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Identifying the Role of Final Consumption in Structural Path Analysis:

An Application to Water Uses

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Abstract

The complexity of the connexions 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.

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Keywords

Input-Output Analysis, Structural Path Analysis, Final Consumption, Water uses.

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 *et al.*, 2007) and clustering sectors based on similarities between their linkage profiles (García Muñiz, 2013).

Moreover, 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

[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. (2006), Llop (2007) and Wood and Lenzen (2009).

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).

Despite the undoubted usefulness of the 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 raise 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.

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 reveals the direct and indirect effects on sectors, as conventional SPA does, but it 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]

[6] Catalonia has a small surface area of 32,000 square kilometres, 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.

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 organized as follows. Section 2 describes and 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

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

[7] Lenzen and Murray (2010) state 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.

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]

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

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 equation (1), matrix **A** of structural coefficients has the following structure:

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

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, **u** is a row vector

[8] See, for instance, Miller and Blair (2009) for a description of the extended input-output model.

calculated by dividing the labour income by the corresponding output in each sector, and being $\bar{\mathbf{A}}$ 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.

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 connections related to consumption ($\mathbf{A}_2$). By taking this distinction into account, we can write:

$$\mathbf{A} = \mathbf{A}_1 + \mathbf{A}_2 = \begin{bmatrix} \bar{\mathbf{A}} & 0 \\ 0 & 0 \end{bmatrix} + \begin{bmatrix} 0 & \mathbf{c} \\ \mathbf{u} & 0 \end{bmatrix}.$$

This division of share coefficients in conjunction with the power series expansion allows us to distinguish the infinite paths of impacts within total multipliers, as follows:

$$[\mathbf{I}-\mathbf{A}]^{-1} = [\mathbf{I}-(\mathbf{A}_1+\mathbf{A}_2)]^{-1} =$$

$$\mathbf{I}+(\mathbf{A}_1+\mathbf{A}_2)+(\mathbf{A}_1+\mathbf{A}_2)^2+(\mathbf{A}_1+\mathbf{A}_2)^3+\ldots=$$

$$\mathbf{I}+(\mathbf{A}_1+\mathbf{A}_2)+(\mathbf{A}_1^2+2\mathbf{A}_1\mathbf{A}_2+\mathbf{A}_2^2)+(\mathbf{A}_1^3+3\mathbf{A}_1^2\mathbf{A}_2+3\mathbf{A}_1\mathbf{A}_2^2+\mathbf{A}_2^3)+\ldots \quad (2)$$

This expression shows the chains that are activated when there are exogenous inflows to production and consumption, and is an extension of the traditional SPA decomposition. Note that the difference between the proposed SPA method and the traditional one responds to:[9]

$$[\mathbf{I}-(\mathbf{A}_1+\mathbf{A}_2)]^{-1}-[\mathbf{I}-\mathbf{A}_1]^{-1}=$$

$$\mathbf{I}+(\mathbf{A}_1+\mathbf{A}_2)+(\mathbf{A}_1+\mathbf{A}_2)^2+(\mathbf{A}_1+\mathbf{A}_2)^3+\ldots-(\mathbf{I}+(\mathbf{A}_1)+(\mathbf{A}_1)^2+(\mathbf{A}_1)^3+\ldots)=$$

$$\mathbf{A}_2+(2\mathbf{A}_1\mathbf{A}_2+\mathbf{A}_2^2)+(3\mathbf{A}_1^2\mathbf{A}_2+3\mathbf{A}_1\mathbf{A}_2^2+\mathbf{A}_2^3)+\ldots. \quad (3)$$

This shows the added impacts corresponding to each of the infinite layers by the extended approach. These new impacts are those that come about from private consumption decisions ($\mathbf{A}_2$, $\mathbf{A}_2^2$, $\mathbf{A}_2^3$, …) and the connections between sectors and private consumption ($2\mathbf{A}_1\mathbf{A}_2, 3\mathbf{A}_1^2\mathbf{A}_2, 3\mathbf{A}_1\mathbf{A}_2^2$, …). The sum of all these terms in equation (3) responds, in fact, to the induced effects that capture the new income channels added by the expanded SPA method.

