstream dependencies. Traditional sectors such as food processing, wholesale trade, and energy demonstrate strong backward linkages, reinforcing their foundational role in production networks. In contrast, the real estate sector emerges as the dominant driver of final demand, raising significant concerns about the sustainability and efficiency of Greece's economic structure.

Industries with high backward linkages play a pivotal role in sustaining economic activity by stimulating demand for intermediate inputs. Food, beverages, and tobacco manufacturing stands out as a major industrial pillar, deeply embedded in domestic and international supply chains. Its extensive backward linkages reflect the sector's reliance on agricultural production, packaging, and distribution networks. Despite its strong interconnections, the industry remains vulnerable to external shocks, including global commodity price fluctuations and trade policy changes. The wholesale trade sector also ranks high in backward linkages, functioning as a critical intermediary in supply chains and ensuring the smooth distribution of goods across industries. Its strong position indicates that disruptions in trade logistics or retail networks could have significant ripple effects throughout the economy.

Energy production and distribution, particularly electricity, gas, steam, and air conditioning, exhibit high backward linkages due to their essential role as inputs for virtually all industrial activities. However, the sector's structural rigidity, high capital intensity, and reliance on energy imports pose risks to economic stability. The country's exposure to geopolitical uncertainties in energy markets underscores the need for enhanced domestic energy production, investment in renewables, and improved grid infrastructure.

In contrast, sectors with weak backward linkages, such as forestry and logging, demonstrate minimal integration into the broader production system. The limited size of Greece's forestry industry, coupled with the lack of extensive downstream processing, results in a sector that contributes little to broader industrial expansion. Similarly, employment services rank low in backward linkages, reflecting their role as facilitators rather than generators of economic activity. Their weak propagation effects suggest that labor market flexibility alone is insufficient to drive structural transformation without complementary industrial policies.

The ranking of industries based on forward linkages paints a different picture of the Greek economy, with real estate services emerging as the most influential sector in terms of final demand. Unlike industries that generate economic activity through supply chain integration, real estate's impact is primarily demand-driven. Its dominance highlights the extent to which economic activity revolves around property transactions, speculative investments, and household wealth accumulation rather than productive industrial activity.

The overwhelming role of real estate in Greece's economic structure raises critical concerns. A disproportionate allocation of capital toward real estate investment, rather than high-productivity sectors, has long-term implications for economic growth and innovation. Overinvestment in non-productive assets, coupled with speculative market dynamics, mirrors trends observed in economies that have experienced housing bubbles and financial instability. The limited spillover effects of real estate further compound these concerns, as its economic benefits are largely concentrated in landowners, property developers, and financial institutions rather than in broad-based industrial growth.

Beyond real estate, public administration and defense services rank prominently in forward linkages, underscoring the state's significant role in economic activity. While government spending is essential for macroeconomic stability, the relative size of the public sector in final demand highlights Greece's structural dependence on state intervention. The financial services sector also ranks high, reflecting its role in facilitating transactions, credit expansion, and investment flows. However, given Greece's history of banking crises and financial volatility, reliance on financial services as a driver of final demand necessitates prudent regulatory oversight and efforts to diversify financing mechanisms.

The contrast between backward and forward linkages reveals fundamental imbalances in the Greek economy. Sectors such as energy and food processing play a critical role in sustaining production networks but exhibit weaker forward linkages, indicating that their output is primarily consumed as intermediate goods rather than driving final demand. Conversely, real estate and accommodation services rank high in forward linkages but demonstrate weak backward linkages, suggesting that their economic influence is concentrated in direct consumption rather than in stimulating broad industrial activity.

These structural asymmetries highlight key policy challenges. An economy overly reliant on real estate for final demand is inherently vulnerable to cyclical downturns, speculative distortions, and financial instability. Similarly, the presence of large public administration and financial services sectors as primary drivers of economic activity suggests a need for more dynamic private-sector investment in high-value-added industries. Addressing these imbalances requires targeted policy interventions aimed at fostering industrial diversification, strengthening supply chain linkages, and mitigating excessive dependence on non-productive asset accumulation.

A strategic realignment of industrial policy should prioritize investments in sectors with strong backward linkages to enhance domestic production capabilities and reduce external dependencies. Strengthening manufacturing, renewable energy, and advanced services could help mitigate vulnerabilities associated with Greece's current economic structure. In parallel, regulatory measures should be implemented to curb speculative real estate investment and redirect financial resources toward productive economic activities. Enhancing innovation and technology diffusion within key industries would further support sustainable economic development and reduce reliance on traditional, low-productivity sectors.

The analysis of backward and forward linkages underscores the structural challenges facing the Greek economy. While certain industries serve as essential supply chain hubs, their contributions to final demand remain limited. Conversely, the dominance of real estate and public administration in final demand reflects an economic model that is overly dependent on property transactions and state spending. Without targeted policy interventions, Greece risks remaining in a low-productivity equilibrium, where speculative investments and public sector expenditures overshadow industrial growth and technological progress.

Rebalancing the economy requires a multifaceted approach. Policies should focus on strengthening intersectoral linkages, promoting investment in productive industries, and ensuring a more equitable distribution of economic benefits. A more resilient and diversified industrial base would reduce vulnerabilities, enhance economic stability, and position Greece for sustainable long-term growth. The challenge lies not only in identifying key sectors but in designing and implementing policies that foster meaningful structural transformation.

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CONCLUSION

The application of IO analysis to sectoral interdependencies highlights the significance of industries with strong backward and forward linkages in sustaining economic activity. By evaluating these linkages, it becomes evident which sectors serve as economic hubs with extensive interconnections and which operate in relative isolation with limited spillover effects. The study underscores the importance of traditional sectors such as food processing, wholesale trade, and energy production, which exhibit strong backward linkages and serve as essential pillars of Greece's industrial framework. These industries play a crucial role in generating demand for intermediate inputs and maintaining production networks. However, their vulnerability to external shocks, including global commodity price fluctuations and trade policy changes, necessitates strategic policy interventions to enhance their resilience.

At the same time, the dominance of the real estate sector in forward linkages raises concerns regarding the sustainability of Greece's economic model. The disproportionate emphasis on real estate investment, speculative property transactions, and household wealth accumulation over high-productivity sectors limits the country's long-term growth potential. The study highlights the need for a more balanced economic structure that prioritizes productive investments over asset speculation. The contrast between backward and forward linkages reveals fundamental imbalances in Greece's industrial framework. While certain industries sustain supply chains, their contributions to final demand remain constrained. Conversely, sectors such as real estate and public administration drive final demand but lack strong production linkages, reinforcing structural inefficiencies. Addressing these asymmetries requires a targeted industrial policy that fosters sectoral diversification and strengthens supply chain integration.

To enhance economic stability and promote sustainable growth, policy interventions should focus on encouraging investment in industries with strong backward linkages, such as manufacturing, renewable energy, and high-value-added services. Additionally, regulatory measures should mitigate speculative real estate investment and redirect financial resources toward productive activities. Encouraging innovation and technology diffusion within key sectors would further support economic development and reduce reliance on traditional low-productivity industries. Beyond the analysis of backward and forward linkages, the study highlights the importance of methodological advancements in IO analysis. The use of the

Hypothetical Extraction Method (HEM) provides a more dynamic and policy-relevant approach to identifying critical industries. By simulating the removal of specific sectors, the study demonstrates the interdependencies and vulnerabilities embedded within Greece's economic structure. The insights gained from this approach underscore the need for strategic interventions that align sectoral development with long-term economic resilience.

The study's findings emphasize the need for a strategic realignment of economic priorities to mitigate Greece's structural vulnerabilities. Without targeted policy measures, the country risks remaining in a low-productivity equilibrium characterized by speculative investments and excessive reliance on public sector expenditures. A multifaceted approach—incorporating industrial diversification, enhanced intersectoral linkages, and regulatory reforms—would foster a more resilient and competitive economic landscape. By leveraging the insights of IO analysis, policymakers can design interventions that facilitate meaningful structural transformation, positioning Greece for long-term economic stability and sustainable growth.

Rebalancing the economy requires a holistic strategy that integrates industrial policy, technological innovation, and financial regulations. Strengthening intersectoral linkages and enhancing supply chain resilience are crucial for fostering a more diversified economic structure. The findings of this study provide valuable insights into the mechanisms that drive economic interdependencies and offer a roadmap for policymakers to implement effective strategies for sustainable economic development. The challenge lies not only in identifying key sectors but in designing and implementing policies that foster meaningful structural transformation and long-term economic stability.

Modeling Fiscal Interventions in a Post-Keynesian Framework: A Model Simulation Approach

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Abstract

This paper develops a dynamic Post-Keynesian macroeconomic model to evaluate the effectiveness of alternative fiscal policy strategies in driving output growth, stabilizing public debt, and improving employment outcomes. Drawing on Post-Keynesian theory, the model emphasizes the central role of aggregate demand, the delayed response of investment to past behavior, and the endogenous nature of economic cycles. Five distinct fiscal scenarios are implemented—ranging from passive non-intervention to fully optimized control—simulating their performance within a discrete-time control-theoretic framework. Scenario A serves as a baseline with no fiscal stimulus, Scenarios B through D apply rule-based government spending paths with optimized intensity, while Scenario E utilizes a fully endogenized policy solution. All different cases are evaluated against target trajectories for GDP and public debt, allowing for a rigorous comparison of macroeconomic trade-offs. The results reveal that while rule-based fiscal strategies can support short-run growth, only a dynamically optimized fiscal path achieves both high employment and debt stabilization in the long run. These findings reaffirm the argument for active fiscal intervention and provide practical insights for designing growth-oriented, debt-conscious fiscal rules in demand-constrained economies.

Keywords: Fiscal policy, Policy rules, GDP, Debt, Post-Keynesian model, Algorithmic control

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1. Introduction

The role and effectiveness of fiscal policy remain deeply contested in contemporary macroeconomic theory. Mainstream economic thought often views fiscal intervention with skepticism, citing its limited capacity to stimulate long-term output without exacerbating public debt (Bernanke, 2004). From this perspective, government spending is frequently criticized for its high budgetary costs, and expansionary fiscal measures are seen as unsustainable, particularly in economies with constrained fiscal space (O. Blanchard et al., 2010) . In contrast, Post-Keynesian and Kaleckian economists argue that fiscal policy can and should play an active role in driving aggregate demand, restoring confidence, and supporting structural investment, particularly in economies experiencing demand-side stagnation (Arestis, 2011; Hein, 2018).

Following the retreat of Keynesianism in the late 1970s, fiscal consolidation emerged as the dominant paradigm. Policies of deregulation, financial liberalization, and privatization were accompanied by growing hostility to state-led spending, which was increasingly viewed as a source of inefficiency and market distortion (Streeck, 2014). Within this framework, contractionary fiscal policy—such as expenditure cuts and balanced budget rules—was presented as a precondition for growth (Alesina & Perotti, 1994; Giavazzi & Pagano, 1990). Yet, the global financial crisis of 2008 undermined this orthodoxy, revealing that austerity policies often failed to deliver either economic stability or sustained growth (O. J. Blanchard & Leigh, 2013). In the aftermath, scholarly and policy interest in fiscal multipliers has revived, particularly in light of evidence suggesting that discretionary fiscal stimulus can be both effective and necessary in deep recessions (Gechert, 2015).

Building on this renewed interest, a growing body of Post-Keynesian research reasserts the strategic role of fiscal policy in steering macroeconomic outcomes (Allain, 2015; Tavani & Zamparelli, 2017). In these models, government spending is not just a stabilizer, but a dynamic instrument for managing demand, employment, and investment expectations. Crucially, if policymakers define explicit targets for macroeconomic performance—such as output growth or debt containment—then the question becomes: how can fiscal policy be formulated to guide the economy along the desired trajectory?

To address this challenge, researchers have increasingly turned to tools from mathematical control theory. In particular, feedback-based closed-loop systems offer a way to dynamically correct policy paths in response to deviations from target variables (Domenikos & Kotsios, 2024; Kaas, 1998; D. Kendrick, 1993; Kostarakos & Kotsios, 2018). In such frameworks, the policy instrument (e.g., government spending) adjusts over time to minimize the error between actual and desired outcomes. This feedback mechanism improves policy responsiveness, reduces implementation lags, and enables smoother economic transitions (Frank, 2018; D. A. Kendrick & Amman, 2008).

This methodological approach is especially pertinent in the post-2008 context, where many economies adopted a dual strategy of rapid fiscal consolidation and internal devaluation—

particularly within the Eurozone. However, these measures often weakened domestic consumption and social investment, undermining long-term recovery (Ruiz, 2024). Against this backdrop, this study explores an alternative strategy: the design of fiscal policy rules that support GDP growth while managing debt accumulation in a more sustainable manner.

To that end, we build a discrete-time Kaleckian model with delayed investment dynamics and endogenous employment. Through a series of simulations—ranging from passive policy to linear and cyclical spending rules—we compare the macroeconomic implications of different fiscal trajectories. We then introduce an optimized scenario that endogenizes public investment as a control variable, constrained by fiscal limits. By doing so, we evaluate the feasibility of achieving both growth and debt sustainability—not as competing objectives, but as jointly attainable outcomes under a well-designed policy path.

2. Post-Keynesian Literature on Fiscal Policy

While mainstream economic thought largely dismissed expansionary fiscal policy during the neoliberal era, the Post-Keynesian (P-K) tradition maintained that government spending remains a vital tool for stabilizing output and promoting long-run growth. Within this framework, fiscal policy is not merely a short-run stabilizer but a structural lever to sustain aggregate demand, raise employment, and shape the income distribution. Several Post-Keynesian models emphasize that fiscal expansions—particularly when combined with redistributive policies that favor labor—can foster both demand-side growth and improved socio-economic outcomes.

A central tenet in this literature is that public spending raises effective demand directly through government purchases and indirectly through higher consumption by wage earners. Ciccone (2013) underscores that fiscal deficits, if directed toward public investment or wage-based transfers, can increase output, profits, and employment. Moreover, Bhaduri and Marglin (1990), Blecker (1989), and Dutt (1984) argue that when investment responds positively to both capacity utilization and realized profits, income redistribution toward labor can lead to a higher accumulation path. These models challenge the neoclassical assumption of crowding-out and instead propose that public investment can “crowd in” private investment (Dutt, 2013; Palley, 2013).

Recent Post-Keynesian contributions further strengthen the theoretical foundation for fiscal activism. Hein and Stockhammer (2011), Allain (2015), and Tavani and Zamparelli (2017) construct models where fiscal expenditures not only raise short-term output but also influence the long-run growth path. Allain (2015) demonstrates, within a Kaleckian structure, that autonomous government spending can act as a stabilizing force for demand and employment, while Tavani and Zamparelli (2017) show that growth can remain wage-led even in the presence of rising public debt. Similarly, Nah and Lavoie (2017) integrate Kaleckian principles with a supermultiplier mechanism to show that a falling labor share or declining consumption propensity undermines capital accumulation and growth.

