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# ENHANCING INPUT-OUTPUT ANALYSIS: MODERN APPROACHES TO ASSESSING STRUCTURAL LINKAGES IN THE ECONOMY

*The study reviews and critically evaluates the approaches used to assess intersectoral linkages. The study concludes that modernizing intersectoral analysis through methodological diversification is crucial for producing relevant, multidimensional policy insights. The integration of classical transparency with modern complexity enhances the capacity to assess structural changes and to formulate evidence-based strategies in an increasingly interconnected and volatile global economy. The article presents a comparative table of methods and discusses their use by international organizations (e.g., OECD, UNCTAD, EU Commission), national governments, and academic researchers. Special attention is given to how these tools have been adapted in Ukraine and other emerging economies for regional planning, industrial policy, and evaluating the socio-economic impacts of green transition policies. The study concludes that modernizing intersectoral analysis through methodological diversification is crucial for producing relevant, multidimensional policy insights. The integration of classical transparency with modern complexity enhances the capacity to assess structural changes and to formulate evidence-based strategies.*

***Keywords**: intersectoral analysis, input-output, structural linkages, SDA, hypothetical extraction, Chenery-Watanabe coefficients, Rasmussen linkages, MRIO, import substitution.*

**Коваль Л. П. УДОСКОНАЛЕННЯ МІЖГАЛУЗЕВОГО АНАЛІЗУ: СУЧАСНІ ПІДХОДИ ДО ОЦІНЮВАННЯ СТРУКТУРНИХ ЗВ'ЯЗКІВ В ЕКОНОМІЦІ**

*Здійснено комплексний аналіз сучасних підходів до міжгалузевого аналізу в економіці, який охоплює як класичні, так і новітні методи дослідження структурних зв'язків між секторами національної та світової економіки. На основі систематизації теоретичних і методологічних підходів обґрунтовано необхідність удосконалення традиційної таблиці «витрати-випуск», розробленої В. Леонтьєвим, ураховуючи нові глобальні виклики – структурну трансформацію економік, дедалі більшу взаємозалежність через глобальні ланцюги доданої вартості, цифровізацію, екологічні ризики й нестабільність міжнародних ринків. У першій частині статті розглянуто класичні методи міжгалузевого аналізу, які заклали основу для подальших наукових розробок. Серед них – методи прямих і зворотних зв'язків Расмуссена, коефіцієнти Ченері-Ватанабе, а також метод гіпотетичної екстракції, що дає змогу визначити вплив кожного сектору на економічну систему через його умовне вилучення. Надано порівняльну характеристику цих підходів, визначено їхні переваги та обмеження з огляду на використання в аналітичних дослідженнях та у процесі формування державної економічної політики. Друга частина присвячена сучасним методологічним розширенням міжгалузевого аналізу, зокрема структурному розкладанню (SDA), мережевому аналізу міжсекторальних взаємозв'язків, а також мультирегіональному міжгалузевому аналізу (MRIO). Ці підходи відкривають можливості для дослідження не лише економічної динаміки, але й просторових, соціальних та екологічних вимірів розвитку. Вони застосовуються для аналізу наслідків «зеленої» трансформації, оцінювання структурних зрушень у зайнятості, дослідження вуглецевого сліду, ефективності політик імпортозаміщення та розвитку стратегічних секторів національної економіки. Окрему увагу приділено порівнянню аналітичного потенціалу класичних і сучасних підходів, що свідчить про доцільність їх інтеграції. Зазначено, що поєднання традиційних моделей, які забезпечують прозорість і стабільність оцінок, із гнучкими інструментами нового покоління, такими як елементи мережевого моделювання чи динамічного SDA, дає змогу підвищити точність і прогностичні властивості аналітики. Доведено, що удосконалення міжгалузевого аналізу на основі розширеного методичного інструментарію є необхідною умовою для глибшого розуміння складних взаємозв'язків у національній та глобальній економіці. Це створює підґрунтя для розроблення більш ефективних, збалансованих і екологічно стійких стратегій економічного розвитку в умовах нової світової економічної реальності. Хоча міжгалузевий аналіз в Україні переважно базується на класичних підходах, у відповідь на зовнішні виклики (війна, енергетичний перехід, інтеграція з ЄС) зростає інтерес до сучасних інструментів, таких як MRIO, SDA, гіпотетична екстракція та мережевий аналіз. Ширше використання цих інструментів наразі обмежене відсутністю детальних статистичних даних, але їхній потенціал високий, особливо в контексті економічного відновлення та зеленого переходу.*