The model described in expression (1) can be transformed to account for the water used by economic agents. Let us define $\mathbf{W}$ as a diagonal matrix of water usages per unit of output in activities and consumers. In this matrix, each element in the main diagonal is the amount of water used, measured in physical units, per monetary unit of final production in sectors of production (that is, the technical water coefficients) or, alternatively, per monetary unit of final consumption in the consumers' account. Also in matrix $\mathbf{W}$, the elements outside the main diagonal are null. So, the amount of water usage corresponding to an exogenous level of final demand can be calculated as:

$$\mathbf{z}=\mathbf{W}(\mathbf{I}-\mathbf{A})^{-1}\mathbf{y}, \quad (4)$$

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

where $\mathbf{z}$ is a column vector of the physical water consumed by sectors and consumers and $\mathbf{W}(\mathbf{I}-\mathbf{A})^{-1}$ is the matrix of (extended) water multipliers. Parallel to expression (2), we can show the different paths within the total water multiplier impacts, by applying the power series expansion as follows:

$$\mathbf{W}[\mathbf{I}-\mathbf{A}]^{-1}=\mathbf{W}[\mathbf{I}-(\mathbf{A}_1+\mathbf{A}_2)]^{-1}=$$

$$\mathbf{W}+\mathbf{W}(\mathbf{A}_1+\mathbf{A}_2)+\mathbf{W}(\mathbf{A}_1+\mathbf{A}_2)^2+\mathbf{W}(\mathbf{A}_1+\mathbf{A}_2)^3+\ldots=$$

$$\mathbf{W}+\mathbf{W}(\mathbf{A}_1+\mathbf{A}_2)+\mathbf{W}(\mathbf{A}_1^2+2\mathbf{A}_1\mathbf{A}_2+\mathbf{A}_2^2)+\mathbf{W}(\mathbf{A}_1^3+3\mathbf{A}_1^2\mathbf{A}_2+3\mathbf{A}_1\mathbf{A}_2^2+\mathbf{A}_2^3)+\ldots\,, \quad (5)$$

where each term in the addition shows the water impacts in each of the infinite layers of intersectoral relationships. This expression shows that, after an initial income shock, the multiplier effects are triggered from the second and following layers of impacts while the first layer shows the effects on water consumption caused by the initial exogenous shocks.

One interesting aspect of water resource analysis is the distribution of water among users or, in other words, the relative importance of agents in terms of their water consumption. In what follows, the extended water model (expressions (4) and (5)) is redefined to show the process of water consumption from the perspective of water distribution. In particular, we define the vector of water distribution (or relative water consumption) by normalizing expression (4).[10] Then, we use this context of relative water to identify the contribution that the different paths of impacts make to the relative position of the accounts in terms of the water used, as follows:

[10] See Llop (2013) for a multiplier analysis of water usages in relative terms.

$$\mathbf{r} = \frac{\mathbf{W}[\mathbf{I}-(\mathbf{A}_1+\mathbf{A}_2)]^{-1}\mathbf{y}}{\mathbf{e}'\mathbf{W}[\mathbf{I}-(\mathbf{A}_1+\mathbf{A}_2)]^{-1}\mathbf{y}} =$$

$$\frac{[\mathbf{W}+\mathbf{W}(\mathbf{A}_1+\mathbf{A}_2)+\mathbf{W}(\mathbf{A}_1+\mathbf{A}_2)^2+\mathbf{W}(\mathbf{A}_1+\mathbf{A}_2)^3+\ldots]\mathbf{y}}{\mathbf{e}'\mathbf{W}[\mathbf{I}-(\mathbf{A}_1+\mathbf{A}_2)]^{-1}\mathbf{y}} =$$

$$\frac{[\mathbf{W}]\mathbf{y}}{\mathbf{e}'\mathbf{W}[\mathbf{I}-(\mathbf{A}_1+\mathbf{A}_2)]^{-1}\mathbf{y}} + \frac{[\mathbf{W}(\mathbf{A}_1+\mathbf{A}_2)]\mathbf{y}}{\mathbf{e}'\mathbf{W}[\mathbf{I}-(\mathbf{A}_1+\mathbf{A}_2)]^{-1}\mathbf{y}} +$$
$$\frac{\mathbf{W}(\mathbf{A}_1+\mathbf{A}_2)^2\mathbf{y}}{\mathbf{e}'\mathbf{W}[\mathbf{I}-(\mathbf{A}_1+\mathbf{A}_2)]^{-1}\mathbf{y}} + \frac{[\mathbf{W}(\mathbf{A}_1+\mathbf{A}_2)^3]\mathbf{y}}{\mathbf{e}'\mathbf{W}[\mathbf{I}-(\mathbf{A}_1+\mathbf{A}_2)]^{-1}\mathbf{y}} + \ldots =$$

$$\mathbf{r}_1 + \mathbf{r}_2 + \mathbf{r}_3 + \mathbf{r}_4 \ldots. \qquad (6)$$

where $\mathbf{e}'$ is a unitary row vector and **r** is a column vector of the relative water consumption or *water distribution*.[11] Expression (6) divides the water distribution into the infinite paths involved in water uses, by showing how much each path contributes to the relative position of the accounts in terms of the water they consume. In other words, vector **r** consists of the water distribution attributed to each of the infinite layers that explain the water consumption in an economy.