Debt sustainability also features prominently in Post-Keynesian fiscal models. Hein (2018) argues that public debt can remain stable, or even decline relative to output, provided that the government's growth impact exceeds the cost of debt servicing. This condition supports a non-deflationary path toward higher output and public spending ratios. Ko (2018) also finds that increased taxation on capital can enhance capacity utilization and thus growth, although excessive debt accumulation may eventually weigh on aggregate demand.

The distinction between taxes on labor and capital—emphasized by Kalecki (1971)—has significant implications for the fiscal multiplier and distributional effects. Progressive taxation, especially when applied to capital income, can sustain employment and output without damping investment in the short run due to lagged responses (Asada, 2001; Toporowski, 2020). Empirical and theoretical studies (Laramie, 1991; You & Dutt, 1996; Nikolaidi et al., 2020) further support the claim that redistributive taxation toward labor income can stimulate GDP growth and enhance fiscal sustainability.

These insights resonate with the simulations developed in our model, where various fiscal policy scenarios—ranging from constant and linear interventions to a fully optimized control path—are shown to substantially influence output, employment, and debt dynamics. Our results reinforce the P-K view that fiscal policy can be both effective and sustainable when guided by growth-oriented rules. In particular, they highlight the importance of endogenously calibrated interventions that adapt to macroeconomic conditions and support the economy's movement toward its potential output path.

3. The Model

This section outlines a discrete-time linear macroeconomic model inspired by Kaleckian dynamics, designed to simulate the interaction between output, investment, employment, and public debt under varying fiscal policy conditions. Specifically, we reformulate Kalecki's insights into a discrete-time dynamical system, preserving the core structure of lagged investment responses while making it amenable to control-theoretic and computational analysis. Kalecki proposed a macroeconomic model that explains endogenous cycles in capitalist economies through the dynamics of investment and capital accumulation (Kalecki, 1935). His theory emphasizes the delayed response of investment to past profits, leading to oscillatory and potentially unstable paths of output and employment. The main feature of the model is that investment decisions at time t depend not only on current or past profits, but crucially on past investment behavior, introducing a time lag in economic dynamics. The model reflects key post-Keynesian principles: output and employment are demand-driven, investment is a function of past behavior, and fiscal policy is a primary stabilizing force.

3.1 Model Structure and Assumptions

The model is constructed around five core components:

1. **Investment behavior** with lagged responses,
2. **Capital accumulation** with depreciation,
3. **Output generation** via a fixed capital-output ratio,
4. **Employment adjustment** based on output demand and labor productivity,
5. **Government debt dynamics**, including taxation and interest payments.

The system is fully deterministic, operates in discrete time over t periods (interpreted as years), and features linear relations for tractability and transparency. Although grounded in the nonlinear tradition of Kaldor and Kalecki, this linear form enables practical policy simulation and optimization without requiring numerical solutions to differential equations.

3.2 Model Equations

Investment is expressed by:

$$I_t = (1 - a)I_{t-1} + a(1 - n)I_{t-m} + u_t \qquad (1)$$

Where it is determined by a weighted average of lagged values and a fiscal policy input u_t, representing public demand stimulus. Parameters a and n control inertia and profit retention, respectively, while m introduces an internal delay following Kalecki's treatment of investment processes.

Capital accumulation

$$K_{t+1} = K_t + I_t - \delta K_t \qquad (2)$$

Where capital stock evolves through net investment, accounting for a constant depreciation rate δ.

$$Y_t = \nu K_t \qquad (3)$$

Output is proportional to capital, assuming a fixed capital-output ratio ν.

Employment dynamics:

$$L_t = (1-\gamma)L_{t-1} + \gamma(\frac{Y_t}{\varphi}) \quad (4)$$

$$e_t = \max(\frac{L_t}{N}, 0.5) \quad (5)$$

Employment adjusts gradually toward the level required to produce Y, given labor productivity φ. The employment rate , e_t, is bound below 50% to reflect structural floors in labor markets, particularly relevant for economies with persistent underemployment.

Debt accumulation:

$$D_t = (1+r)D_{t-1} + u_t - \tau Y_t \, (6)$$

Public debt increases with the fiscal stimulus, u_t, net tax revenue, τY_t, and grows further with interest rate r applied to the previous debt stock.

The above discrete system can be rewritten more compactly via utilizing the statespace form. To write (3), (6) in their state-space form, we introduce the state vector:

$$\vec{x}(t)=\begin{bmatrix} Y(t) \\ D(t) \end{bmatrix}, \quad \vec{u}(t)=\begin{bmatrix} G(t) \\ G(t-1) \end{bmatrix} \quad (7)$$

, and thus

$$\vec{x}(t) = \boldsymbol{A}\vec{x}(t-1) + \mathbf{F}\,\vec{u}(t) \quad (8)$$

3.3 Policy Input and Scenarios

The variable u_t , government fiscal intervention — interpreted as public investment, infrastructure spending, or transfer programs- serves as the primary lever in all policy simulations. Five fiscal policy scenarios are analyzed (detailed in Section 4), ranging no intervention to dynamically optimized stimulus.

3.4 Initialization and Parameters

The model is calibrated to approximate the macroeconomic conditions of the Greek economy. Initial values and parameter choices are as follows:

$Y_0 = 200$	Initial GDP (in millions)
$D_0 = 300$	Initial debt (in millions)
$N = 5$	Labor force (in millions)
$a = 0.6$	Investment inertia
$n = 0.3$	Profit retention ratio
$m = 2$	Investment delay
$\delta = 0.05$	Depreciation rate
$\nu = 0.5$	Capital-output ratio
$\varphi = 0.05$	Output per worker
$\gamma = 0.1$	Labor adjustment speed
$r = 0.02$	Investment on debt
$\tau tax = 0.4$	Tax-to-GDP ratio

These parameters reflect stylized features of the Greek macroeconomy, and the structure enables a focused analysis of fiscal policy effects in a demand-constrained setting.

4. Scenario-Based Framework

To explore the dynamic effects of fiscal policy under a Kaleckian investment model with delayed adjustment and endogenous employment, we simulate five distinct policy scenarios. These scenarios vary in their fiscal design—ranging from passive to actively optimized strategies—and allow us to evaluate how different forms of public investment impact macroeconomic trajectories such as output, employment, and debt accumulation. While all scenarios are plotted against a normative target output path (e.g., 2.2% annual growth), only one scenario (Scenario E) explicitly attempts to achieve that target through optimization. The others serve as comparative benchmarks or stylized fiscal policy experiments.

Scenario A: Passive Fiscal Stance (No Policy Input)

This scenario represents a counterfactual benchmark where no discretionary fiscal stimulus is applied ($u_t = 0$ for all t). The economy evolves autonomously based on past investment decisions, internal dynamics, and the accumulation of capital. This scenario helps to isolate the endogenous behavior of the Kaleckian model in the absence of government intervention, thereby serving as a baseline for comparison. It serves the purpose of establishing the "default" behavior of the model without policy.

Scenario B: Constant Fiscal Stimulus

In this simulation, the government maintains a fixed level of fiscal stimulus equivalent to 10% of initial GDP throughout the entire simulation horizon. This policy is exogenous and unresponsive to macroeconomic conditions and assists in evaluating the stabilizing potential of a persistent, rules-based fiscal expansion.

Scenario C: Linearly Increasing Fiscal Policy

Here, government spending increases linearly from a modest initial level (e.g., 5% of GDP) to a more aggressive stance (e.g., 20% of GDP) over time. This represents a developmental or counter-cyclical approach where policy support intensifies as the economy evolves. Specifically, tests whether gradually ramping up fiscal commitment can stimulate growth without explicitly optimizing policy paths.

Scenario D: Periodic Fiscal Policy (Cyclical/Seasonal Stimulus)

In this case, government stimulus follows a sinusoidal pattern, mimicking cyclical or seasonal intervention (e.g., subsidies, infrastructure cycles, or election-driven spending). The mean level is anchored around 10% of GDP and it shows how cyclical public investment interacts with Kaleckian delays and endogenous cycles.

Scenario E: Optimized Fiscal Policy

Unlike the preceding exogenous policies, Scenario E employs a control-theoretic optimization. The policy input u_t is endogenously selected to minimize a loss function that penalizes deviations from a target output path and accumulations of public debt. This scenario represents the best-case policy, subject to model constraints and bounded fiscal space. It helps identify an optimal path of public investment that balances growth and debt sustainability.

Objective Function**:**

$$\min_{u_t} \sum_t (Y_t - Y_t^*)^2 + \lambda \sum_t (\frac{D_t}{Y_t})^2$$

In the context of this analysis, Scenario E introduces an optimized fiscal policy path derived through control-theoretic techniques. Unlike the exogenously imposed fiscal profiles in Scenarios A to D, Scenario E endogenizes public investment decisions by minimizing a quadratic loss function that penalizes deviations from a target output path and the accumulation of public debt. The inclusion of a debt-related penalty reflects a critical aspect of real-world policymaking: fiscal restrictions. These restrictions often emerge from a combination of legal rules, institutional frameworks, market pressures, and international oversight. For example, within the European Union, member states are subject to the Stability and Growth Pact, which imposes strict limits on public deficits and debt levels (typically 3% of GDP and 60% of GDP, respectively). Similarly, countries engaged in adjustment programs or fiscal surveillance—such as those under International Monetary Fund (IMF) conditionalities—are frequently required to maintain primary surpluses and reduce debt ratios over time. From a market perspective, excessive debt accumulation may raise sovereign borrowing costs, limit fiscal space, and damage policy credibility. Scenario E captures this institutional realism by incorporating debt discipline into the optimization process, thereby producing a stimulus trajectory that seeks to balance short-term demand support with long-term fiscal sustainability. It reflects a policymaker who operates under constrained optimization—attempting to stimulate output and employment while staying within politically and financially acceptable debt limits.

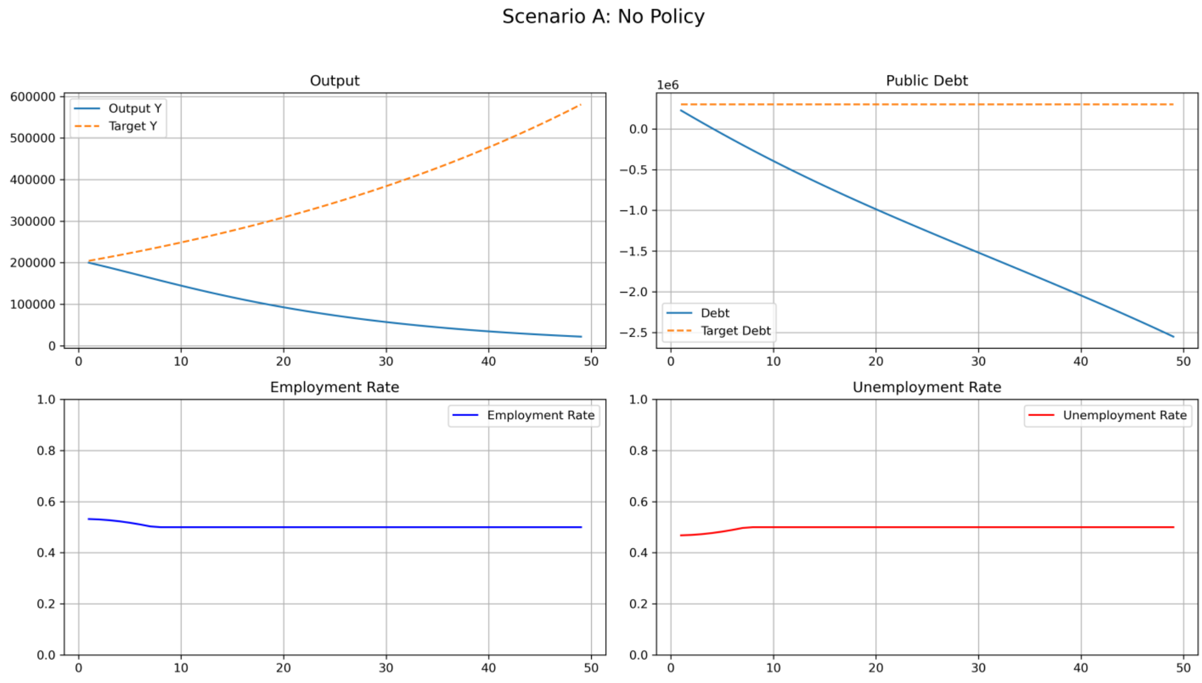
5. Policy Simulations

This section presents the results of simulating five fiscal policy scenarios within the Kaleckian macroeconomic framework outlined in Section 3. The purpose is to assess how different fiscal strategies affect output, employment, and public debt over time. The simulations are implemented using a calibrated linear, discrete-time model of the Greek economy.

All scenarios simulate a 50-period horizon, with initial conditions reflecting contemporary macroeconomic realities for the Greek economy, while government spending is introduced through a time-varying fiscal input, u_t, which represents public demand interventions such as investment or transfers. Tax revenue is collected as a fixed share of output via the tax-to-GDP ratio, τ_{tax},

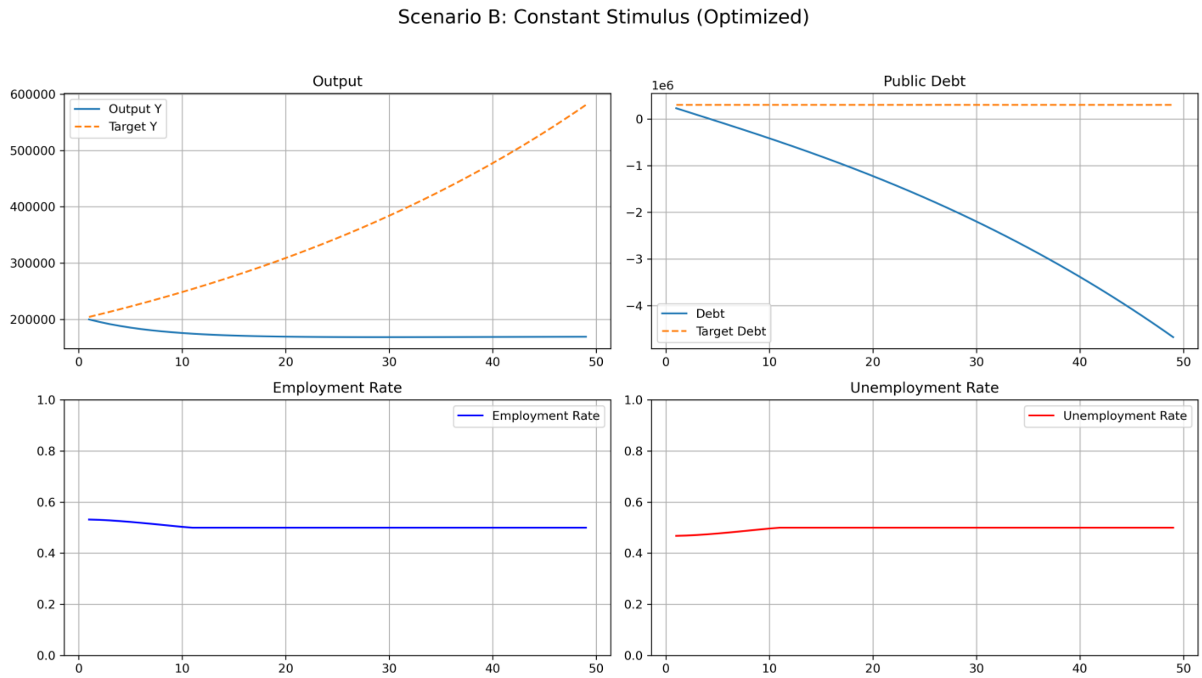
5.1 Scenario A: No Policy

In this baseline case, fiscal stimulus is absent (u_t) for all t.