***Ключові слова**: міжгалузевий аналіз, витрати-випуск, структурні зв'язки, SDA, гіпотетична екстракція, коефіцієнти Ченері-Ватанабе, зв'язки Расмуссена, MRIO, імпортозаміщення.*

**Problem Statement.** Input-output analysis (IOA) has historically played a crucial role in studying economic structure by modeling interdependencies between production and consumption sectors. The input-output table developed by W. Leontief remains a fundamental tool for economic planning and forecasting. However, the transformations of the 21st century – globalized production, increasingly complex global value chains (GVCs), digitalization, environmental challenges, and regional disparities – have necessitated an upgrade of the analytical framework.

The core problem lies in the limitations of traditional IOA approaches to capture the multidimensional effects of economic policy, particularly regarding social, investment, spatial, and environmental impacts. The lack of flexibility in classical models diminishes their relevance for strategic decision-making and the analysis of structural change.

The scientific and practical relevance of this issue stems from the need to expand the methodology of intersectoral analysis to:

- evaluate the effects of the green transition and decarbonization;
- identify key sectors for innovation-led development;
- analyze vulnerability to shocks in global supply chains;
- assess social consequences such as employment, income, and regional inequality.

Research methods used in this article include: comparative analysis of intersectoral approaches (Rasmussen, Chenery-Watanabe, Strassert, Ghosh, SDA, MRIO), content analysis of academic publications and international best practices, systematization of advantages and limitations of various methods, and construction of typologies of analytical tools.

**Analysis of recent research.** Intersectoral analysis has undergone significant methodological advancements in recent decades. Several key directions of methodological expansion can be identified:

Assessment of structural linkages: Rasmussen's approach (1956) [1], using backward and forward linkages, is widely applied in identifying key sectors. Modified versions (Cella, 1984) further refine the analysis, and comparative studies (Temurshoev & Oosterhaven, 2014) provide empirical validation across European economies.

Hypothetical extraction method (Strassert, 1968; Miller & Lahr, 2001) [3-4] is employed to evaluate the systemic importance of specific sectors and model the effects of disruptions or policy exclusions.

Structural decomposition analysis (SDA) by Dietzenbacher & Los (2002) [5] is widely used in China, the EU, and the US to decompose GDP growth, decarbonization trends, and technological shifts (e.g., Timmer et al., 2016; Wang et al., 2020).

Network analysis, as developed by Acemoglu et al. and Bartelme & Gorodnichenko, provides tools to measure systemic risk and evaluate the structure of production networks. These methods are relevant in macro-financial studies and resilience planning.

Multiregional input-output models (MRIO) have been advanced by projects such as WIOD, EXIOBASE, and GTAP to assess cross-border flows, trade dependencies, and environmental footprints. These are actively used in evaluating the European Green Deal, the Circular Economy Action Plan, and global sustainability strategies.

A growing body of research has applied IO frameworks to evaluate import substitution policies (e.g., China, South Korea), deindustrialization and service economy transitions (e.g., USA, EU), and labor market effects across social groups (Ghosh & Chakraborty, 2019). Others have extended IO models to environmental domains, including assessments of carbon and ecological footprints (Wiedmann et al., 2007; Lenzen et al., 2012).

As such, the literature shows a clear evolution from narrow production-based IO analysis to multidimensional approaches that integrate environmental, social, and spatial dimensions of economic systems.

**The paper purpose** is to analyze contemporary methods for assessing intersectoral linkages, their significance for understanding structural changes in the economy, and to outline prospects for their further development.

**Major research findings.** The assessment of intersectoral linkages in the economy has traditionally been carried out using input-output models, which allow for analysis of production structures and the interdependence of sectors. Classical approaches were developed in the mid-20th century and have formed the foundation of the analytical tools still used today. They help identify key sectors in the economy and assess their systemic influence and interrelationships. This section discusses three key methods that form the basis of intersectoral analysis: Rasmussen's backward and forward linkage coefficients [1], the Chenery-Watanabe technical coefficients [2], and the hypothetical extraction method.