3. Application to water uses in Catalonia

It is well known that pressure on freshwater resources is increasing around the world. The total volume of water on Earth is about 1.4 billion km^3, but only around 1% is usable for humans (UNEP, 2008). Water scarcity already affects almost every continent and 40% of people in our planet are living under water stressed conditions. Forecasts predict that the situation will only get worse (FAO, 2011). The pressure on water resources comes from a variety of sources. One is the growth of the population in

[11] Note that the sum of components in vector **r** is equal to one.

conjunction with the economic growth, because economic development means that diets shift from starch-based food to meat and dairy.[12] Another source of pressure is global climate change, which is predicted to increase the frequency and severity of floods and droughts, and also disrupt ecosystems so that water quality can be maintained (Bates *et al.*, 2008).

In this context of increasing water scarcity, agriculture is usually pointed to as a sector that uses considerable amounts of water. Statistics show that 70% of consumptive water is used for irrigation, while 20% goes to industry and only 10% to households (WWDR, 2012). From this evidence, it is commonly suggested that water for agriculture should be reallocated to other sectors with higher value added by introducing economic instruments in water management and providing incentives for saving water. Despite this general consensus, it would be interesting to review this situation. Sometimes new questions to old problems can generate new knowledge that can be used to find solutions.

In this section, we apply the extended SPA model to water issues in Catalonia and we compare the results with the ones obtained using the traditional SPA method. The empirical application uses regional information containing both economic variables and water use data.[13]

First, we consider the differences between both methods in terms of water distribution and its importance in the different chains (see expression (6) of the model). Water distribution provides deeper insight into the relevance of sectors and activities to total

[12] According to WWDR (2012), meat production requires 8-10 times more water than cereal production.
[13]The economic information is compiled into a Social Accounting Matrix for the Catalan economy. The water information is compiled into a vector of sectoral water uses (see Llop (2013) for details).

water usages. Table 1 shows water distribution across sectors throughout the layers in both the traditional and extended SPA method. It can be seen that in the two models the multiplier effects are activated from the second and subsequent stages, while the first layer of impacts captures the effects on water caused by the initial income shock.

TABLE 1. *Traditional vs extended SPA method. Distribution of water among sectors (% of total).*

	TRADITIONAL SPA METHOD						**EXTENDED SPA METHOD**					
	1st layer	*2nd layer*	*3rd layer*	*4th layer*	*Other layers*	TOTAL	*1st layer*	*2nd layer*	*3rd layer*	*4th layer*	*Other layers*	TOTAL
Agriculture	12,1%	42,9%	13,9%	7,3%	8,6%	84,7%	9,5%	33,7%	13,4%	10,6%	13,9%	81,2%
Animal husbandry	0,1%	1,6%	0,4%	0,3%	0,3%	2,7%	0,1%	1,3%	0,3%	0,3%	0,4%	2,5%
Fishing	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Energy	0,1%	0,1%	0,0%	0,0%	0,2%	0,4%	0,1%	0,1%	0,0%	0,0%	0,0%	0,2%
Chemistry	1,5%	0,6%	0,3%	0,1%	0,4%	2,8%	1,2%	0,5%	0,2%	0,1%	0,1%	2,1%
Metals & electric equipment	0,2%	0,1%	0,0%	0,0%	0,1%	0,4%	0,2%	0,1%	0,0%	0,0%	0,0%	0,3%
Automobiles	0,1%	0,0%	0,0%	0,0%	0,0%	0,2%	0,1%	0,0%	0,0%	0,0%	0,0%	0,1%
Food production	0,5%	0,1%	0,1%	0,0%	0,5%	1,3%	0,4%	0,1%	0,1%	0,1%	0,1%	0,8%
Textiles	0,5%	0,1%	0,1%	0,0%	0,3%	1,0%	0,4%	0,1%	0,1%	0,0%	0,0%	0,6%
Paper	0,3%	0,2%	0,1%	0,0%	0,2%	0,8%	0,2%	0,1%	0,1%	0,0%	0,0%	0,5%
Other industries	0,1%	0,1%	0,0%	0,0%	0,0%	0,2%	0,1%	0,0%	0,0%	0,0%	0,0%	0,1%
Construction	0,3%	0,1%	0,0%	0,0%	0,1%	0,5%	0,2%	0,1%	0,0%	0,0%	0,0%	0,4%
Commerce	0,1%	0,0%	0,0%	0,0%	0,2%	0,3%	0,1%	0,0%	0,0%	0,0%	0,0%	0,1%
Transport	0,1%	0,1%	0,0%	0,0%	0,2%	0,4%	0,1%	0,1%	0,0%	0,0%	0,0%	0,2%
Finance	0,0%	0,0%	0,0%	0,0%	0,2%	0,3%	0,0%	0,0%	0,0%	0,0%	0,0%	0,1%
Other services	1,0%	0,4%	0,2%	0,1%	1,4%	3,0%	0,8%	0,3%	0,2%	0,1%	0,2%	1,6%
Public services	1,0%	0,0%	0,0%	0,0%	0,0%	1,0%	0,8%	0,0%	0,0%	0,0%	0,0%	0,8%
Consumption	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	4,4%	1,6%	1,1%	1,3%	8,4%
TOTAL	17,9%	46,4%	15,2%	7,9%	12,6%	100%	14,1%	40,9%	16,3%	12,5%	16,3%	100%