Scenario A provides a benchmark case where fiscal policy is completely absent. As expected from Kalecki's investment-driven dynamics, the economy exhibits a weak growth profile, with output stagnating relative to the target path. The lack of government spending fails to stimulate demand, resulting in subdued capital accumulation and a persistent shortfall in output. Although the debt ratio grows modestly due to compounding interest and tax shortfalls, it remains relatively stable compared to other active scenarios. Employment remains below potential, declining slowly as output fails to meet its productive capacity. This result highlights Kalecki's view that capitalist economies can settle into underemployment equilibria in the absence of intervention.

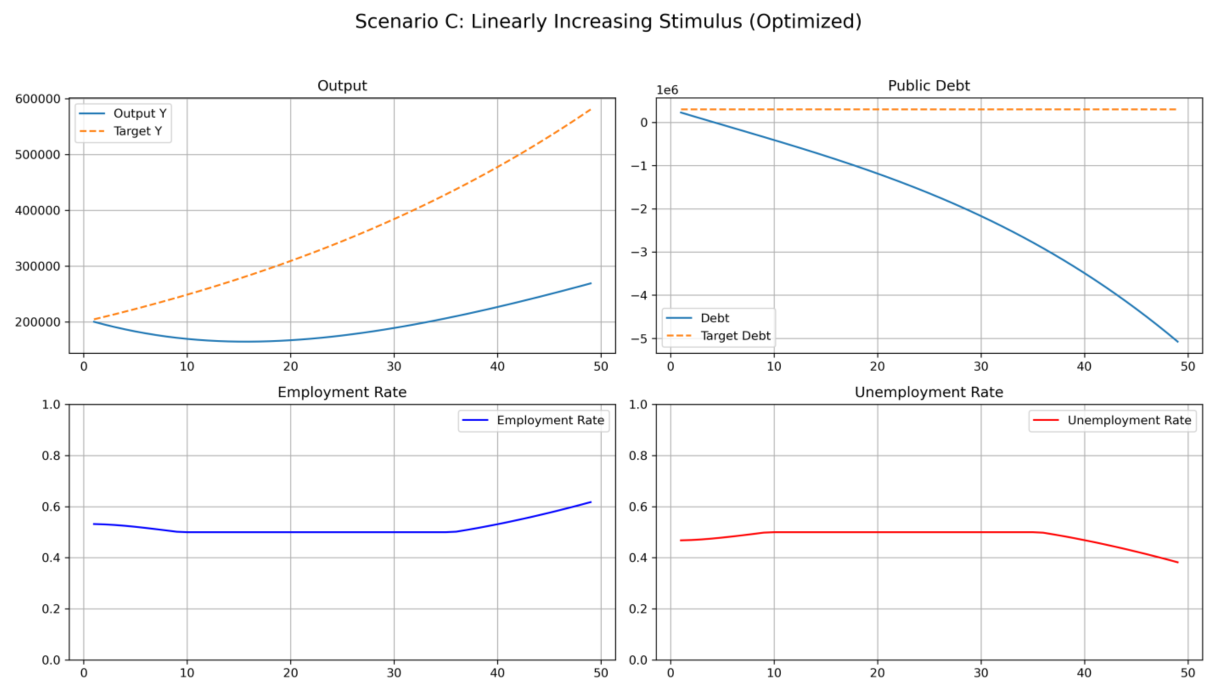
5.2 Scenario B: Constant Fiscal Stimulus



Under Scenario B, a constant fiscal impulse is applied across time, with its intensity calibrated through scalar optimization. The optimized constant stimulus supports moderate output growth, improving upon Scenario A, but fails to fully close the gap to the target trajectory. Public debt accumulates more rapidly than in the passive case, due to the fixed size of the stimulus regardless of macroeconomic needs or tax feedback. While employment rises relative to the baseline, the gains are limited by the inflexibility of the policy path. The results suggest that although a well-sized constant stimulus improves outcomes, its lack of responsiveness leads to both inefficiency and excess fiscal cost compared to more adaptive approaches.

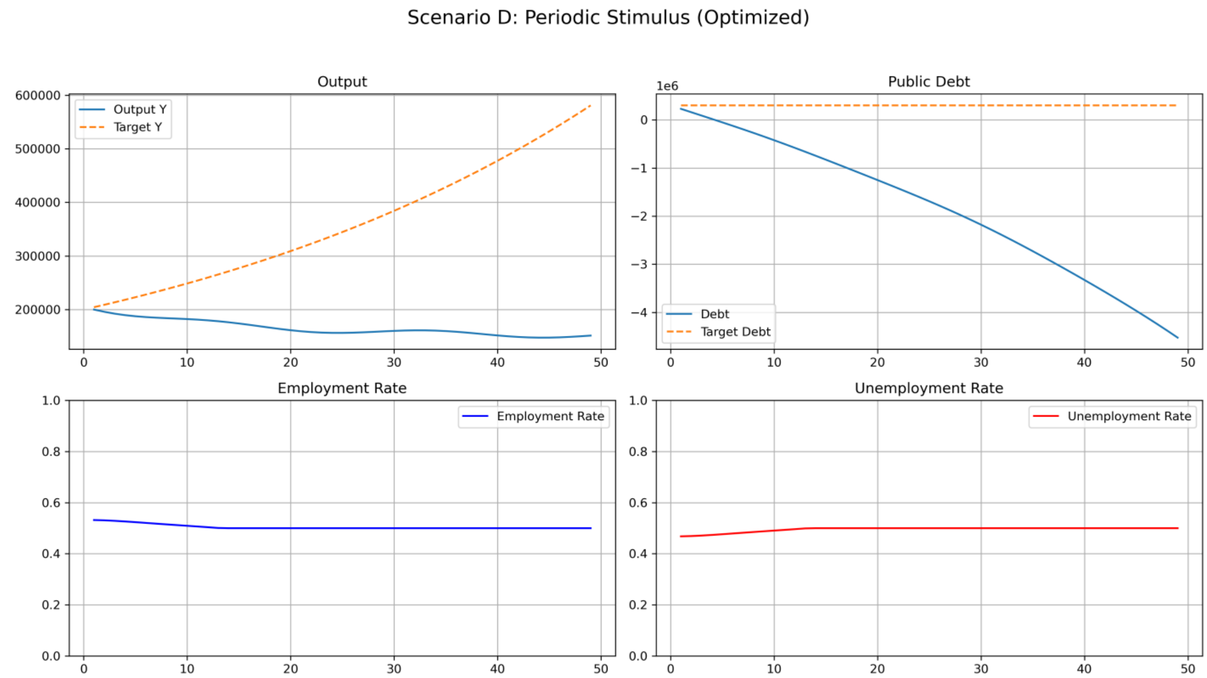
5.3 Scenario C: Linearly Increasing Stimulus (Optimized Slope)

Scenario C applies a time-progressive fiscal expansion, where public investment grows linearly and its slope is optimized. This scenario achieves stronger output growth, outperforming Scenarios A and B, especially in later periods. The increasing stimulus significantly boosts capital accumulation, translating into rising employment and narrowing the output gap. However, this comes at a substantial debt cost**.** The fiscal expansion outpaces tax revenues, and without any endogenous debt correction mechanism, public debt rises steeply. The unemployment rate falls more sharply than in previous scenarios, suggesting better labor market performance. Yet, the results underscore the trade-off between aggressive demand stimulation and fiscal sustainability.



5.4 Scenario D: Periodic Stimulus (Optimized Amplitude)

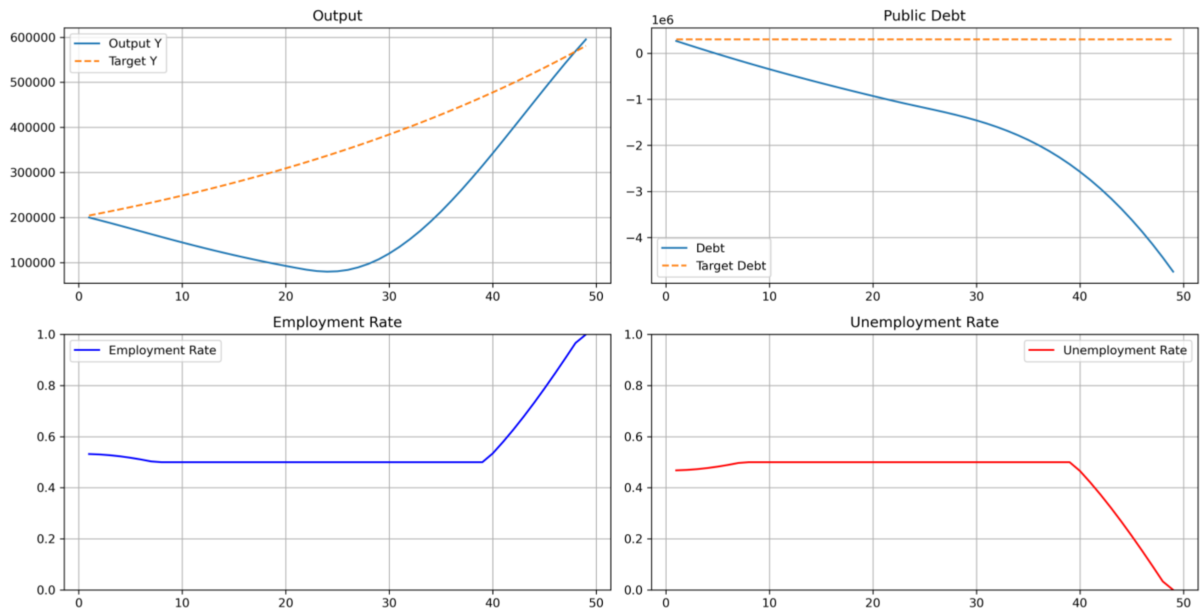
Scenario D introduces cyclical fluctuations in fiscal policy, mimicking pro-cyclical or counter-cyclical interventions tied to business or political cycles. The amplitude of the sine wave stimulus is optimized, yielding moderate improvement in output and employment. However, the performance is volatile. Periods of under- and over-stimulation cause fluctuations in both output and employment, with the unemployment rate improving only intermittently. Debt accumulation in this case remains high and uneven, driven by temporary mismatches between stimulus and tax revenues. While this scenario may reflect political economy realities (e.g., election cycles), it underperforms more deliberate or steady fiscal strategies, both in stability and efficiency.



5.5 Scenario E: Fully Optimized Policy

Scenario E outperforms all others in terms of overall efficiency. Here, fiscal policy is endogenously determined to minimize a combined loss in output gap and debt burden. The resulting path balances early interventions with tapering later spending, aligning closely with the target output trajectory. Employment rises steadily and smoothly, achieving near full employment in a fiscally sustainable manner. Public debt remains controlled due to the careful calibration of stimulus to economic needs. This scenario confirms the value of rule-based optimization under constraints, particularly for countries with limited fiscal space. It also demonstrates the advantage of dynamically adaptive policy compared to fixed or heuristic spending paths.

Scenario E: Fully Optimized



6. Concluding Remarks

This paper explores the macroeconomic implications of alternative fiscal policy strategies within a Post-Keynesian framework that emphasizes the role of aggregate demand, investment dynamics, and employment determination. By implementing and simulating five distinct fiscal scenarios—ranging from passive non-intervention to fully optimized policy—we demonstrated the critical influence of public spending on output stabilization, employment outcomes, and debt sustainability. The results reaffirm the proposition that capitalist economies require active fiscal intervention to avoid demand-deficient stagnation and underemployment. Notably, the fully optimized scenario outperforms all rule-based strategies by flexibly aligning fiscal stimulus with evolving economic conditions, thereby achieving strong and stable growth while containing debt accumulation. However, even simpler rule-based approaches, when properly calibrated, can deliver meaningful gains over a passive fiscal stance. These findings underscore the importance of incorporating both growth and debt targets into fiscal rule design, particularly in economies facing structural demand constraints or constrained monetary policy. The control-theoretic approach adopted here offers a tractable and policy-relevant method for designing time-consistent fiscal strategies that reconcile short-term stabilization with long-term fiscal responsibility.

7. Concluding Economic Results

From a Post-Keynesian perspective, the results reinforce the view that fiscal policy is not merely a short-term stabilizing tool but a central component of long-run economic management. The model supports the argument that government spending can, when well-targeted and adaptively managed, generate self-reinforcing growth dynamics by stimulating investment and reducing unemployment. Moreover, it highlights the importance of fiscal credibility and responsiveness: when policy is both disciplined (in targeting debt limits) and flexible (in adjusting to real-time feedback), it can foster stable expectations and mitigate pro-cyclical fluctuations.

The model also contributes to the broader critique of austerity-based policy frameworks. By demonstrating that government expenditure can be calibrated in real time to respect debt constraints while still achieving growth objectives, the analysis weakens the common narrative that fiscal expansion is inherently unsustainable. Instead, it supports a nuanced, data-driven approach to public finance, one that allows for counter-cyclical interventions without undermining long-run fiscal credibility.

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In search of efficient tools for macroeconomic analysis: Empirical dynamic stochastic general equilibrium and stock-flow consistent models

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Abstract

In this paper we provide a technical and methodological comparison of empirical DSGE and SFC models, aiming to highlight which of those two approaches is more appropriate for policy making, when implemented in actual economies. The comparison tackles issues related to consumption and investment behaviour, the function of labour and product markets, the role of finance and of the financial sector and the effectiveness of fiscal and monetary policy. We find that SFC models provide a more realistic view on how actual economies function, while the associated short-run dynamics render this type of models able to track imbalances and destabilizing tendencies.