Backward and Forward Linkages Method (Rasmussen, 1956). Forward and backward linkage coefficients help identify sectors with high systemic impact. The method's advantage lies in its simplicity and ease of application. Limitations: the model assumes fixed input coefficients and does not account for endogenous technological changes or external shocks.

This method has been applied in various policy and industrial studies, including by the European Commission and national governments (e.g., Germany, Poland, and Spain) to identify key sectors for strategic investment and industrial policy design.

Chenery-Watanabe Technical Coefficients (1958) [2]. This method is based on a matrix of technical coefficients that allows for the classification of sectors by their degree of integration into production processes. Its main advantage is the ability to identify sectors dependent on imports or export-oriented. Limitations: the method does not consider time dynamics or interactions with external shocks.

The approach is widely used by international institutions such as the World Bank, the OECD, and UNIDO for assessing industrial integration and evaluating policies aimed at import substitution, especially in East Asia (China, South Korea) and Latin America.

Hypothetical Extraction Method was originally proposed by Strassert (1968) [3] and later developed by Miller & Lahr (2001) [4]. This method models the impact of removing a particular sector. It helps assess how critical a sector is to the economy. Its strength lies in realistically simulating the consequences of sectoral loss.

The main drawback is the theoretical radicalism of assuming full sectoral extraction.

Applications include environmental and disaster risk assessments, for example in Japan after the 2011 tsunami and by the European Environment Agency to evaluate the systemic role of fossil fuel sectors.

Modern intersectoral analysis methodologies expand beyond traditional models, enabling a deeper understanding of economic change dynamics, structural shifts, and regional or international interdependencies. The integration of innovative approaches, such as structural decomposition and network-based models, allows researchers to go beyond static analysis and address environmental, social, and technological dimensions of economic interaction.

Structural Decomposition Analysis (SDA). Developed by Dietzenbacher & Los (2002), the SDA method allows for the identification of individual factor contributions (e.g., technology, demand structure, imports) to changes in economic indicators. Advantages: multidimensional analytics and the ability to study dynamics. Disadvantages: requires large volumes of detailed data and is sensitive to decomposition methods.

SDA has been widely used by researchers in China, the EU, and the US to analyze drivers of GDP growth, decarbonization trends, and global value chain (GVC) participation. It is also applied in ex-ante policy analysis, such as assessing the impact of carbon taxation or renewable energy subsidies.

SDA is applied in analytical work across the following areas:

Economic Growth Analysis: SDA is used to assess the contribution of technology, capital, and final demand to GDP. For example, the application of SDA in China revealed that most of the GDP growth between 2000 and 2020 was driven by technological development rather than an increase in labor force.

Globalization and Trade Impact: SDA is used to evaluate changes in the structure of international trade and global value chains. Analyses of the EU and the US showed that rising imports from China transformed the production structure in developed countries, reducing the share of traditional manufacturing.

Environmental Analysis: SDA is employed to assess the environmental impact of economic growth, particularly in terms of $CO_2$ emissions. For instance, in studies by the International Energy Agency (IEA), SDA is used to determine the contribution of energy efficiency to emission reductions.

The analysis of changes in Backward Linkage (BL) and Forward Linkage (FL) coefficients over time helps to identify how the economic structure evolves – for example, the shift from a resource-based to an innovation-driven model. The use of SDA allows researchers to separate changes in the economy into technological changes, shifts in demand, and alterations in production structure.

Rasmussen's methodology is also applied to assess the effects of deindustrialization and the transition to a service-based economy.

In the EU, intersectoral linkage analysis is used to evaluate the effects of the «green transition» on the economy – identifying which sectors benefit from environmental reforms and which may lose competitiveness. In China, BL and FL calculations have been used to measure the economic shift from manufacturing toward innovation and IT.

This method remains highly relevant in contemporary research, particularly in the context of globalization, digital transformation, and the transition to a green economy.

Network-based approaches (Bartelme & Gorodnichenko, Acemoglu et al.) [6] allow for the analysis of shock propagation through production networks. The main advantage of the approach is the coverage of systemic risks and identification of central nodes. At the same time the models are complex that causes calibration challenges.

The method is increasingly used in macro-financial risk research (IMF, ECB), resilience studies (OECD), and industrial policy analysis in countries like the Netherlands, Austria, and South Korea.