Table 1 reveals an interesting difference between the two frameworks: the role played by the different layers. Early layers are less important in the induced effects of final consumption as an element of the multiplier process (i. e. in the extended model), while the role played by layers away from the initial shock are higher compared with the traditional SPA. This result calls into question the conventional results based on the idea that early layers have higher influence in terms of the impacts involved. In other words, when consumption is taken into account in the multiplier process effects are displaced into layers that are more remote from the initial impact.

Table 1 also shows another fundamental difference between the traditional and extended SPA method: the sectoral water consumed, in relative terms, is quantitatively different. Although the primary sector is the main consumer of water when any SPA method is used, the addition of the induced effects to the extended framework increases the role of the tertiary sector. This increase in the relative water consumption of services is quantitatively important (about 6%), but it is even more important in qualitative terms because it highlights the importance of some economic linkages that should be considered in the design of a sustainable water policy.

Table 2 and Figure 1 show the diffusion effects, calculated as the column sums in the matrices of water multipliers in each path of impacts. These values show the amount of water needed to satisfy a unitary increase in the exogenous demand of the corresponding sector.

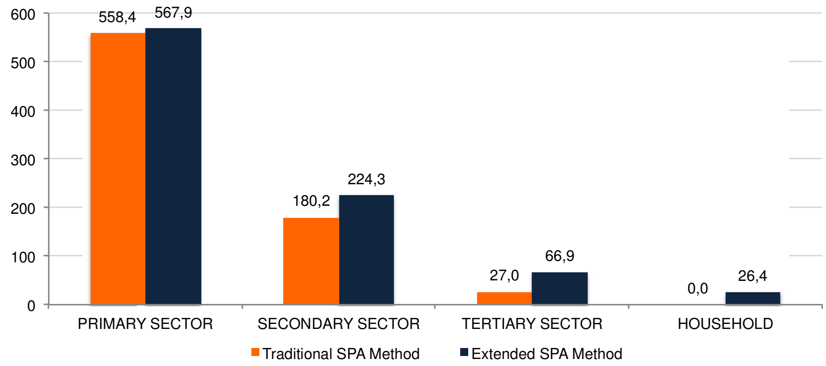
Table 2 shows that the extended SPA method gives an increase in total water consumption of about 15%. In sectoral terms, although agriculture and food production are the largest trigger of water consumption, it should be pointed out that in the two SPA models these sectors show similar multiplier effects, while the diffusion effects in the other sectors increase significantly when the extended model is used. In particular, the differences between the traditional and the extended SPA are especially important in services because the induced effects of consumption exert high pressure on water usages in these sectors which cannot be reflected in the conventional method.

TABLE 2. *Traditional vs extended SPA method. Diffusion effects. Water consumption (hm^3).*

	TRADITIONAL SPA METHOD						EXTENDED SPA METHOD					
	1st layer	*2nd layer*	*3rd layer*	*4th layer*	*Other layers*	TOTAL	*1st layer*	*2nd layer*	*3rd layer*	*4th layer*	*Other layers*	TOTAL
Agriculture	456,5	12,4	15,4	3,5	2,8	490,5	456,5	12,7	15,8	4,2	4,6	493,8
Animal husbandry	20,3	16,1	21,1	5,0	3,8	66,4	20,3	16,3	21,6	5,6	5,9	69,7
Fishing	0,0	0,1	0,8	0,3	0,3	1,5	0,0	0,6	1,3	1,0	1,5	4,4
Energy	0,6	0,2	0,2	0,2	0,3	1,4	0,6	0,4	0,5	0,6	1,4	3,5
Chemistry	2,7	0,9	2,3	1,1	0,9	7,9	2,7	1,4	2,9	1,9	2,8	11,8
Metals & electric equipment	0,2	0,2	0,5	0,4	0,4	1,7	0,2	0,8	1,2	1,3	2,3	5,8
Automobiles	0,2	0,2	0,6	0,5	0,6	2,1	0,2	0,7	1,3	1,4	2,8	6,3
Food production	1,3	96,9	17,8	9,8	5,1	131,1	1,3	97,4	18,5	10,8	8,0	136,1
Textiles	1,8	6,7	4,2	2,1	1,7	16,5	1,8	7,5	5,0	3,4	4,3	22,1
Paper	1,6	2,5	1,3	0,8	0,7	6,9	1,6	3,3	2,2	2,0	3,3	12,4
Other industries	0,2	4,7	1,6	1,0	0,8	8,3	0,2	5,4	2,4	2,1	3,2	13,4
Construction	0,6	0,9	1,2	0,8	0,8	4,3	0,6	2,3	2,6	2,8	4,7	13,0
Commerce	0,2	5,1	5,4	1,5	1,2	13,5	0,2	6,4	6,7	3,3	4,3	20,8
Transport	0,4	0,3	0,4	0,4	0,4	1,8	0,4	1,0	1,2	1,5	2,8	6,8
Finance	0,7	0,2	0,1	0,1	0,2	1,3	0,7	1,8	1,5	2,1	3,0	9,0
Other services	1,1	0,7	0,8	0,5	0,4	3,5	1,1	2,2	2,1	2,3	3,4	11,0
Public services	4,2	1,7	0,5	0,4	0,3	7,0	4,2	4,5	2,5	3,6	4,5	19,3
Consumption	0,0	0,0	0,0	0,0	0,0	0,0	7,0	4,4	7,4	3,2	4,4	26,4
TOTAL	492,5	149,7	74,1	28,4	27,8	765,6	499,6	169,2	96,6	53,3	66,9	885,5