1. Introduction

The purpose of this paper is to compare two contesting approaches to empirical modelling used by monetary authorities, aiming to assess in technical and methodological terms their ability to best describe the manner according to which actual economies function. Specifically, the New Keynesian Dynamic Stochastic General Equilibrium (DSGE) model EAGLE (Gomes *et al*., 2010), that is used by the European Central Bank (ECB), is compared to the Stock-flow Consistent (SFC) model SFCBoE (Burgess *et al*., 2016), which is used by the Bank of England (BoE). The choice of the EAGLE is justified on the fact that in its own, albeit, very simplistic terms it is stock-flow consistent, in strict accounting terms. However, this argument does not hold for every empirical DSGE model. For instance QUEST III, (see Appendix), which is a DSGE model used by the European Commission (Ratto *et al*. 2008) is not stock-flow consistent. The EAGLE and the SFCBoE models apply different technical structures and pursue diverse empirical purposes. In particular, the EAGLE model captures spill-over effects and macroeconomic interdependence within and outside the Euro Area (Gomes *et al*. 2010, p.5). The SFCBoE model monitors and assesses the evolution of economic and financial imbalances in the UK (Burgess *et al*. 2016, p.2).

Our aim is to consider the institutional foundations of the EAGLE and SFCBoE models, their capacity to analyse real world economies and which of them is more appropriate for policy making.[1] Emphasis is given to their technical specifications and to the pragmatism of their assumptions regarding the formation of consumption and investment, the price and wage setting procedures, the role of money and of the financial sector and the fiscal and monetary policy framework. We argue that the Walrasian micro-foundations of the DSGE models limit their realism compared to the institutional

[1] A similar brief attempt has been made by Burgess *et al*. (2016, p.3), but in our view it is found unsatisfactory as it critically undermined the theoretical structure of the SFC methodology.

foundations of the SFC models that make them more appropriate in quantifying the function of real world economies.

The paper is organised as follows. Section 2 examines the accounting consistency and the institutional structure of each model. Section 3 focuses on consumption and investment behaviour. Section 4 describes the wage and price setting procedures, while section 5 examines how money and the financial sector are treated in each of them. The penultimate section considers their fiscal and monetary policy framework, with conclusions following in the last section.

2. Accounting consistency and institutional structure

The accounting framework in macroeconomic modelling is essential because it determines the minimum order of relationships required in its formation and the degrees of freedom, while it safeguards from logical fallacies (Nikiforos and Zezza 2017). In order to carry out the comparison in terms of accounting structures a transactions flow matrix (TFM) that includes a flow-of-funds matrix, and a balance sheet (BS) for each model is built.[2]

Table 1 presents the BS of the SFCBoE model in which the institutional sectors are the households, the firms, the banks, the insurance companies and the pensions funds, the government, the BoE and the rest of the world denoted by *h*, *f, b, icpf, g, BoE* and *row* respectively. Note that the plus sign represents an asset and the minus sign a liability. All variables are expressed in nominal values.[3] The structure of the financial system is sophisticated, as it includes three financial sectors and thirteen financial instruments, which serve different purposes. Observing the BS, we can identify the implicit assumptions made in the construction of the model. For instance, firms and households do not hold equities as assets, while the equities that are issued by the firms are held only

[2] For a technical discussion on how these matrices are constructed see Godley and Lavoie (2007a, ch.2).

[3] In SFC models the nominal flows are "inflation accounted" in the behavioural framework of the models (Godley 1997).

by the *icpf* and the external sector.[4] In addition, households do not receive consumer loans.

The BS is consistent since every stock is an asset for one sector and simultaneously a liability for another, save the physical capital stock. The accounting structure of the model implies specific identities. For instance, since every financial stock is properly determined as an asset and a liability, it follows that the bonds held by the BoE are equal to the reserves. This denotes that the purchase of bonds by the central bank corresponds to the debiting of bank accounts in the central bank, by the same amount. In this manner, the SFCBoE model, and the SFC models in general, report explicitly the channel through which newly issued money flows into the economy (Godley 2004).

Table 1. The balance sheet of the SFCBoE model

	Households	Firms	Banks	ICPF	Government	BoE	Rest of the world	Sum
Reserves			+Res			-Res		0
Deposits	+M		-M					0
Mortgages	-mort		+mort					0
Pension wealth	+ITR			-ITR				0
Govt. bonds				$+gbond_{icpf}$	-gbond	$+gbond_{BoE}$	$+gbond_{row}$	0
Govt. bills					-gbill		+gbill	0
Bank bonds			-bbond	$+bbond_{icpf}$			$+bbond_{row}$	0
Bank bills			-bbill				+bbill	0
ROW bonds				+rowbond			-rowbond	0
Firm loans		-L	+L					0
Bank eq.			$-E_b$				+Eb	0
Firm eq.		$-E_f$		$+E_{ficpf}$			$+E_{frow}$	0
ICPF eq.				$-E_{icpf}$			$+E_{icpf}$	0
ROW eq.				$+E_{rowicpf}$			$-E_{rowicpf}$	0
Physical capital		+K						+K
Net wealth	+Vh	+Vf	+Vb	+Vicpf	-gbond	0	+Vrow	+K

Table 2 depicts the TFM of the model, which is an extended version of the TFM found in Burgess *et al*. (2016, p.14). The first subscript in each variable denotes the sector for which the transaction is an outflow; the second subscript indicates

[4] This assumption is quite strong. According to the financial accounts of Eurostat, 37% of UK firm equities were held by firms and households, in 2008.

the sector for which the transaction is an inflow; the plus sign denotes an inflow and the minus sign an outflow.

Horizontal and vertical flow consistency is ensured since every transaction has at least two counterparts and that the sum of every column adds up to zero. In other words, as Godley (1996) remarks, there are no "black holes" in the accounting of the system.

Table 2. The transactions flow matrix of the SFCBoE model

	Households	Firms		Banks	ICPF	Government	BoE	Rest of the world	Sum
		Current	Capital						
Consumption	$-C$	$+C$							0
Investment		$+I$	$-I$						0
Housing	$-I_h$	$+I_h$							0
Public expenditure		$+G$				$-G$			0
Exports		$+X$						$-X$	0
Imports		$-M$						$+M$	0
Compensation of employees	$+Comp$	$-Comp$							0
Annuities	$+Ann$				$-Ann$				0
Pension contr.	$-Pens$				$+Pens$				0
Taxes	$-T_h$	$-T_f$				$+T$			0
Transfers	$+Trans_h$	$+Trans_f$				$-Trans$			0
Profits/Dividends on bank eq.				$F_b - F_{bu} - div_b$				$+div_b$	0
Profits/Dividends on firm eq.		$-F$	$+FU$		$+div_{ficpf}$			$+div_{frow}$	0
Profits/Dividends on ICPF eq.					$F_{icpf} - FU_{icpf} - div_{icpf}$			$+div_{icpf}$	0
Dividends on RoW eq.					$+div_{row}$			$-div_{row}$	0
Interest on deposits	$+i_d * M_h$	$+i_d * M_f$		$-i_d * M$					0
Interest on mortgages	$-i_m * mort$			$+i_m * mort$					0
Interest on govt. bonds					$+i_{gb} * gbond_{icpf}$	$-i_{gb} * gbond$	$+i_{gb} * gbond_{BoE}$	$+i_{gb} * gbond_{row}$	0
Return on govt. bills						$-gbills$		$+gbills$	0
Interest on bank bonds				$-i_{bb} * bbond$	$+i_{bb} * bbond_{icpf}$			$+i_{bb} * bbond_{row}$	0
Return on bank bills				$-bill$				$+bbill$	0
Interest on ROW bonds					$+i_{brow} * rowbond$			$-i_{brow} * rowbond$	0
Interest on firm loans		$-i_l * L$		$+i_l * L$					0
Profits of BoE						$+F_{BoE}$	$-F_{BoE}$		0
[Memo] Net lending/Net borrowing	NL_h	NL_f		NL_b	NL_{icpf}	NL_g	NL_{BoE}	NL_{row}	0
Change in bank eq.				$+\Delta E_b$				$-\Delta E_b$	0
Change in firm eq.			$+\Delta E_f$		$-\Delta E_{ficpf}$			$-\Delta E_{frow}$	0
Change in ICPF eq.					$+\Delta E_{icpf}$			$-\Delta E_{icpf}$	0
Change in ROW eq.					$-\Delta E_{rowicpf}$			$+\Delta E_{rowicpf}$	0
Change in deposits	$-\Delta M_h$	$-\Delta M_f$		$+\Delta M$					0
Change in mortgages	$+\Delta mort$			$-\Delta mort$					0
Change in govt. bonds					$-\Delta gbond_{gicpf}$	$+\Delta gbond$	$-\Delta gbond_{gBoE}$	$-\Delta gbond_{grow}$	0
Change in govt. bills						$+\Delta gbill$		$-\Delta gbill$	0
Change in bank bonds				$+\Delta bbond$	$-\Delta bbond_{bicpf}$			$-\Delta bbond_{brow}$	0
Change in bank bills				$+\Delta bbill$				$-\Delta bbill$	0
Change in reserves				$-\Delta Res$			$+\Delta Res$		0
Change in ROW bonds					$-\Delta rowbond$			$+\Delta rowbond$	0
Change in firm loans			$+\Delta L$	$-\Delta L$					0
Sum	0	0	0	0	0	0	0	0	0

Turning the attention to the EAGLE model, Table 3 presents the associated BS. There are two types of households and two types of firms. The first type of households (Household *A*) holds a share of the stock of money issued by the

ECB, all the physical capital stock and part of the domestic and foreign bonds, as assets in its portfolio. The second type (Household *B*) is liquidity constrained, that is, it doesn't have access to finance, but places its entire savings in bank deposits. The firm structure in the EAGLE model is more detailed as compared to the SFCBoE model, as it incorporates one type of firms producing intermediate tradable and non-tradable goods (Firm *T*) and another type (Firm *NT*) producing non-tradable final goods.

Table 3. The balance sheet of the EAGLE model

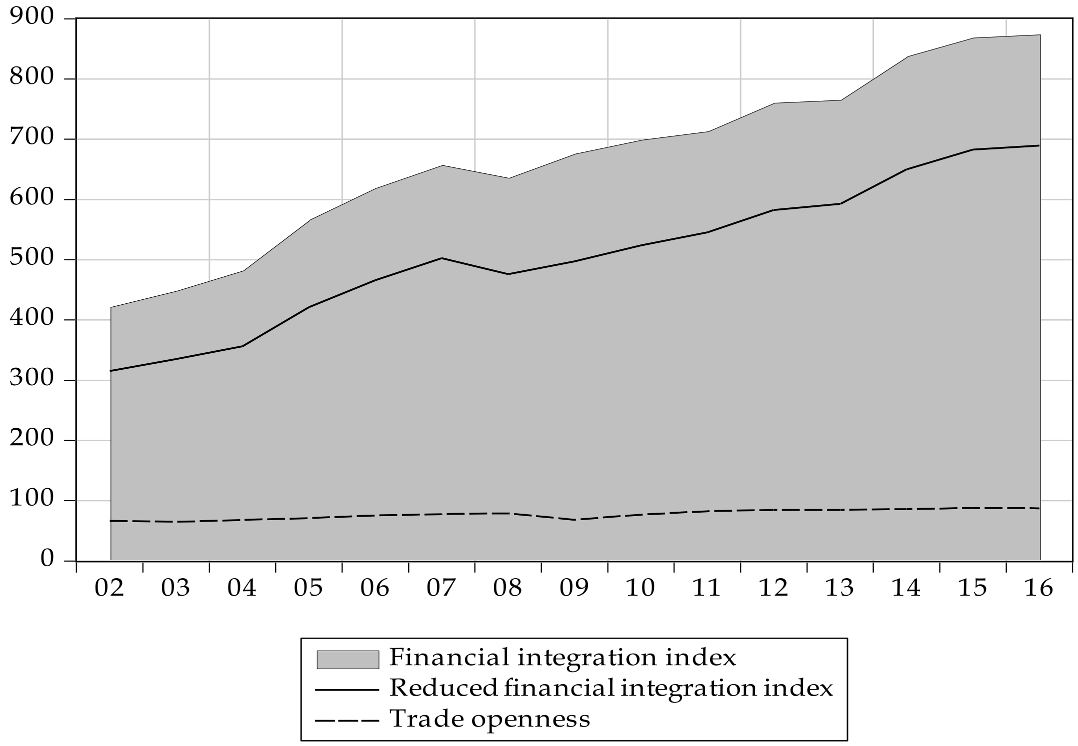
	Household A	Household B	Firm T	Firm NT	Government	ECB	Rest of the world	Sum
Stock of money	$+M_A$	$+M_B$				$-M$		0
Physical capital stock	$+K$							$+K$
Dometsic bonds	$+GB_A$				$-GB$		$+GB_{ROW}$	0
Foreign bonds	$+ROWB$						$-ROWB$	0
Sum	V_A	V_B	0	0	$-GB$	$-M$	V_{ROW}	$+K$

In contrast, the structure of the financial sector is clearly inadequate in capturing macrofinancial dynamics. It only contains the central bank and three financial instruments, namely domestic and foreign government bonds and the state-contingent securities traded amongst households of type *A*.[5] This is a typical institutional flaw of the DSGE models, which leads to a critical exclusion of a vast amount of financial instruments from the BS. In example, Figure 1 denotes the financial integration index of the Euro Area (EA), which is defined as the sum of the stocks of financial assets and liabilities *vis-a-vis* the rest of the world over GDP (see e.g. Lane and Milesi-Ferretti 2007), with and without corporate and government bonds. The trade openness, which is the sum of exports and imports over GDP, serves as a reference flow. Note that in 2016 the corresponding financial assets and liabilities accounted to 875% of the EA GDP, as compared to a mere 87% of the GDP with respect to imports and exports. Impressively, more than 76 trillion euro have been excluded from the balance

[5] Since state-contingent securities are a transaction within a sector, they are not reported in the TFM.

sheet of the EAGLE model, constituting a serious omission for a model that aims to capture transmission shocks across regions. The financial interdependence of the global economy, and in particular the EA's financial role, is critically downgraded.

Figure 1. Financial integration index and trade openness of the Euro Area vis-a-vis the rest of the world (%GDP, 2002-2016)



Source: Eurostat (authors' calculations). Note: The reduced financial integration index excludes government bonds.

Furthermore, physical capital stock and equities are used interchangeably. There is an implicit assumption that the replacement value of the capital stock is always equal to its market value, i.e. Tobin's *Q*, is always equal to one. Long-run equilibrium conditions prevail in the stock market, even in the short-run, ruling out cyclical patterns of economic activity, which are triggered by fluctuations in the capital market. Besides, capital gains stemming from changes in equity prices are excluded. It is worthy to note that Tobin's Q is unlikely to be equal to one in the long-run, since there are no background forces balancing the ratio (Bernardo *et al*. 2016). The realism of the model is further undermined considering that the physical capital stock corresponds simultaneously to equities and loans. On top of that, private debt is totally excluded. Overall, despite that the stock consistency of the EAGLE model holds, its institutional structure is highly unrealistic.

The TFM of the EAGLE model is presented in Table 4. An important feature of the TFM is that the Household *A* lends capital to Firm *T* and purchases final investment goods from Firm *NT*. Thereby, in this setup it is the Household *A* that accumulates physical capital, as it "pierces the corporate veil". Household *A* is simultaneously a wager, a shareholder, an investor in both physical and financial assets and a banker, as it receives income from wages, dividends, profits and interest after lending capital to the firms. This is a paradoxical institutional formation, since these sources of income correspond to significantly different behavioural patterns. Besides, in the social structure of the real world economies, such a household belongs to the very upper quantile of income distribution, casting doubts over the validity of the realism of the representative household assumption.

