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Analysis

Identifying the role of final consumption in structural path analysis: An application to water uses

Maria Llop [a,b,*], Xavier Ponce-Alifonso [a,1]

[a] Universitat Rovira i Virgili, Spain
[b] CREIP, Spain

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ABSTRACT

The complexity of the connections within an economic system can only be reliably reflected in academic research if powerful methods are used. Researchers have used structural path analysis (SPA) to capture not only the linkages within the production system but also the propagation of the effects into different channels of impacts. However, the SPA literature has restricted itself to showing the relations among sectors of production, while the connections between these sectors and final consumption have attracted little attention. In order to consider the complete set of channels involved, in this paper we propose a structural path method that endogenously incorporates not only sectors of production but also the final consumption of the economy. The empirical application comprises water usages, and analyses the dissemination of exogenous impacts into various channels of water consumption. The results show that the responsibility for water stress is imputed to different sectors and depends on the hypothesis used for the role played by final consumption in the model. This highlights the importance of consumers' decisions in the determination of ecological impacts.

1. Introduction

An economic system can be defined as a complex network with multiple interdependencies among agents and sectors. Structural path analysis (SPA) has been largely used in economics as a method to describe this economic complexity, hierarchically decomposing the main upstream impacts of products or organisations. Identifying the distinct production chains provides a deeper understanding of the paths of the interactions in the economic system by extracting the set of basic inter-industry relationships (Sonis and Hewings, 1998; Aroche-Reyes, 2003; Ferreira do Amaral et al., 2007) and clustering sectors based on similarities between their linkage profiles (García Muñiz, 2013).

In a seminal paper, Defourny and Thorbecke (1984) applied structural path analysis to a Social Accounting Matrix (SAM) framework by specifying the transmission of economic influence within the network of the SAM structural relations. Also using a SAM structure, Sonis et al. (1997) defined a generalised structural path analysis that offers a macro level for the evaluation of the structure of an economy.

Moreover, Leontief (1971) proposed the extension of his economic input–output model[2] to capture the interactions between the economy and the environment. Following Leontief's approach, in the last two decades the addition of environmental accounts to the traditional input–output model has provided valuable knowledge about the ecological consequences of production processes. The literature on pollutant emissions is extensive and, among other things, deals with total greenhouse gas emissions, [3]calculating how the composition of total emissions can be modified by changes in exogenous components, [4]or analysing the temporal changes in the impacts involved within a full production perspective.[5]

In recent years, SPA has become a prominent tool in ecological research that is increasingly used to measure flows in both ecological and linked economic–ecological networks. The application of SPA methods to environmental issues has focused on identifying the main drivers of atmospheric emissions by decomposing the total emissions of an economy into its subsequent infinite paths within the production system (Lenzen, 2002, 2007; Butnar et al., 2011; Skelton et al., 2011).

Structural path analysis has also been used to estimate the embodied energy of water supply systems (Mo et al., 2011), to develop a complete upstream carbon footprint for screening purposes (Huang et al., 2009), to identify the main pathways of change for the ecological footprint and economic growth (Mattila, 2012), and to define downstream and upstream responsibilities in carbon reporting companies (Gallego and Lenzen, 2005; Lenzen and Murray, 2010).

* Corresponding author at: Avinguda Universitat n° 1, 43204 Reus, Spain.
E-mail addresses: maria.llop@urv.cat (M. Llop), xavier.ponce@urv.cat (X. Ponce-Alifonso).
[1] Avinguda Universitat n° 1, 43204 Reus (Spain).
[2] Leontief (1941).

[3] See, among others, Lenzen (2001) and Lenzen et al. (2004).
[4] For instance, Wood et al. (2006) and Butnar and Llop (2007).
[5] For example, Sonis et al. (1997), Llop (2007) and Wood and Lenzen (2009).

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Despite the undoubted usefulness of the environmental SPA analysis undertaken so far, the potentialities of the method have by no means been exhausted. In this respect, the decomposition of environmental impacts into the subsequent sectoral paths of influence has traditionally been limited to the analysis of the production system, whereas the environmental consequences of final consumption have not attracted much research attention. We must bear in mind, however, that the pressure on ecosystems is not limited to production activities, given that private consumption decisions also cause environmental damage that should be taken into account if the aim is to reflect the completeness of the environmental loads.

To capture the entire channel of impacts, the circular flow of income must be fully reflected in any economic–ecological model. Traditional input–output assumptions, however, do not show all the mechanisms that have both economic and ecological impacts, because this conventional model merely shows the impacts of production.

Additionally, about the analysis of the environmental consequences of economic activity it raises the question of attributing responsibilities to the agents of such consequences. Logically, any answer to this crucial question needs to take into account all the economic agents behind the environmental impacts. Only by incorporating all the actors involved can environmental research provide outcomes that are accurate enough for (efficient) corrective measures to be designed and applied.

More recently, consumption-based environmental accounting has become an important method for environmental policy (Peters, 2008; Wiedmann, 2009). The consumption-based approach provides a more precise knowledge of the environmental responsibility between agents, by allocating all the environmental damages occurring within the production activities to final consumers.