Figure 1 illustrates the quantitative differences in the diffusion effects with some aggregated sectoral information. As can be seen, when the induced effects in the income creation mechanism are taken into account, the diffusion effects increase most in industry (24.5%) and especially in services (over 147%), while in agriculture the differences are much smaller (1.7%). This asymmetric sectoral behaviour is explained by the different influence of final consumption decisions on sectors and suggests that sectoral water stress should be reinterpreted when water impacts reflect the role played by final consumption in the transmission of ecological consequences.

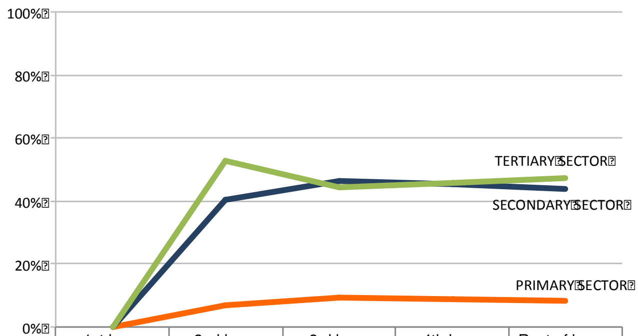
FIGURE 1. *Water consumption generated by diffusion effects (hm^3).*



Additionally, the distinction between direct, indirect and induced effects is important because it gives information about the different connections captured by the SPA methodology. Specifically, the traditional model is limited to showing the direct and indirect multipliers, while the extended model proposed in this paper adds the induced effects caused by consumption. According to Figure 1, inflows to agriculture generate a considerable water impact because of its direct and indirect effects while the induced effects caused by consumption in the agricultural sector are relatively low. On the other hand, inflows to services generate low water impacts because of their direct and indirect connections but they generate high impact because of the induced effects. These sectoral differences in the origin of water usages must be taken into account in the definition of a sustainable water system.

Figure 2 and Table 3 contain the percentage of induced effects generated in the diffusion process, and have been obtained by calculating the difference in multipliers between the two models in each sector and in each of the subsequent chains of impact.[14]

FIGURE 2. *Induced effects generated by diffusion effects (% of total)*



	1st layer	2nd layer	3rd layer	4th layer	Rest of layers
PRIMARY SECTOR	0,0%	7,0%	9,4%	9,0%	8,5%
SECONDARY SECTOR	0,0%	40,5%	46,2%	45,1%	44,1%
TERTIARY SECTOR	0,0%	52,5%	44,4%	45,9%	47,4%

The sectoral differences in the diffusion effects illustrate the usefulness of completing the circular flow of income by adding final consumption. While agriculture directly consumes water in its production system, which contributes to high direct and indirect diffusion effects, services and industry do not directly use so much water and their impacts on water are mostly transmitted by the induced effects of final consumption demand.

In terms of the various layers involved, it should be pointed out that the importance of induced effects in the diffusion multipliers remains almost equal in all the chains analysed and for all sectors of production.

[14] Note that the induced effects are equal to the premultiplication of expression (3) by matrix **W** of water coefficients.