Table 4. The transactions flow matrix of the EAGLE model

	Household A	Household B	Firm T	Firm NT	Government	ECB	Rest of the world	Sum
Non-tradable intermediate goods			$+NT$	$-NT_{NT}$	$-NT_{G}$			0
Domestic intermediate goods			$+TT$	$-TT_{NT}$			$-TT_{ROW}$	0
Foreign intermediate goods				$-IM_{NT}$			$+IM_{NT}$	0
Consumption	$-C_{A}$	$-C_{B}$		$+C$				0
Household investment	$-I_{A}$			$+I_{A}$				0
Compensation of employees in T	$+COMP_{T,A}$	$+COMP_{T,B}$	$-COMP_{T}$					0
Compensation of employees in NT	$+COMP_{NT,A}$	$+COMP_{NT,B}$		$-COMP_{NT}$				0
Compensation of employees in G	$+COMP_{G,A}$	$+COMP_{G,B}$			$-COMP_{G}$			0
Interest on capital	$+R$		$-R$					0
Interest on bonds	$+GR_{A}$				$-GR$		$+GR_{ROW}$	0
Interest on foreign bonds	$+ROWR$						$-ROWR$	0
Dividends	$+Div$		$-Div$					0
Premium	$-PREM$						$+PREM$	0
Indirect taxes	$-TC_{A}$	$-TC_{B}$			$+TC$			0
Taxes on wages	$-TW_{A}$	$-TW_{B}$			$+TW$			0
Taxes on dividends	$-TDiv$				$+TDiv$			0
Taxes on interest	$-TR$				$+TR$			0
Lump-sum taxes	$-TLS_{A}$	$-TLS_{B}$			$+TLS$			0
Social contributions	$-SOC_{A}$	$-SOC_{B}$	$-SOC_{T}$	$-SOC_{NT}$	$+SOC$			0
Transfers	$-TRANS_{A}$	$-TRANS_{B}$			$+TRANS$			0
Seigniorage					$+SEIGN$	$-SEIGN$		0
[Memo] Net lending/Net borrowing	NL_{A}	NL_{B}	NL_{T}	NL_{NT}	NL_{G}	NL_{ECB}	NL_{row}	0
Change in the stock of money	$-\Delta M_{A}$	$-\Delta M_{B}$				$+\Delta M$		0
Change in capital stock	$-\Delta K$		$+\Delta K$					0
Change in domestic bonds	$-\Delta GB_{A}$				$+\Delta B$		$-\Delta GB_{ROW}$	0
Change in foreign bonds	$-\Delta ROWB$						$+\Delta ROWB$	0
Sum	0	0	0	0	0	0	0	0

Considering the flow-of-funds at the lower part of the TFM, Firm *T* borrows within one period all the physical capital stock from Household *A* and returns it at the end of the period. Therefore, the balance sheet of Firm *T* remains intact. This assumption is necessary to advance the institutional foundations of the TFM.

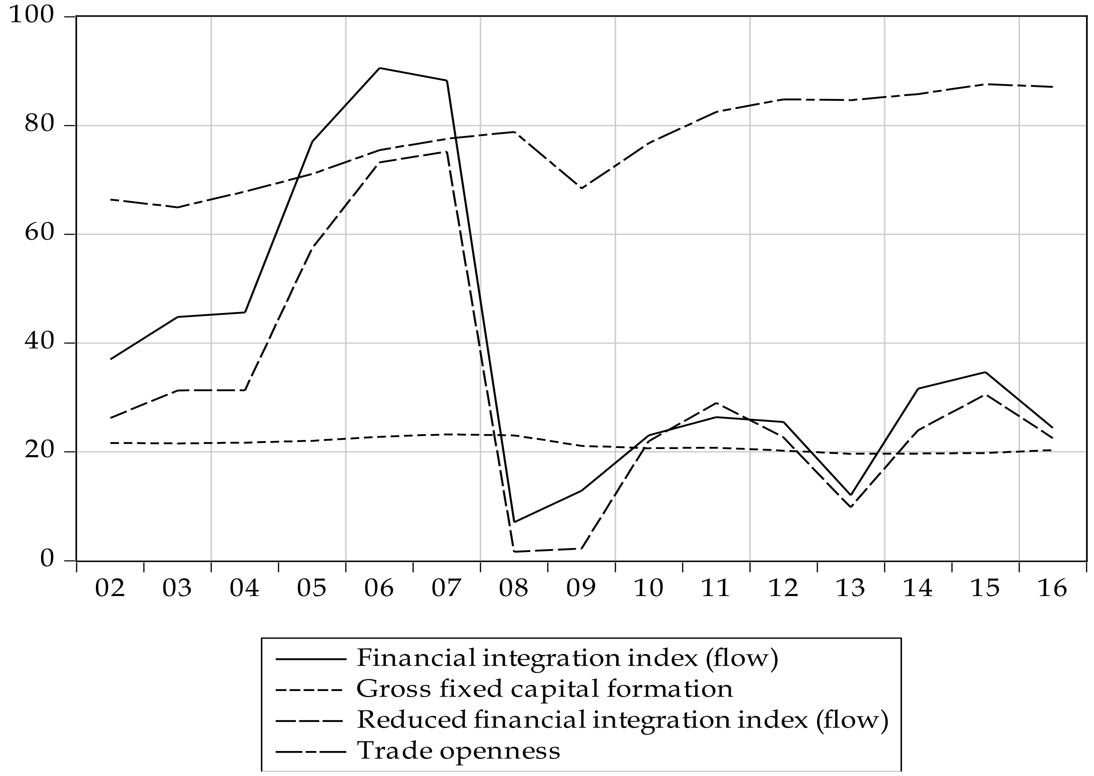
Firm *NT* is supposed not to use capital and to function under perfect competition. This implies that zero profit conditions prevail. Under this specification there are no profits and all gains equal production costs, that is, wages. Similar to the case of the stock market, perfect competition in the product and the labour market is imposed by assumption, even in the short-run. The omission of profits trivially oversimplifies the behaviour of the sector and undermines its financial conditions.

The government finances its deficit through the issuance of bonds, while the ECB distributes gains from seigniorage, e.g. printing money, to the public sector. The course of money flowing in the economy is not properly registered. The transmission mechanisms of new cash entering the balance sheet of the private sector are poorly established.

Finally, the rest of the world account suffers from the same conceptual flaws as noted in the case of BS. Figure 2 reports the financial asset and liability flows between the EA and the rest of the world, with and without government and corporate bonds. It also includes the trade openness and the investment of the EA. We observe that financial trading exhibits a completely diversified pattern as compared to international trade in goods and investment activity. Furthermore, the government bonds play only a minor role in the overall trading, while the financial accelerator, which is often integrated in DSGE models, is inappropriate to capture the connection between the financial and the real spheres of the economy.[6] Furthermore, note that the sluggish trading since 2008 in financial flows partially corresponds to the upward movement of financial stocks reported in Figure 1. This fact points to the presence of financial gains, which are trivially treated in the EAGLE model, even though, as we will argue below, they constitute a significant factor in the behaviour of the economic system.

[6] Kumhof *et al*. (2010) introduce a financial accelerator in the global policy model of the IMF, which presents similar deficiencies.

Figure 2. Trade openness, investment and financial asset and liability flows of the Euro Area vis-a-vis the rest of the world (%GDP, 2002-2016)



Source: Eurostat (authors' calculations)

In general, the EAGLE model is consistent, since everything comes from somewhere and ends up somewhere, an argument that, as we have already point out does not holds for every empirical DSGE model (see the TFM analysis of QUEST III model in the Appendix).

3. The behavioural framework

The SFCBoE model is an aggregated structural macro model and, thus, it is subject to Lucas' critique. Although that the EAGLE version of DSGE models is supposed to rely on Walrasian micro-foundations, it suffers from logical inconsistency, since, as Wren-Lewis (2018) pinpoints, the micro-foundations of DSGE models are mis-specified. Marchionatti and Sella (2017) argue in particular that the neo-Walrasian micro-foundations of DSGE models are ill-formed to avoid Lucas' critique. In this respect, parameters which are considered as structural, in reality they are continuously subject to change (for empirical studies supporting this critique see Cogley and Yagihasi, 2010; Hurtado 2014). Therefore, both models are subject to Lucas' critique. Be that as it may, we pay particular attention on the consumption and the investment behaviour in both models.

3.1 Consumption

In the EAGLE model households of type A are ricardian. In the presence of fiscal expansion they anticipate a future increase in taxes and, hence, reduce their current level of consumption. Households of type B are non-ricardian. This technical specification is a necessary logical presupposition to allow fiscal policy to be effective in the short-run. The consumption function is derived after the rational household has maximised its utility U. Eq. (1) presents the expected utility function of Household A, in which β is the discount rate of households, σ is the inverse of the elasticity of substitution ζ between real wage and leisure and κ reflects habit formation.

$$U_{i,t} = E_t[\sum_{k=0}^{\infty} \beta^k \left(\frac{1-\kappa}{1-\sigma}\left(\frac{C_{t+k,(i)}-\kappa C_{I,t+k-1}}{1-\kappa}\right)^{1-\sigma} - \frac{1}{1-\zeta} N_{t+k,(i)}^{1-\zeta}\right] \quad (1)$$

The level of consumption C depends on agent's utility, the budget constraint and the trade-off between the real wage and the disutility from working N. The standard critique of this typical formulation (e.g. Carroll, 2001; De Grauwe, 2010; Muellbauer, 2016) regards the theoretical inconsistency of the consumption function. This is because habit formation is not micro-founded and it is used as a device to allow the model to fit the data. This construction generates ambiguousness since agents are assumed to be rational, but they do not have perfect knowledge. In addition, the use of a common discount factor is a rather unrealistic feature (Blanchard, 2018), while, and even more importantly, the process of maximisation assumes that agents choose optimal outcomes, which in practice are only known *ex post*.

This type of consumption function downgrades the institutional, cultural and social characteristics of an economy. In fact, agents share collective beliefs which are determined by habits, routines and social norms (see e.g. Akerlof, 2007; McCombie and Negru, 2014). In this sense, micro behaviour is formulated by the institutional setting of the economy.

It is worthy to note that in eq. (1) all parameters are predetermined, imposing long-run conditions in the short-run, save the habit formation that is a lag term. There is a clear absence of short-run dynamics, which could explain deviations from the predetermined tendency. There is also a trivial treatment of the relationship between finance and consumption. The budget constraint contextualises the financing of consumption, which, however, does not have a direct impact on the balance sheet of households. The assumption of consumption optimisation excludes from consideration excessive and unsustainable lending.

Consumption in the SFCBoE model has a rather too simple form but is entirely based on actual data. As shown in eq. (2) consumption depends on the expected disposable income of households YD and their previously accumulated net financial wealth NW.

$$C_t = \alpha_1 E(YD)_t + \alpha_2 NW_{h,t-1} \qquad (2)$$

The configuration of eq. (2) has a dual role. First, it underlines the importance of historic time when decisions are made. As pointed out by Lavoie and Godley (2001-02) households are not aware of the actual level of the disposable income they will accrue at the end of the period, thus they make consumption decisions according to what they expect to gain. The fact that agents are not rational but follow rules of thumb, allows the formation of erroneous expectations, bearing sub-optimal outcomes.

Second, the inclusion of net financial wealth implies that there is a significant wealth effect on consumption, in the sense that households have the option to use funds from their accumulated wealth for consumption purposes. In this vein, financial gains, which are accumulated in the financial wealth and are likely to have a considerable impact on consumption (for an empirical validation of this view see Ludvigson and Steindel, 1998), are implicitly taken into account. The same applies for interest on deposits and mortgages, even though they do not affect the consuming behaviour directly.[7] Besides, as noted by Blanchard (2018), there is not enough empirical evidence supporting the view that the interest rate has any significant impact on consumption.

Financing conditions are critical for household spending in consumption goods, since erroneous expectations on the disposable income are directly related to the financial balance and consequently to the level of deposits of households (see eq. (6)-(7) in Burgess *et al.*, 2016). For example, if households' expectations are such that they consume based on a higher than the actual level of disposable income, they will end up at the end of the period with lower deposits.

A main drawback of the overall setting is that not all financial assets could be easily liquidated. A formation of the consumption function as in Meijers *et al.* (2015) would improve the overall structure. In addition, the linearity of the consumption function is questionable, while cultural and institutional features underlying the consuming behaviour of UK households are lacklustre.

Overall, both functions come with their own merits and drawbacks. Consumption in the EAGLE model is inappropriate for tracking *ex-ante* short-run dynamics in historic time and if and how they affect medium and long-run

[7] However, this does not apply for the whole SFC methodology. For instance, Godley and Lavoie (2007b) allow the interest rate to affect negatively the coefficient of the expected disposable income. In this sense, a change in the policy rate of the central bank would have a partial effect on consumption, given that the impact of net financial wealth on consumption remains intact.

outcomes. Besides, the assumptions regarding the behaviour of agents are too demanding to be considered as realistic.

Consumption in the SFCBoE is less stringent with regards to the comprehensive abilities of the agents, it is derived from actual data and properly deploys buffers that absorb falsified expectations. However, it ought to include further factors which are likely to affect consumption (e.g. consumer loans, stock-market effect, etc.). Yet in our view, consumption in the SFCBoE model is a closer approximation to reality, providing a better sense of how consumption affects the aggregate economy in historic time, thus it is rather more appropriate for policy making.

3.2 Investment

Investment in the EAGLE model is relatively complex due to the rich structure of the firm sector. Investment demand depends on the current level of production, the set of the associated prices and the weights and the intratemporal elasticities of substitution between tradables, produced domestically and abroad, and non-tradables. Production of investment goods is partially determined by a Cobb-Douglas function, given that the final goods sector does not utilise capital stock in its production. Capital services are provided under perfect competition, implying that the access to capital is the same for all firms. Given these assumptions, capital stock, ultimately owned by Household *A*, accumulates according to its marginal value, after taking under consideration the depreciation rate and the adjustment costs which are found in a non-linear relationship with changes in investment (see eq. (A.10)-(A.17) in Gomes *et al*., 2010).

In this framework, investment is substantially determined in a *quasi* mechanistic way, by the properties of the Cobb-Douglas function. Output and investment are determined concurrently, with the causation running from the former to the latter. Thereby investment is stripped off from any behavioural considerations.

This setting is problematic for a number of reasons. Firstly, the adjusting costs introduce implicitly a Tobin's Q effect on investment (Carlin and Soskice, 2005, pp.234-236) when in the BS of the model the market value of the capital stock has been assumed equal to its replacement cost, at all times. Thereby, the construction of the EAGLE model is theoretically inconsistent.