In this paper, to capture the completeness of impacts, we propose a structural path decomposition that endogenously incorporates not only sectors of production but also the final consumption of the economy. This extension not only reveals the direct and indirect effects on sectors, as conventional SPA does, but also shows the induced effects of consumption decisions on the environment. These effects come from the linkages between new demand, the subsequent increase in production expansion of income, which generates new demand, and so on. The addition of the induced effects goes one step further than the restrictive input–output assumption based on the idea that the income creation chain – and the corresponding environmental loads – is limited to the production system.

The empirical application, which focuses on water usages, is for the Spanish region of Catalonia, a typical Mediterranean region where water resources are limited and there is a permanent imbalance between the availability of water and water requirements.[6]

Our extension of the SPA method, by adding the induced effects of consumption to the income transmission mechanism, is especially relevant in the case of water usage. In particular, the method reported in this paper can be seen as a new starting-point for determining both downstream and upstream responsibilities,[7] especially if we bear in mind that it provides a more precise understanding about which sectors effectively generate water stress in our ecosystems and the different channels that cause such stress. Undoubtedly, a comprehensive method for detecting sectoral impacts on water resources, directly and indirectly but also inductively, is extremely helpful at making water management policies more effective.

The rest of the paper is organised as follows. Section 2 describes an extension of structural path analysis by making final consumption endogenous, and Section 3 reports an empirical application to water uses in the Catalan economy. Finally, a conclusion section ends the paper.

2. Methodology

2.1. Extension of the SPA Method

Structural path analysis decomposes total input–output multiplier effects into the effects coming from each layer of production within the complete supply chain. This method, which has mainly focused on the production system, can also be extended to include the joint analysis of both production activities and private consumption decisions.

The conventional input–output model assumes that consumption demand is exogenous and, accordingly, all the possible changes in this variable are represented as exogenous shocks that affect sectoral output, while the subsequent transmission from new output to new income and new consumption and so on is neglected. This common input–output assumption regarding consumption, therefore, goes against the most elementary economic theory because of all the income creation mechanisms it only considers production. In fact, consumers earn income for their endowments of labour and capital and, at the same time, they spend income on goods and services. Output increase, subsequent income increase and increase in final consumption – all of which are transmitted throughout the economic system – can be taken into account if the input–output model is completed by moving households decisions from the final (exogenous) demand to the input–output matrix.

In what follows, we define the extended input–output approach used in our analysis. The representation of the model, in matrix notation, responds to:[8]

$$\mathbf{x} = (\mathbf{I}-\mathbf{A})^{-1}\mathbf{y}, \tag{1}$$

where $\mathbf{x}$ is the vector of final output and has $n+1$ entries (n for production activities and 1 for households). Similarly, $\mathbf{y}$ is the vector of final demand containing $n+1$ elements (n final demand net of consumption for sectors and 1 remaining final demand for households or final consumption). Also in Eq. (1), matrix $\mathbf{A}$ of structural coefficients has the following structure:

$$\mathbf{A} = \begin{bmatrix} \bar{\mathbf{A}} & \mathbf{c} \\ \mathbf{u} & 0 \end{bmatrix},$$

where $\mathbf{c}$ is a column vector of sectoral consumption coefficients, calculated by dividing the sectoral consumption by the total value added of the economy, $\mathbf{u}$ is a row vector calculated by dividing the labour income by the corresponding output in each sector, and $\bar{\mathbf{A}}$ is the submatrix of input–output technical coefficients for the n activities, calculated by dividing the intersectoral consumption by the corresponding sectoral output. Matrix $(\mathbf{I}-\mathbf{A})^{-1}$ contains the extended input–output multipliers and shows the overall effects (direct, indirect and induced) on both sectoral production and consumption from unitary and exogenous changes in final demand.[9]

In order to gain a deeper insight into the analysis of the preceding multipliers, we can split matrix $\mathbf{A}$ of structural coefficients into two parts, which reflect different economic relationships. In this analysis, we separate the connections related to production ($\mathbf{A}_1$) from those

[6] Catalonia has a small surface area of 32,000 km^2, which is approximately 16% of Spain as a whole, and it has over 7,500,000 citizens. Catalonia is a highly industrialized region that represents around 20% of the total Spanish GDP. Around 10–20% of water consumption is for urban or industrial uses, and the remaining 80–90% is used in agriculture (ACA, 2008). Catalonia undergoes periodic water shortages, which are exacerbated by population density and economic activity.

[7] Lenzen and Murray (2010) stated that the responsibility for greenhouse gas emissions is shared by both producers and consumers. Looking downstream, production itself enables emissions. But looking upstream, final demand embodies emissions through the production of consumption goods.

[8] Following Leontief and Miller (1980), the extended model provides the Type II income multipliers. See, for instance, Miller and Blair (2009) for a description of the extended input–output model.

[9] In the traditional approach $\mathbf{A}_2$ is equal to zero.