TABLE 3. *Induced effects generated by diffusion effects (% of total)*

	1st layer	*2^{nd} layer*	*3^{rd} layer*	*4^{th} layer*	*Other layers*
Agriculture	0%	2,2%	3,2%	3,0%	4,3%
Animal husbandry	0%	1,2%	3,1%	2,7%	5,0%
Fishing	0%	3,6%	3,1%	3,2%	2,8%
Energy	0%	1,4%	2,0%	1,9%	2,7%
Chemistry	0%	3,4%	4,1%	3,9%	4,5%
Metals & electric equipment	0%	4,2%	4,5%	4,3%	4,4%
Automobiles	0%	3,4%	4,4%	4,2%	5,2%
Food production	0%	3,1%	4,5%	4,5%	6,9%
Textiles	0%	5,4%	5,9%	5,8%	6,3%
Paper	0%	5,5%	6,0%	5,8%	6,2%
Other industries	0%	5,2%	5,5%	5,4%	5,6%
Construction	0%	9,0%	9,4%	9,2%	9,3%
Commerce	0%	8,7%	8,0%	8,1%	7,3%
Transport	0%	4,9%	5,4%	5,3%	5,7%
Finance	0%	10,5%	8,9%	9,0%	6,9%
Other services	0%	9,7%	8,5%	8,6%	7,1%
Public services	0%	18,8%	13,6%	14,9%	9,9%
TOTAL	0%	100%	100%	100%	100%

Table 4 and Figure 3 compare the traditional and extended SPA method is terms of the absorption effect. This effect, which is obtained by adding the rows in the water multiplier matrices, reflects the increase in the water used by the corresponding sector when the final demand rises by 1 monetary unit in all sectors.

Table 4 shows that the extension of the SPA method increases the total amount of water consumed when there is a generalised and unitary increase in the income of all accounts. Like the total diffusion effects in Table 2, this increase is quantified as 15% of the total absorption multipliers. At a sectoral level, however, Table 4 shows different outcomes than that in the diffusion effects. In particular, agriculture accounts for more than 95% of total absorption effects, so industry and services jointly represent barely 1-

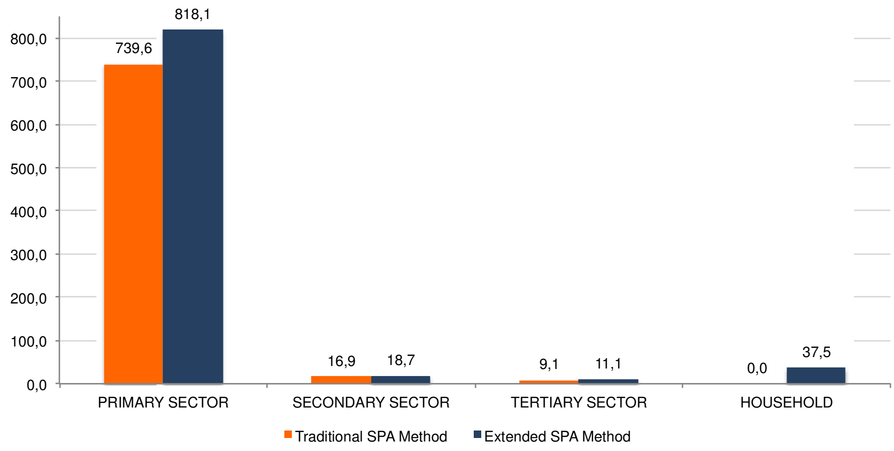
2% of total water impacts. It is also interesting to point out that these percentages of sectoral importance remain stable through the different layers.

TABLE 4. *Traditional vs extended SPA method. Absorption effects. Water consumption (hm^3).*

	TRADITIONAL SPA METHOD						**EXTENDED SPA METHOD**					
	1st layer	*2nd layer*	*3rd layer*	*4th layer*	*Other layers*	TOTAL	*1st layer*	*2nd layer*	*3rd layer*	*4th layer*	*Other layers*	TOTAL
Agriculture	456,5	139,4	69,2	26,4	19,4	710,8	456,5	143,4	84,0	45,8	57,7	787,4
Animal husbandry	20,3	4,4	2,5	0,9	0,7	28,8	20,3	4,4	2,7	1,5	1,8	30,8
Fishing	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Energy	0,6	0,4	0,2	0,1	0,1	1,3	0,6	0,4	0,2	0,1	0,1	1,4
Chemistry	2,7	1,6	0,7	0,3	0,2	5,6	2,7	1,6	0,8	0,4	0,5	6,0
Metals & electric equipment	0,2	0,2	0,1	0,0	0,0	0,5	0,2	0,2	0,1	0,0	0,1	0,6
Automobiles	0,2	0,0	0,0	0,0	0,0	0,2	0,2	0,1	0,0	0,0	0,0	0,3
Food production	1,3	0,8	0,3	0,1	0,1	2,6	1,3	0,9	0,5	0,3	0,3	3,2
Textiles	1,8	0,6	0,2	0,1	0,0	2,7	1,8	0,6	0,3	0,1	0,1	2,9
Paper	1,6	0,6	0,2	0,1	0,1	2,6	1,6	0,6	0,3	0,1	0,2	2,8
Other industries	0,2	0,1	0,0	0,0	0,0	0,4	0,2	0,1	0,1	0,0	0,0	0,5
Construction	0,6	0,2	0,1	0,0	0,0	0,9	0,6	0,2	0,1	0,0	0,1	0,9
Commerce	0,2	0,1	0,0	0,0	0,0	0,3	0,2	0,1	0,1	0,1	0,1	0,5
Transport	0,4	0,2	0,1	0,0	0,0	0,8	0,4	0,2	0,1	0,1	0,1	0,9
Finance	0,7	0,2	0,1	0,0	0,0	1,0	0,7	0,2	0,1	0,1	0,1	1,1
Other services	1,1	1,0	0,5	0,2	0,1	2,9	1,1	1,2	0,9	0,5	0,7	4,3
Public services	4,2	0,0	0,0	0,0	0,0	4,2	4,2	0,0	0,0	0,0	0,0	4,2
Consumption	0,0	0,0	0,0	0,0	0,0	0,0	7,0	15,0	6,3	4,1	5,0	37,5
TOTAL	492,5	149,7	74,1	28,4	27,8	765,6	499,6	169,2	96,6	53,3	66,9	885,5