Secondly, uncertainty with respect to future economic outcomes, which affects the pace and the direction of investment (Minsky, 1983) is ruled out. The market risk which has a significant impact on investment and the portfolio of firms and the fragility of the banking sector is totally absent (Minsky, 1986; Pollin and Dymski, 1993). The volatility of investment, which is owed to firms' subjective evaluations regarding future events (Minsky, 1986), is neglected.

Thirdly, financing of investment activity is absent. Specifically, Firm *T* borrows capital from Household *A*, though it uses no funds to borrow the capital required in the production process. In the real world firms retain a part of their profits in order to finance their operations, they issue equities and they receive loans from the banking sector (Lavoie and Godley 2001-02). The problem of the interchangeable use of capital, loans and equities, mentioned earlier, is present in the case of investment. Apart from being unrealistic, the present formation deprives the analysis from insights related to the financial stability of the firm sector (e.g. Minsky 1992).

Fourthly, the loanable funds theory underlying DSGE models ensures that savings determine, in large, investment. In this respect, consumption affects investment activity *via* savings. A false hierarchy is created, in which the interest rate is the dominant tool of policy making, due to its impact on consumption. Ironically, in its website[8] the ECB considers that loans, e.g. provided to the firm sector, are not created by deposits, but on the contrary they generate deposits. Thereby, investment is not constrained by the level of savings. The causality between savings and investment is the opposite from

[8] https://www.ecb.europa.eu/ecb-and-you/explainers/tell-me-more/html/what_is_money.en.html

that imposed on the structure of the EAGLE model. Lastly, one of the most fundamental determinants of investment, the profit rate, is missing.

Other approaches within the DSGE framework introduce firms' debt aiming to finance investment, though they are lacking of an endogenous mechanism of fragility. Firms' default is usually modelled in a probabilistic manner (e.g. Walque *et al.*, 2010). Overall, there is a misapprehension of the internally unstable nature of investment activity, both in real and financial terms (Fontana and Passarella, 2018).

The form of the investment function in the SFCBoE model is more straightforward. As shown in eq. (3) the growth rate of physical capital g depends on the autonomous component γ_Y, the capacity utilisation defined as the GDP over the capital stock and the interest rate on bank loans i_L, save the interest on reserves held by the banking sector in the BoE, i_R.

$$g_{k,t} = \gamma_Y + \gamma_u \frac{GDP_{t-1}}{k_{t-1}} - \gamma_r(i_{L,t-1} - i_{R,t-1}) \quad (3)$$

The capacity utilisation represents the impact of effective demand on investment decisions. Specifically, strong demand, close to full capacity, prompts firms to further investment, so as to increase capacity. This specification follows form the work of Kalceki (1971). However, the absent volatility of investment due to subjective evaluations of future events, noted in the EAGLE model, applies also in this case. Furthermore, structural or technological considerations with respect to the capacity utilisation are not properly registered. The profit rate is also missing in the investment function of this model.

The second component relates to the impact of financial conditions on investment, as a higher interest rate is likely to discourage any further investment. However, the introduction of leverage would have proven theoretically sounder since it is the nominal level of interest flows that affect investment decisions and not just the interest rate (i.e. see van Treeck, 2009). For instance, a high level of debt is likely to have different implications for the interest payments of a firm as compared to one with a low level of debt, even though the interest rate is the same for both.

In general, in the EAGLE model there is a clear avoidance of issues that are connected to firms' volatile behaviour, owed to the unrealistic institutional structure of the model and the assumption of rational agents optimising their behaviour. Investment in the SFCBoE model is likely a better approximation to realistic investment decision making. It is not directly affected by the level of consumption, while the accumulation of capital is closely connected with the financial conditions of the firm sector, though in a simplistic manner, for SFC standards (for detailed implications of this interconnection see e.g. Lavoie, 2006). In advance, this interconnection is monitored in historic time. However, there is a considerable lack of structural considerations, while the deterministic nature of investment is a major drawback. Finally, both models could greatly benefit from the introduction of the profit rate as a determinant of capital accumulation.

4. Price and wages formation

The comparison of the two models on the grounds of price and wage formation is uneven, since in the SFCBoE model the determination of prices is not reported. This is a rather critical omission, given the importance monetary authorities pay to inflation. Besides, the absence of price setting deprives the SFCBoE model of the associated theoretical structure embedded in the SFC methodology (for a detailed presentation of how prices are set in SFC models see Godley and Lavoie, 2007a, ch.8). For this reason we draw relevant information from other SFC models.

In the EAGLE model, as in most DSGE models, price and wage rigidities are present, serving two different scopes. Firstly, they prevent the economy from reaching instantaneously general equilibrium conditions, thus the model is able to fit the data sufficiently. Secondly, fiscal policy becomes effective in the short-run.

Price changes follow a Calvo pricing process, according to which some firms are allowed to re-optimise their prices and others to partially adjust them. The same applies with households and wages (eq. (38)-(44) and (63)-(66) in Gomes *et al.,* 2010). With respect to prices, the main drivers of this process are forward looking expectations on inflation and the maximisation of firms' profits. Once again, the problem of rationality emerges, as it pre-empts the behavioural pattern of agents. Furthermore, the Calvo pricing process does not aim to explain how firms set their prices but to allow DSGE models to fit inflation data properly, with the use of probabilistic calculus.

Besides, market power on which the mark-ups are owed is addressed in an abstract manner. The analysis is lacklustre in terms of dynamics generated by the market power affecting i.e. the functional income distribution. Following Kalecki (1971), it would be more plausible to assume that firms exhibiting increased levels of market power are equally, or more, concerned with the level of mark-up *per se*, rather than just the marginal costs.

None the less, prices in the EAGLE model are the transmitting channels upon which economic activity evolves. Their rich structure allows a detailed examination of movements in quantities both within and across regions. Despite the merits of this high form of interdependence and complexity, a major drawback of this theoretical as well as technical formulation is that in periods of moderate or low inflation it is the quantities that adjust to demand and not the prices (Godley 1997). Besides, price rigidity presents varying intensity according to the phase of the cycle on which the economy is found (Beker 2017). In this context, Calvo pricing becomes problematic, notwithstanding the fact that probabilistic calculus hardly suffices to describe firms' behaviour, in the presence of fundamental uncertainty.

Furthermore, prices have various functions and multiple effects, such as the impact of the two price system on the capital accumulation rate (Argitis, 2013a). As noted by Minsky (1986), whenever the demand price of capital exceeds its supply price, expectations regarding future profits are improved, thus enhancing investment activity. Firms' mark-ups are set according to these conditions (*ibid*). Relative prices are a mere residual.

Wage frictions of Calvo type present the same drawbacks as with price frictions. Of more importance is the fact that households are the ones setting the mark-ups with respect to wages. They are assumed to decide in a fashion which is uncorrelated to social norms and collective bargaining procedures. In addition, an abstract form of hierarchy is generated in which the bargaining outcome determines the amount of jobs offered and not the other way around. As a result, unemployment and in particular involuntary unemployment is an outcome determined by households' preferences. In this constellation, there are conflicting claims between households. This notion is rather unrealistic, given that the major conflict is between firms and workers.[9]

In the SFC methodology conflicting claims between firms and workers are properly registered. Furthermore, the analysis is enriched with the inclusion of shareholders, the motives of which diverge from those of the firms (for the impact of conflicting claims on the long-run macroeconomic performance see Dallery and van Treeck, 2011). The latter are assumed to apply cost-plus pricing procedures (e.g. Godley and Lavoie, 2007a, ch.11), which in turn determine the functional distribution of income. The determination of the mark-up depends on the relative strength of firms and labour unions, though usually in the SFC models, there is a considerable lack of an explicit, rigorous and formalistic exposition of this relation (i.e. the mark-up is set exogenously).

[9] It may be true that other DSGE models introduce explicitly labour unions. However, their analysis emphasises the distinction between insiders and outsiders in the labour market (see Blanchard and Summers, 1986), or the elasticity of demand with respect to wages (see Calmfors and Driffill, 1988). In most cases, firms are mere wage takers.

5. The role of money and finance

In the DSGE framework, there is a clear dichotomy between the real and the nominal values.[10] The only role of money is to serve as a unit of account (Gali and Gertler 2007). Credit frictions, which were mainly introduced after the 2007-08 events, ensure that money is non-neutral in the short-run (see Woodford 2010), though the money supply is controlled by the central bank. In the long-run, money is strictly exogenous, constraining the monetary policy (Argitis, 2013a). In fact, as noted by Rogers (2018), money is more of a friction in the DSGE universe rather than an institution present in the real economy.

On the contrary, in the New Cambridge school of thought, that underlines the function of the SFC models, money is considered as endogenous, driven by demand. According to this view, the role of historic time in the production process is such that renders the role of finance inseparable from the workings in the real side of the economy. As mentioned by Godley (1996), production takes place prior to sales, implying that firms require funds to finance the production process in advance. Therefore, credit demand precedes the payment of wages and the production of output. Additionally, when loans are provided from a bank to a firm, a deposit account is created, which is unrelated to the deposits held up to that point in the bank. In other words, banks create money *ex nihilo*. This feature is termed as "inside money" and by now is widely acknowledged by the monetary authorities such as the Bank of England, Bundesbank (McLeay *et al*., 2014; Deutsche Bundesbank, 2017) and the ECB, as noted earlier. In this context, money is endogenous, not controlled by the central bank (Godley, 2004a).

As it has been already apparent, the EAGLE model allows a very limited role for financial considerations, while the banking sector is altogether absent. The exogenous nature of money is overtly present in simulations carried out by

[10] Integrating the real and the nominal sides of the economy, potentially alter the policy implications of the model. For instance see Godley and Shaikh (2002) who integrate both sides in a IS-LM model.

Gomes *et al*. (2010), where i.e. a fiscal expansion in the Home country is ensued by a reduction of consumption and investment in the rest of the EA so as to finance the trade deficit of the Home country (Gomes *et al*. 2010, p.39). This theoretical construction neglects the presence of "inside money" and the dynamics of the financial structure of the EA that likely affect the interest rate policy of the ECB. The same applies for most of the DSGE models introducing a banking sector explicitly (e.g. Coimbra and Rey, 2017), even though a significant advancement has been observed lately (e.g. Jakab and Kumhof, 2015). However, even in the presence of “inside money” zero-profit conditions in the banking sector are imposed, excluding by assumption endogenous financial instability. The “fundamentals” of the DSGE framework remain, more or less, the same (Argitis 2013a).

However, what appears as a novelty in the DSGE literature, in the structure of SFC models it is a norm. In example, in the SFCBoE model money supply is bound to firms’ credit demand. The latter is a residual function following directly from the capital account of firms in Table 2.

$$L_t = L_{t-1} - NPL_t - NL_{F,t} - P_{V,F,t}\Delta v_{F,t} + \Delta D_{F,t} \quad (4)$$

where *L* are the loans, *NPL* are the non-performing loans, *NL* is the net lending position of the firm, *D* represents the stock of deposits, *v* is the stock of equities and *Pv* is the respective price. According to eq. (4), credit demand depends on the financial needs of firms. For instance, whenever the constraints regarding other means of financing investment are binding, thus net lending takes a substantially negative value, firms demand credit from the banking sector. Despite that credit demand is stripped off from other aspects of firms’ behaviour (in example for fraudulent or manipulating activities, e.g. Argitis, 2013b; Jager 2014), or that credit rationing is rather implicit in this set up (for an introduction of credit rationing in SFC models see Dafermos, 2012), it still is an efficient and consistent approach to the integration of “inside money” and firm’s debt within a macroeconomic framework (for a proper illustration of how endogenous money is integrated in SFC models see Godley, 2004). In addition, investment behaviour is affected but also affects the financial conditions of firms. Nevertheless, the introduction of bankers' expectations with respect to credit provision, conditional to firms' expected profitability would improve considerably the structure of the SFCBoE model.

Banks are considered as profit making institutions, which interact directly with all the rest sectors of the economy. Loan provision determines economic activity on the real side of the economy, while equity, bills and bond issuing affect the financial side. Once again, historic time is properly taken into account since the price of bonds issued by the banks is not known *ex-ante* thus any imbalances between the demand and supply for banks bonds are absorbed through the issuance of non-interest bearing bills (Burgess *et al.,* 2016, p.10). In parallel, equity issuing is set in relation with the minimum capital requirements. In this fashion, macroprudential policies affect the entire economy through the behaviour of the banking sector, a point discussed in the next section.

Another important feature of the financial sector is the structure of the associated portfolios. The portfolios are constructed in accordance with the method proposed by Brainard and Tobin (1968), in which the adding-up constraints secure consistency between the choice of assets.[11] Portfolio decisions of the *icpf* and the external sector generate dynamics which feed back to the aggregate economy. In turn, the aggregate outcome affects the portfolio decisions. Therefore, financial decisions evolve in historic time. Potentially this leads to path-dependency (Caverzasi and Godin 2015). The latter indicates that not every outcome is possible (Macedo e Silva and Dos Santos, 2011). The short-run dynamics highlight a specific path in which the economy is evolving, since there are no imposed specifications ensuring that the economy would converge to a deterministic long-run equilibrium (this is in line with the interplay between short and long-run dynamics proposed by Carvalho, 1984).

[11] For a detailed analysis regarding the constraints in the structure of the portfolio see Godley and Lavoie (2007a, ch.5).

On the contrary, in the DSGE framework optimal changes in financial stocks take place instantly. This is one of the main reasons behind the inability of the DSGE models to properly account for financial fragility and systemic unsustainability. Furthermore, asset prices, which serve as signals of coherence, connecting past with present and future decisions, are relatively absent (Kregel 1983).

Given the above, the role of the financial sector in SFC models is considerably more complex than the financial frictions employed in DSGE models. Furthermore, the EAGLE model is lacklustre in terms of properly exposing the financial behaviour of the economy. Considerations with respect to the financial premium provide only a minor view of the highly complex financial relations which are present in the actual economy. Illiquidity and credit risk are critically underplayed (Buiter, 2009). On the contrary, the SFCBoE highlights in an efficient manner the interplay between the real and the financial side of the economy, the dynamics of which are multidimensional and properly registered in historic time.

6. Fiscal and monetary policy

In the EAGLE model, the ricardian households ensure the limited effectiveness of fiscal expansion in the long-run, while the constrained households render it effective in the short-run. This condition is augmented by the drop of the real interest rate, as the nominal one does not increase in line with inflation, which is generated by fiscal expansion. Ultimately, fiscal expansion is followed by an increase in the current account deficit, leading to the twin deficit phenomenon. In parallel, the holdings of domestic bonds abroad correspond to the movements of the trade balance (eq. (75)-(78) in Gomes *et al.*, 2010).

Firstly, as already noted, the latter is an invalid specification, since the decision to hold bonds depends on portfolio decisions and not on international trade. Secondly, the public spending has a triple effect, as it i) affects income and employment, ii) generates cash flows towards the rest sectors of the economy and iii) causes changes in portfolios (Minsky, 1986). In the DSGE framework, fiscal policy is related only to the first function.