In network analysis, the economy is viewed as a network, where nodes represent economic sectors and edges represent flows of goods and services between sectors (intermediate consumption volumes). The network can be weighted (accounting for the magnitude of the connections) and directed (considering the direction of resource flows).

The main indicators of network analysis include:

- Node Centrality – indicates the importance of a sector within the economy;
- Modularity – detects groups of sectors that have tighter interconnections;
- Network Density – evaluates the overall level of interconnectedness within the economy;
- Clustering Coefficient – analyzes the tendency of sectors to form «local» intersectoral links.

Centrality reflects how crucial a particular sector is within the broader economic structure. Key types of centrality:

Degree Centrality: the number of direct connections a sector has with other sectors;

Eigenvector Centrality: how strongly a sector is linked to other influential sectors;

Betweenness Centrality: whether a sector acts as a «bridge» between other sectors.

Cluster analysis methods allow the identification of groups of sectors with strong internal linkages. Algorithms such as Louvain and Girvan–Newman are used to detect sectoral clusters. This method helps identify specialized economic zones and regional production clusters. For example, clearly defined industrial clusters in the EU include the automotive industry (Germany, Czech Republic, Slovakia) and tech startups (Netherlands, Estonia, Finland).

The network approach makes it possible to assess how a local economic shock propagates throughout the system. If a critical sector is disrupted (e.g., supply chain issues with microchips), the consequences cascade into other industries.

To evaluate vulnerable sectors, resilience analysis methods are applied. For instance, the COVID-19 pandemic revealed weaknesses in global supply chains – a disruption in China triggered a crisis in global manufacturing.

MRIO (Multiregional Input-Output) is a crucial tool for evaluating global flows of resources and interdependencies between countries (e.g., WIOD, EXIOBASE). Its strength lies in integrating spatial dimensions; its limitation – high complexity and resource intensity.

MRIO is applied by the European Commission, UNCTAD, and UNEP to model carbon footprints, trade dependency, and supply chain risks. It also supports the analysis of the European Green Deal, Circular Economy Action Plan, and national sustainability transitions.

Applications of MRIOA (Multiregional Input-Output Analysis):

Input-output analysis, particularly in its multiregional form, offers several key advantages over other methodological approaches. The most important advantages include: high granularity in mapping global flows of goods and services, which supports the development of sustainable development and international trade policies.

A major benefit of input-output analysis is that it allows for the calculation of material footprints for all products or sectors, including those with highly complex global supply chains, because the entire economic system is incorporated into the calculation framework. As a result, IOA avoids truncation errors commonly found in coefficient-based approaches – errors that arise because it is impossible to fully analyze the complexity of production chains in life cycle assessment approaches, leading to certain upstream chains being cut off.

Another general strength of IO-based approaches is their ability to disaggregate the RMC (Raw Material Consumption) indicator by various categories of final demand (e.g., private consumption, public consumption, capital investments) as well as by product groups disaggregated in the input-output table.

Multiregional Input-Output (MRIO) models also offer an advantage by accounting for the different resource intensities across countries. By following a top-down approach, IO analysis also avoids double counting. A specific material resource can be allocated to final consumption only once, as the supply and use chains are fully represented. This also helps avoid inaccuracies related to system boundary definitions.

Another benefit of the input-output approach is its close alignment with standard systems of economic and environmental accounting (United Nations, 2012), which ensures a continuous data collection and quality verification process – at least at the national level.

Limitations of MRIOA include: the high complexity of data collection and harmonization; reliance on estimates and assumptions, which can affect accuracy; and time lags, as IO tables often trail real-time data by several years. Most IO models operate at the level of aggregated economic sectors and product groups, assuming that each sector produces a homogeneous product. This means that several different products – potentially with very different material intensities – are grouped and averaged within a single sector. This homogeneity assumption can distort results, for example when very different materials like industrial minerals and metal ores are combined into one sector.

Given these issues, a number of recent research projects have focused on improving input-output tables and multiregional input-output systems for footprint-type indicators (Dietzenbacher et al., 2013 [5]; Lenzen et al., 2012 [8]). The goal is to create globally harmonized systems, potentially with higher sectoral resolution, especially in environmentally sensitive primary sectors (e.g., mining).

See the comparative overview of intersectoral analysis methods in Table 1.