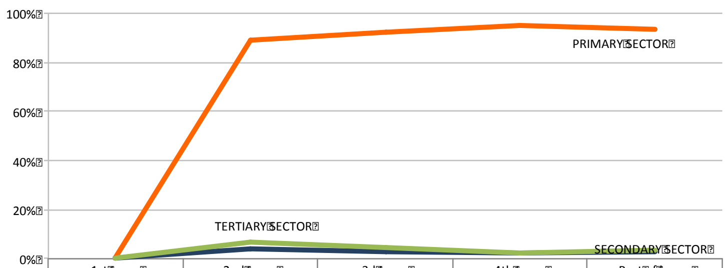
A comparison of the two models reveals that the decreasing effect of the absorption multipliers along the subsequent paths is more attenuated in the extended SPA. Another result of this comparison can be seen in Figure 3, which shows the total effects for aggregated sectors. In this Figure, the most important difference in the absorption multipliers is in the primary sector, while in industry and services the two models provide similar quantitative values.

FIGURE 3. *Water consumption generated by absorption effects (hm^3).*



The comparison of Figure 1 and Figure 3 illustrates that the increase in the multipliers caused by the extended model is distributed differently among sectors in the diffusion and absorption effects. While there is an increase in the diffusion multipliers of services and to a lesser extent of industry, in the primary sector there is an increase in the absorption multipliers.

FIGURE 4. *Induced effects generated by absorption effects (% of total)*



	1st Layer	2nd Layer	3d Layer	4th Layer	Rest of layers
PRIMARY SECTOR	0,0%	89,3%	92,4%	95,2%	93,5%
SECONDARY SECTOR	0,0%	4,2%	3,2%	2,3%	2,8%
TERTIARY SECTOR	0,0%	6,5%	4,4%	2,5%	3,7%

As far as the contribution of induced effects to the absorption multipliers is concerned, Figure 4 and Table 5 show that the consumption-income channel has a greater impact on the primary sector than services and industry. In addition, the importance of agriculture in the induced effects is highest all layers.

TABLE 5. *Induced effects generated by absorption effects (% of total).*

	1st layer	*2nd layer*	*3rd layer*	*4th layer*	*Other layers*
Agriculture	0%	90,8%	92,1%	93,4%	93,3%
Animal husbandry	0%	0,3%	1,5%	2,7%	2,9%
Fishing	0%	0,0%	0,0%	0,0%	0,0%
Energy	0%	0,3%	0,2%	0,2%	0,2%
Chemistry	0%	0,4%	0,4%	0,4%	0,6%
Metals & electric equipment	0%	0,0%	0,0%	0,1%	0,1%
Automobiles	0%	0,1%	0,1%	0,0%	0,0%
Food production	0%	1,6%	1,1%	0,6%	0,6%
Textiles	0%	0,8%	0,5%	0,3%	0,2%
Paper	0%	0,2%	0,2%	0,2%	0,2%
Other industries	0%	0,1%	0,1%	0,0%	0,0%
Construction	0%	0,1%	0,1%	0,1%	0,1%
Commerce	0%	0,8%	0,5%	0,2%	0,1%
Transport	0%	0,3%	0,3%	0,2%	0,2%
Finance	0%	0,4%	0,3%	0,2%	0,2%
Other services	0%	3,9%	2,7%	1,5%	1,2%
Public services	0%	0,0%	0,0%	0,0%	0,0%
TOTAL	0%	100,0%	100,0%	100,0%	100,0%

In summary, our results reveal both quantitative and qualitative differences between the two SPA methods. Specifically, not only are the multiplier effects higher under the extended SPA, but also the relative importance of sectors and layers change significantly in relation to the traditional approach.