In the SFCBoE model, the transmitting channels are somewhat different. In the absence of rationality, fiscal expansion generates additional cash inflows for the private sector, simultaneously boosting effective demand. The increased public debt generates higher interest payments to the bond holders, which on the one hand improve the financial balance of the domestic sectors, i.e. of the *icpf*, but on the other deteriorate the balance of payments due to the interest paid abroad.

In this context, the ownership of debt becomes a critical factor with respect to the stability of the economy and the sustainability of public debt. For instance, a continuous fiscal expansion is expected to deteriorate significantly the current account of the UK due to the interest paid to the rest of the world, which holds a considerable amount of government bonds (Burgess *et al*. 2016, p.31).

Switching to the monetary policy, in the EAGLE model, a change in the interest rate affects directly the budget constraint of Household *A*. Consumption and investment increase in the short-run,[12] in line with overall production, real wages and employment. The critical point in this case is that the monetary policy affects directly household decisions, given that households of type *A* have a multiple role in the economy.

In the SFCBoE model changes of the interest rate follow a more realistic pattern due to the presence of the banking sector and the wider spectre of interest rates. Banks' profitability and balancing of their assets and liabilities are much affected from this process. Consequently, the impact of the policy rate on the productive sector largely depends on banks' behaviour. In this context, it is the banks that ultimately determine the money supply, in conjunction with firm and household demand for credit and mortgages, respectively.

[12] In terms of eq.(A.3) in Gomes *et al*. (2010) a drop of the interest rate induces unconstrained households to hold less bonds and consume more, due to the effect of the Euler equation.

Finally, macroprudential policy is clearly absent in the EAGLE model. In the SFCBoE model, a marginal increase of the capital requirements would affect the funding costs of the banking sector and the yield of the bonds issued by banks. In order to maintain their profitability banks increase the interest rate on loans and mortgages, followed by a decline of the respective volumes. In the associated simulation the GDP is projected to fall marginally. As exposed by Burgess *et al.* (2016, p.25), the estimates with regard to the impact on the interest rates lie closely to those found in the relevant literature. What is important to notice is that the SFCBoE provides the advantage of examining the implications for the real economy as well.

7. Conclusion

In this paper we have attempted a comparison of two empirical models, as representative samples of the DSGE and the SFC methodologies. In particular, we compared the EAGLE model used by the ECB and the SFCBoE model used by the BoE. Since the respective monetary authorities utilise a set of models for monitoring the economy and forecasting, it was infeasible to assess the efficiency of the projections of the two models. Therefore, the focus has been laid upon the technical specification and the pragmatism of the assumptions underlying each model.

The EAGLE model is characterised by unrealistic assumptions in terms of consumption behaviour and wage and price setting procedures and it fails to address the highly volatile investment behaviour. In addition, it lacks of solid short-run dynamics which could alter substantially the long-run tendency of the economy. In fact, the short-run rigidities, which are present in the EAGLE model, but also in the DSGE framework, are essentially designed to explain the sluggishness of the economy to move towards the deterministic long-run equilibrium, rather than to explain reality. There is a clear negligence of historic time and of the associated short-run dynamics.

The SFCBoE model follows a rather more plausible path in the description of realistic behaviour, while its short-run dynamics are sufficiently formed and expressed. The role of money in actual economies and the interplay between the real and the financial side of the economy is well exposed. Nevertheless, it lacks of a pricing procedure, as well as of structural considerations, which would enrich significantly the behavioural framework. Furthermore, the framework regarding expectations connected to investment and credit provision is lacklustre.

Despite the merits and the drawbacks of each approach we conclude that the SFC models are rather more suitable tools for policy making, given their more realistic assumptions and the importance they attribute to the role of finance. The construction of the DSGE models is such that it renders them highly inappropriate for short and medium-run, policy analysis.

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Appendix

The TFM of QUEST III is quite similar to that of EAGLE, even though the firm structure is quite different. In the present case, the Firm *A* undertakes all the productive activity, the Firm *B* accounts for technological shocks and the Firm *C* represents the exporters.

As it is evident in Table 5 below, the accounting framework with respect to Firm *B* and Firm *C* is highly problematic. In example, the investment output is not recorded as a transaction, but affects directly the Cobb-Douglas production function. It appears that production for Firm *B* is not a profit making process but an end in itself. Similarly, the representative exporter receives profits from imposing mark-ups on the price of exported goods, which are not registered within the model. Besides, in the balance sheet of the ECB there is no counterpart to the money issued. Overall, the model is inconsistent, since there are important omissions in the accounting structure of the model.

Table 5. The transaction flow matrix of the QUEST III model

	Household A	*Household B*	*Firm A*	*Firm B*	*Firm C*	*ECB*	*Government*	*Rest of the World*	*Sum*
Investment input			$+I_{inp, A}$	$-I_{inp}$				$+I_{inp, row}$	*0*
Investment output				$+I_{out}$					$+I_{out}$
Consumption	$-C_A$	$-C_B$	$+C$						*0*
Public spending			$+G$				$-G$		*0*
Public investment			$+I_{g, A}$				$-Ig$	$+I_{g, row}$	*0*
Exported goods			$+X_A$		$-X_A$				*0*
Exports					$+X$			$-X$	*0*
Imports			$-M_A$					$+M_A$	*0*
Household Investment		$-I_h$	$+I_{h, A}$					$+I_{h, row}$	*0*
Compensation	$+COMP_A$	$+COMP_B$	$-COMP$						*0*
Taxes on consumption	$-TC_A$	$-TC_B$					$+TC$		*0*
Taxes on wage income	$-TW_A$	$-TW_B$					$+TW$		*0*
Taxes on capital income		$-TK$					$+TK$		*0*
Lump-sum tax	$-TLS_A$	$-TLS_B$					$+TLS$		*0*
Transfers	$+TR$						$-TR$		*0*
Interest on bonds		$+i_b*B$					$-i_b*B$		*0*
Interest on foreign bonds		$+e*i_b*B_{row}$						$-e*i_b*B_{row}$	*0*
Interest on capital		$+i_K*K$	$-i_K*K$						*0*
Profits		$+F$	$-F$						*0*
[Memo] Net lending/Net borrowing	$NL_{h,A}$	$NL_{h,B}$	$NL_{f,A}$	$NL_{f,B}$	$NL_{f,C}$	NL_{ECB}	NL_g	NL_{row}	*?*
Change in cash		$-\Delta M$				$+\Delta M$			*0*
Change in bonds		$-\Delta B$					$+\Delta B$		*0*
Change in foreign bonds		$-e*\Delta B_{row}$						$+e*\Delta B_{row}$	*0*
Change in capital		$-\Delta K$	$+\Delta K$						*0*
Sum	*0*	*0*	*0*	*?*	*?*	ΔM	*0*	*0*	*?*

A small DSGE model for the Greek economy

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1 Description

In this section we present a small DSGE model for the Greek economy. The model is based on the SAMBA model (Castro et al., 2015) for the Brazilian economy. In particular we make use of the SAMBA model as presented in the Macroeconomic Modelling Data Base (Wieland et al., 2012) and calibrate the parameters for the Greek economy.

The household sector lies at the core of SAMBA. Representative households maximize expected lifetime utility, making choices over consumption, savings, labour supply, and asset holdings. Consumption dynamics follow an Euler equation linking current and future consumption to the real interest rate, but the model also incorporates habit formation, which ensures that present consumption depends partly on past consumption and generates persistence in demand. Labour supply decisions arise from the trade-off between real wages and the disutility of work, although wage rigidities prevent households from fully adjusting wages in each period. In terms of assets, households allocate wealth between domestic bonds and limited foreign assets, with incomplete asset markets ensuring that not all international risk is shared. To prevent implausible levels of capital flight, SAMBA introduces a risk premium on foreign debt, which grows with the economy's external indebtedness. This household structure creates the channel through which monetary policy affects consumption, savings, and labour markets.

Production in SAMBA is organized around monopolistically competitive firms that use labour and capital to produce differentiated products, but face nominal rigidities in their pricing. Prices cannot be freely adjusted each period; instead, only a fraction of firms reoptimize at any given time, following the Calvo mechanism. Others rely on partial indexation to past inflation. This framework produces the familiar New Keynesian Phillips Curve, in which current inflation depends on expected future inflation and real marginal costs. Firms, combine intermediate goods into aggregate output, which is then allocated to private consumption, investment, and government spending. Capital accumulation plays an important role in the model, with investment decisions shaped by Tobin's Q and subject to adjustment costs, which introduce frictions and ensure that monetary shocks affect not just consumption but also investment and capital formation.

Rigidities in both prices and wages give SAMBA its realistic short-run dynamics. Price stickiness, implemented through Calvo contracts and indexation, ensures that inflation is persistent, a critical feature given Brazil's inflationary history. Wage stickiness functions in a similar way, with only some households able to reset wages optimally in each period while others rely on backward-looking rules. These rigidities are crucial for monetary policy analysis, as they ensure that policy-induced interest rate changes have real short-run effects on output and employment.

Monetary policy itself is represented through a Taylor-type rule. The Central Bank of Brazil sets its short-term policy rate in response to deviations of inflation from the target, deviations of output from potential, and an element of smoothing that reflects the gradualist approach typically observed in real-world decisions. This structure reflects an inflation-targeting framework, embedding both credibility and systematic behaviour into the model. By responding to inflation and output gaps, the policy rule provides the anchor for expectations and a channel through which monetary tightening or loosening propagates through the economy.

Government spending and taxation are explicitly modelled, with fiscal solvency ensured by a rule that links the primary surplus to the level of public debt. Public expenditures are treated partly as exogenous, following stochastic processes, while taxes adjust in a way that guarantees long-term debt sustainability. This reflects the institutional reality of Brazil, where fiscal credibility strongly influences interest rates, inflation expectations, and overall macroeconomic stability.

Exports in the model depend on foreign demand and relative prices, while imports are linked to domestic absorption and competitiveness. Exchange rate dynamics are governed by an uncovered interest parity condition, but with deviations that stem from a risk premium. The premium increases with net foreign debt, introducing a stabilizing mechanism that prevents explosive borrowing abroad. In this way, the model captures how global shocks, such as changes in U.S. interest rates or shifts in commodity prices, feed into the domestic economy through trade, capital flows, and exchange rate channels.

A key strength of SAMBA is its ability to trace the propagation of a wide range of shocks. It includes supply-side shocks such as productivity changes, mark-up disturbances, and price or wage-setting shifts, as well as demand-side shocks linked to preferences, investment, or fiscal spending. Monetary policy shocks are captured as unexpected changes in the policy rate, while external shocks include movements in foreign interest rates, commodity prices, and the country risk premium. These shocks interact with the model's rigidities and structural features to generate rich and realistic dynamics for inflation, output, interest rates, and exchange rates.

Given that a discussion of most of the theoretical and empirical aspects of DSGE models has already been presented, both in this and in earlier work-packages we focus here solely on the presentation of the model and its results. The model is solved using DYNARE in MATLAB. In particular the model is transformed in its log-linear form, presented in section five below, and estimated around the steady state of the balanced growth path. The parametrization of the model has been discussed in WP3 and in any case follows historical estimates for the Greek economy as well as values reported in **???**. The impulse response functions (IRFs) presented in section six

The rest of this essay is structured in the following way. In the second section we present the endogenous variables of the mode. In the third section we present the strictly exogenous variable. In the fourth section we present the parameters. In the fifth section we present the equations of the model. Finally in the sixth section we present the impulse response functions to an increase in the interest rate.

2 Endogenous Variables

a	Productivity shock
b^y	Government debt to GDP
$b^{y\star}$	Government debt to GDP, world
c	Consumption
c^{h1}	Consumption of optimizing households
c^{h2}	Consumption of rule of thumb households
ϕ^i	Country risk premium
g	Government expenditure
g^f	Government expenditure shock
g^y	Government expenditure to GDP ratio
i	investment demand
k	Capital stock
m	Imports
$m^\star$	Imports, world
mc	Marginal cost, real
n	Employment
n^{h1}	Employment of optimizing households
n^{h2}	Employment of rule of thump households
nx^y	Net exports to GDP
π	Inflation rate
$\bar{\pi}$	Inflation rate, target
$\pi^\star$	Inflation rate, world
π^{va}	Inflation, value added
q	Exchange rate, real
q^i	Shadow price of capital
r	Interest rate
r^k	Rental rate of capital
$r^\star$	World interest rate
$\bar{s}^g$	Fiscal balance, target
$\hat{s}^y$	Fiscal balance, deviation from target
u	Rate of capital utilization
w	Wages, real
x	Exports
y	Gross output
y^{va}	Value added
z^c	Consumption shock
z^{ϕ^i}	Country risk premium shock
$z^{\phi^\star}$	World risk premium shock
z^g	Government spending shock
z^i	Investment shock
z^n	Employment shock
z^r	Interest rate shock

3 Exogenous Variables

$\epsilon_{\bar{\pi}}$	Inflation shock
$\epsilon_{\bar{g}}$	Fiscal balance target shock
ϵ_c	Consumption shock
ϵ_n	Employment shock
ϵ_i	Investment shock
$\epsilon_{\phi^\star}$	World risk premium shock
ϵ_ϕ	Risk premium shock
ϵ_a	Productivity shock
ϵ_r	Interest rate shock
ϵ_g	Government expenditure shock
$\epsilon_{m^\star}$	World demand shock
$\epsilon_{\pi^\star}$	World inflation rate shock
$\epsilon_{r^\star}$	World interest rate shock

4 Parameters

α	0.500	Capital income share in GDP (Cobb-Douglas)
β	0.9923	Time discount factor
γ_r	0.900	Interest rate smoothing
γ_π	1.700	Inflation coefficient
γ_y	0.000	Output gap coefficient
γ_g	0.500	Fiscal policy persistence parameter
γ_s	0.800	Primary balance target coefficient
γ_b	0.200	Government debt coefficient
δ	0.040	Depreciation rate of capital
δ_a	1.000	Adjustment to capacity utilization
δ_s	4.000	Adjustment cost of investment
η	0.600	Habit persistence
θ	0.750	Calvo parameter
κ	0.900	Export sensitivity to exchange rate
κ_u	1.400	Import sensitivity to exchange rate
μ	0.700	Country risk premium sensitivity to International investors' risk aversion
ν	0.400	Employment sensitivity
ρ_a	0.750	Autoregressive shock, productivity
ρ_c	0.750	Autoregressive shock, consumption
ρ_i	0.750	Autoregressive shock, investment
ρ_n	0.750	Autoregressive shock, employment
ρ_q	0.000	Autoregressive shock, exchange rate
ρ_r	0.000	Autoregressive shock, interestr rate
ρ_g	0.000	Autoregressive shock, government expenditure
ρ_s	0.750	Autoregressive shock, fiscal balance
ρ_π	0.750	Autoregressive shock, inflation
ρ_ϕ	0.750	Autoregressive shock, country risk premium
$\rho_{\phi^\star}$	0.750	Autoregressive shock, International investors' risk aversion
$\rho_{m^\star}$	0.750	Autoregressive shock, world import demand
$\rho_{r^\star}$	0.750	Autoregressive shock, world interest rate
$\rho_{\pi^\star}$	0.000	Autoregressive shock, world inflation rate
σ	1.000	Inverse of intertemporal elasticity of substitution
$\phi^\star$	1.000	Risk premium, investors aversion coefficient
ψ	0.040	Country risk premium sensitivity to world government debt
χ	0.057	Investment to capital ratio
ω_b	0.400	Price indexation parameter
ω_c	0.150	Share of rule of thumb households in consumption
ω_n	0.400	Share of rule of thumb households in employment
b^C	1.028	Government debt sensitivity
$b^\star$	0.033	Government debt sensitivity, world
r^C	1.042	Government debt sensitivity
$r^{\star C}$	1.009	Government debt sensitivity, world
s_c	0.688	Consumption to GDP ratio
s_i	0.198	Investment to GDP ratio
s_g	0.179	Government expenditure to GDP ratio
s_m	0.465	Imports to GDP ratio
s_x	0.400	Exports to GDP ratio
s_{va}	0.867	Value added to GDP ratio
s_d	0.867	Weight of domestic input cost in marginal cost