*Table 1*

**Comparative Overview of Intersectoral Analysis Methods**

| Method | Key Features | Advantages | Limitations |
|---|---|---|---|
| Backward & Forward Linkages | Measures sectoral influence via input/output connections (Rasmussen, 1956) | Simple; useful for identifying key sectors | Ignores dynamics and technological changes |
| Chenery–Watanabe Coefficients | Technical coefficient matrix for sector classification (1958) | Identifies import dependence and sector integration | Static model; limited responsiveness to external shocks |
| Hypothetical Extraction | Simulates removal of a sector (Strassert, 1968; Miller & Lahr, 2001) | Reveals economic dependence on specific sectors | Assumes total removal; not always realistic |
| Structural Decomposition (SDA) | Breaks down changes into factors (Dietzenbacher & Los, 2002) | Captures dynamics; multidimensional insight into growth drivers | Data-intensive; sensitive to method of decomposition |
| Network Analysis | Evaluates economic networks and shock diffusion (e.g., Acemoglu et al.) | Identifies systemic risk; reveals production interconnectivity | Complex; requires advanced computation and calibration |
| MRIO (Multiregional IO) | Cross-country/regional interlinkages (e.g., WIOD, EXIOBASE) | Captures spatial economic flows and regional/global interdependencies | High data and resource demands; challenging implementation |

*Source: [1-16].*

In Ukraine, intersectoral analysis is primarily applied within the frameworks of national accounting, economic policy modeling, energy balance analysis, and assessment of the impact of individual sectors on the economy as a whole. The most widely used tools are the classical input-output (IO) tables compiled by the State Statistics Service according to the System of National Accounts (SNA) standards. These tables serve as the basis for:

a) macroeconomic planning (government institutions, especially the Ministry of Economy, use IO tables to forecast structural changes and assess the impact of tax or tariff policy shifts, particularly in agriculture, industry, and energy sectors; computable General Equilibrium (CGE) models built on IO structures are also used for this purpose);

b) evaluation of import substitution and localization effects (research institutes of the National Academy of Sciences of Ukraine (e.g., Institute for Economics and Forecasting, M. I. Dolishniy Institute of Regional Research) apply the Chenery–Watanabe approach to assess import dependency in strategic sectors such as machinery, chemicals, and electronics);

c) regional development policy (IO models are used to analyze regional disparities: for instance, they evaluate the impact of industrial or agricultural sectors on regional income, employment, and investment attractiveness);

d) green transition assessment (in recent years, researchers and public institutions (e.g., Ministry of Environment, «Ukrenergo») have started using elements of MRIO and SDA to assess the effects of decarbonization and renewable energy development; in cooperation with international organizations (e.g., OECD, GIZ, UNDP), methods are being tested to analyze carbon footprints and transitions toward a circular economy);

e) infrastructure and investment projects (intersectoral analysis is applied to justify large-scale projects (e.g., industrial park development, railway modernization), allowing for estimation of the multiplier effects on GDP, employment, and household income).

So, despite intersectoral analysis in Ukraine is still predominantly based on classical approaches, in response to external challenges (war, energy transition, EU integration), there is growing interest in modern tools such as MRIO, SDA, hypothetical extraction, and network analysis. The wider use of these tools is currently limited by the lack of detailed statistical data, but their potential is high – particularly in the context of economic recovery and the green transition.

**Conclusions.** A comparative analysis reveals that classical models offer a general view of intersectoral relationships and remain valuable for their simplicity, transparency, and foundational relevance in macroeconomic planning. However, they are limited in their capacity to capture dynamic processes and multi-dimensional impacts.

Modern approaches, such as Structural Decomposition Analysis (SDA), Network Analysis, and Multiregional Input-Output (MRIO) models, offer enhanced analytical flexibility and the ability to integrate spatial, social, and environmental factors. These methods are particularly useful for analyzing global value chains, environmental footprints, technological transformation, and regional development disparities. Despite their advantages, these methods often require extensive data, sophisticated software tools, and complex calibration, which may limit their application in countries or sectors with lower statistical capacity.

Therefore, the choice of methodology should be aligned with research objectives, data availability, and policy context. The development of hybrid frameworks that combine classical clarity with modern complexity may represent the future of intersectoral analysis, enabling more comprehensive and policy-relevant insights.

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