5 Equations

Taylor rule

$$r_t = \gamma_r * r_{t-1} + (1-\gamma_r) * (\gamma_\pi * (\pi_{t+1} - \bar{\pi}_{t+1})) + \bar{\pi}_t + \gamma_y * y_t^{va}) \quad + z_t^r; \tag{1}$$

Fiscal policy rule

$$g_t^y = \gamma_g * g_{t-1}^y + (1-\gamma_g) * (\gamma_s * s_{t-1}^{\hat{y}} - \gamma_b * b_{t-1}^y) + z_t^g; \tag{2}$$

Consumption of optimizing households

$$\begin{aligned} c_t^{h1} = (\frac{1}{1+\eta}) * c_{t+1}^{h1} + (\frac{\eta}{1+\eta}) * c_{t-1}^{h1} - \frac{1}{\sigma} * (\frac{1-\eta}{1+\eta}) \\ * (r_t - \pi_{t+1}) + \frac{1}{\sigma} * (\frac{1-\eta}{1+\eta}) * (1-\rho_c) * z_t^c; \end{aligned} \tag{3}$$

Consumption of rule of thumb households

$$c_t^{h2} = w_t + n_t^{h2}; \tag{4}$$

Aggregate consumption

$$c_t = (1-\omega_c) * c_t^{h1} + \omega_c * c_t^{h2}; \tag{5}$$

investment demand

$$i_t = \frac{1}{\delta_s * (1+\beta)} * q_t^i + \frac{\beta}{1+\beta} * i_{t+1} + \frac{1}{1+\beta} * i_{t-1} + \frac{1-\rho_i * \beta}{1+\beta} * z_t^i; \tag{6}$$

Shadow price of capital

$$q_t^i = \beta * (1-\delta) * q_{t+1}^i + (1 - \beta * (1-\delta)) * r_{t+1}^k - (r_t - \pi_{t+1}); \tag{7}$$

Exports

$$x_t = m_t^\star + \kappa * q_t; \tag{8}$$

Imports

$$m_t = y_t - \kappa_u * (q_t - mc_t); \tag{9}$$

Labour supply

$$n_t = (1-\omega_n) * n_t^{h1} + \omega_n * n_t^{h2}; \tag{10}$$

Labour demand

$$n_t = y_t - (1-\kappa_u) * a_t - (\kappa_u + \alpha * (1-\kappa_u)) * w_t + \alpha * (1-\kappa_u) * r_t^k + \kappa_u * mc_t; \tag{11}$$

Capital services demand

$$\begin{aligned} k_{t-1} + u_t = y_t - (1-\kappa_u) * a_t - (1 - \alpha * (1-\kappa_u)) \\ * r_t^k + (1-\kappa_u) * (1-\alpha) * w_t + \kappa_u * mc_t; \end{aligned} \tag{12}$$

Capital services supply

$$r_t^k = \delta_a * u_t; \tag{13}$$

Law of motion of capital

$$k_t = (1-\delta) * k_{t-1} + \chi * i_t; \tag{14}$$

Phillips curve

$$\pi_t = (\frac{(1-\theta*\beta)*(1-\omega_b)*(1-\theta)}{(\theta+\omega_b*(1-\theta*(1-\beta)))}) * mc_t + (\frac{\omega_b}{(\theta+\omega_b*(1-\theta*(1-\beta)))}) * \pi_{p-1} + (\frac{(\theta*\beta)}{(\theta+\omega_b*(1-\theta*(1-\beta)))}) * \pi_{t+1}; \tag{15}$$

Marginal cost

$$mc_t = s_d * (\alpha * r_t^k + (1-\alpha) * w_t - a_t) + (1-s_d) * q_t; \tag{16}$$

Real exchange rate

$$q_t = q_{t+1} - ((r_t - \pi_{t+1}) - (r^\star + \phi_t^i - \pi_{t+1}^\star)); \tag{17}$$

Country risk premium

$$\phi^{i_t} = -\psi * b^{y\star} + \mu * z^{\phi^\star} + z^{\phi^i}; \tag{18}$$

Gross Domestic Product

$$y_t = s_c * c_t + s_i *_t + s_g * g_t + s_x * x_t; \tag{19}$$

Value added

$$y_t^{va} = (1/s_{va}) * y_t - (s_m/s_{va}) * m_t; \tag{20}$$

Government Expenditure

$$g_t = y_t^{va} + (s_{va}/s_g) * g_t^y - (s_m/s_{va}) * q; \tag{21}$$

Primary balance deviation from target

$$\hat{s^y}_t + \bar{s^g}_t = -g_t^y; \tag{22}$$

Government debt to GDP

$$b_t^y = r^C * (b_{t-1}^y + g_t^y) - b^C * (y_t^{va} - y_{t-1}^{va} + \pi_t^{va})) \quad + b^C \quad * r_t; \tag{23}$$

Inflation

$$\pi_t^{va} = \pi_t - (s_m/s_{va}) * (q_t - q_{t-1}); \tag{24}$$

Employment of optimizing households

$$n^{h1} = \nu^{-1} * (w_t - (\sigma/(1-\eta)) * (c_t^{h1} - \eta * c_{t-1}^{h1}) - z^n); \tag{25}$$

Employment of rule of thumb households

$$n^{h2} = \nu^{-1} * (w_t - (\sigma/(1-\eta)) * (c_t^{h2} - \eta * c_{t-1}^{h2}) - z^n); \tag{26}$$

Net exports

$$\begin{aligned} nx_t^y &= (s_x/s_{va}) * x_t \\ &\quad -(s_m/s_{va}) * m_t - ((s_x - s_m)/s_{va}) * y_t^{va} - (s_m/s_{va}) * ((1-s_x)/s_{va}) * q_t; \end{aligned} \tag{27}$$

Consumption shock

$$z^c = \rho_c * z_{t-1}^c + \epsilon_c; \tag{28}$$

Employment shock

$$z^n = \rho_n * z_{t-1}^n + \epsilon_n; \tag{29}$$

Investment shock

$$z^i = \rho_i * z_{t-1}^i + \epsilon_i; \tag{30}$$

Interest rate shock

$$z^r = \rho_r * z_{t-1}^r + \epsilon_r; \tag{31}$$

Fiscal shock

$$z^g = \rho_g * z_{t-1}^g + \epsilon_g; \tag{32}$$

World imports

$$m_t^\star = \rho_{m^\star} * m_{t-1}^\star + \epsilon_{m^\star}; \tag{33}$$

World inflation

$$\pi_t^\star = \rho_{\pi^\star} * \pi_{t-1}^\star + \epsilon_{\pi^\star}; \tag{34}$$

World interest rate

$$r_t^\star = \rho_{r^\star} * r_{t-1}^\star + \epsilon_{r^\star}; \tag{35}$$

???

$$\begin{aligned} b_t^{y\star} &= \phi^\star * r^{\star C} \\ &\quad * (b_{t-1}^{y\star} + nx_t^y + b^\star * (y_{t-1}^{va} - y_t^{va} + (1/s_{va}) * (q_t - q_{t-1}) - \pi^\star)) + b^\star * (\phi_t^i + r^\star); \end{aligned} \tag{36}$$

International investors' risk aversion

$$z_t^{\phi^\star} = \rho_{\phi^\star} * z_{t-1}^{\phi^\star} + \epsilon_{\phi^\star}; \tag{37}$$

Shock to country risk premium

$$z_t^{\phi^i} = \rho_\phi * z_{t-1}^{\phi^i} + \epsilon_\phi; \tag{38}$$

Inflation target

$$\bar{\pi}_t = \rho_\pi * \bar{\pi}_{t-1} + \epsilon_{\bar{\pi}}; \tag{39}$$

Primary fiscal balance target

$$\bar{s^g}_t = \rho_s * \bar{s^g}_{t-1} + \epsilon_{\bar{g}}; \tag{40}$$

Productivity shock

$$a_t = \rho_a * a_{t-1} + \epsilon_a; \tag{41}$$

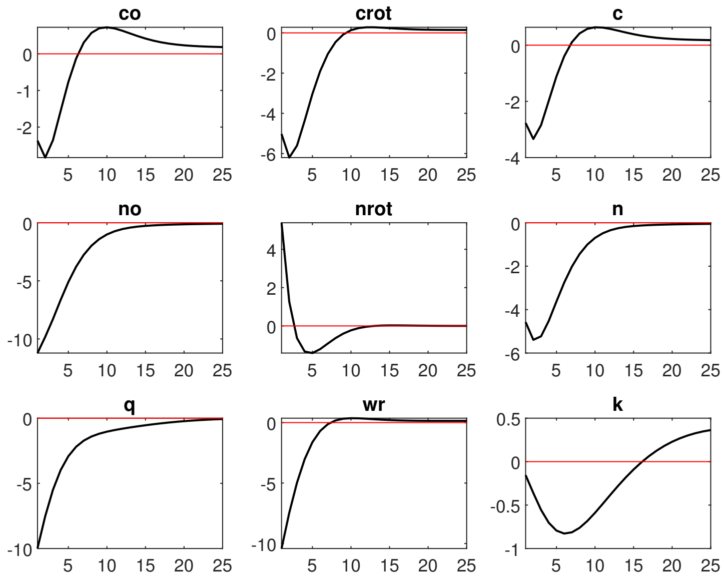

Figure 1: Impulse response functions (orthogonalized shock to *epsilon_r*).

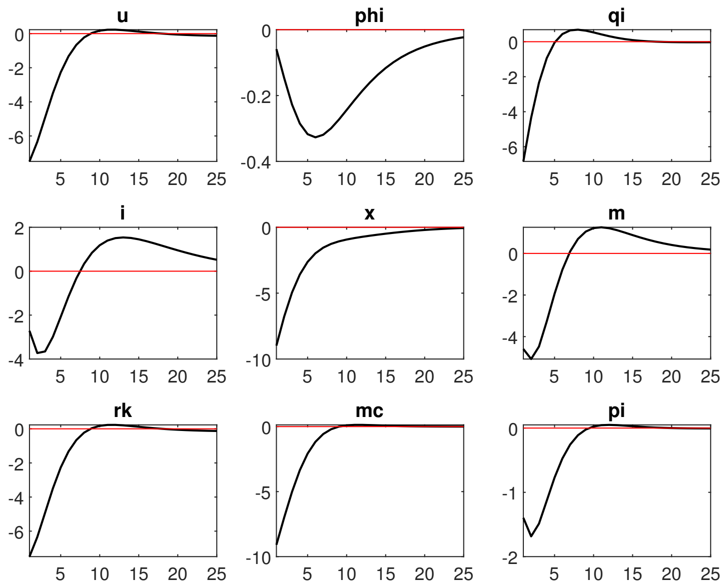

Figure 2: Impulse response functions (orthogonalized shock to *epsilon_r*).

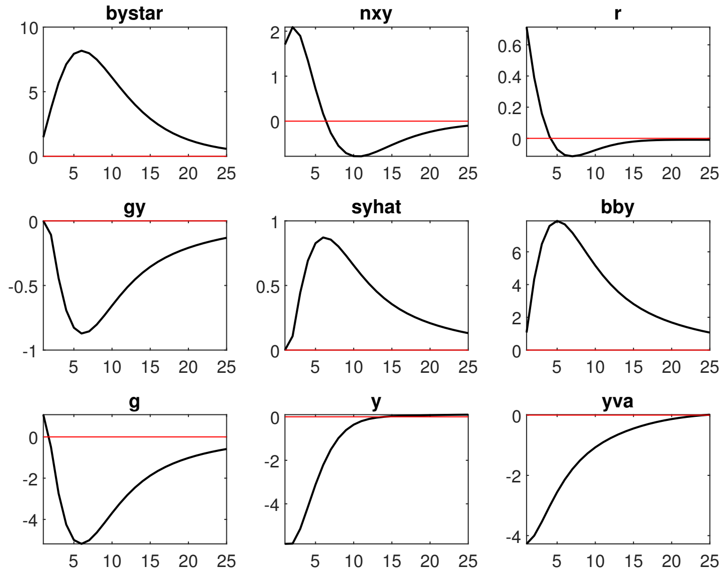

Figure 3: Impulse response functions (orthogonalized shock to *epsilon_r*).

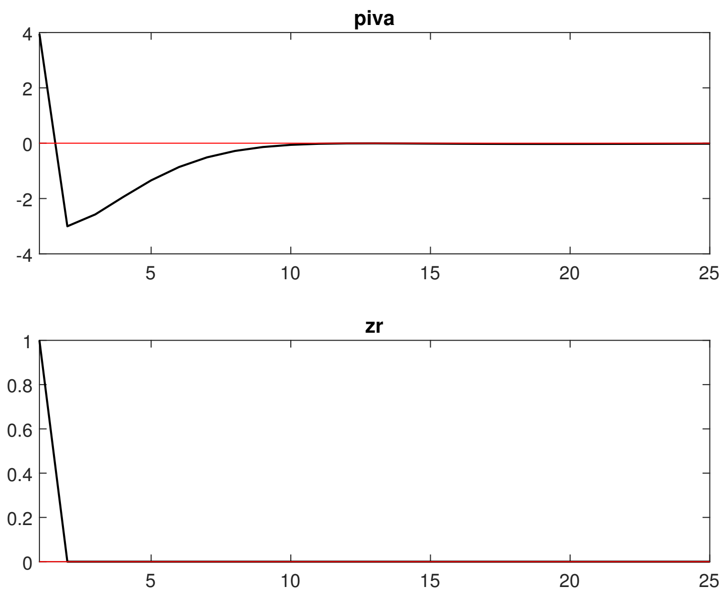

Figure 4: Impulse response functions (orthogonalized shock to *epsilon_r*).

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