4. Conclusions

In this article we have addressed the reasons behind water consumption in an economy. To this end, we defined an SPA tool that considers final consumption in the endogenous part of the input-output model of multipliers. This endogenization extends the traditional SPA model and shows the channels of both intermediate and final water uses. In fact, the addition of final consumption to the SPA method makes it possible to consider not only the direct and indirect effects on water uses, typically captured by the conventional SPA analysis, but also the induced effects.

Traditionally, SPA analysis has not taken into account one important part of the circular flow of income: the factor and private flow of income. To get a complete representation of the connections transmitting income effects and, consequently transmitting environmental impacts, we need to go beyond the description of the economy provided by the traditional approach. Our paper addresses this issue, and improves the assumptions typically used in the related literature.

There are significant differences in the hypotheses behind both methods. The traditional SPA method reflects downstream responsibility, as it includes direct and indirect effects of inflows to production. The extended SPA method proposed in this paper also incorporates upstream responsibility, by adding the effects of final consumption on water usages.

A comparison of both methods provides an approximation of the induced effects of consumption on water usages. The results of our application to Catalonia are meaningful. The conclusions drawn by the traditional and the proposed (extended) approach about which sectors generate water stress differ substantially. Our results suggest that both agriculture and other sectors such as services cause increased pressure on water resources under exogenous inflows. Our analysis also suggests that the role played by the different layers varies in the two approaches, since the relationships that are at some distance from the initial shock gains relevance in the extended SPA.

The incorporation of induced effects is important because it helps to provide a precise view of the economic interrelationships in the economy. Logically, this is extremely necessary so as not to confuse the strategies of policy-makers to combat water stress.

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References

ACA (Catalan Water Agency), 2008. Water in Catalonia: Diagnosis and Proposed Actions. Catalan Water Agency, Barcelona, Spain.

Aroche-Reyes, F. (2003): “A qualitative input-output method to find basic economic structures”, *Papers in Regional Science*, 82, 581-590.

Bates, B.C.; Kundzewicz, Z. W.; Wu, S. and Palutikof, J.P. (eds.) (2008): *Climate Change and Water*. Technical Paper of the Intergovernmental Panel on Climate Change, IPCC Secretariat, Geneva.

Butnar, I. and Llop, M. (2007): “Composition of greenhouse gas emissions in Spain: An input-output analysis”, *Ecological Economics*, 61, 388-395.

Butnar, I.; Gallego, B.; Llop, M. and Castells, F. (2011): “Atmospheric emissions and structural path analysis in the Spanish economy”, in Llop, M. (editor): *Air Pollution: Economic Modeling and Control Policies*, Bentham e-Books, 31-45.

FAO (2011): *The State of the World’s Land and Water Resources for Food and Agriculture. Managing Systems at Risk*. Food and Agriculture Organization of the United Nations, Rome and London.

Ferreira do Amaral, J.; Dias, J. and Lopes, J. C. (2007): “Complexity as interdependence in input-output systems”, *Environment and Planning A*, 39, 1770-1782.

Gallego, B. and Lenzen, M. (2005): “A consistent input-output formulation of shared producer and consumer responsibility”, *Economic Systems Research*, 17 (4), 365-391.

García Muñiz, A. S. (2013): “Input-output research in structural equivalence: Extracting paths and similarities”, *Economic Modelling*, 31, 796-803.

Huang, Y. A.; Lenzen, M.; Weber, C. L.; Murray, J. and Matthews, H. S. (2009): “The role of input-output analysis for the screening of corporate carbon footprints”, *Economic Systems Research*, 21(3), 217-242.

Lenzen, M. (2001). “A generalized input-output multiplier calculus for Australia”, *Economic Systems Research*, 13, 65-92.

Lenzen, M. (2002). "A guide for compiling inventories in hybrid life-cycle inventories: some Australian results", *Journal of Cleaner Production*, 10, 545-572.

Lenzen, M. (2003): “Environmentally important paths, linkages and key sectors in the Australian economy”, *Structural Change and Economic Dynamics*, 14, 1-34.

Lenzen, M. (2007): "Structural path analysis of ecosystem networks", *Ecological Modelling*, 200, 334-342.

Lenzen, M.; Pade, L. L. and Munksgaard, J. (2004). “CO_2 multipliers in multi-region input-output models”, *Economic Systems Research*, 16, 391-412.

Lenzen, M. and J. Murray (2010): “Conceptualising environmental responsibility”, *Ecological Economics*, 70, 261-270.

Llop, M. (2007): “Economic structure and pollution intensity within the environmental input-output framework”, *Energy Policy*, 35, 3410-3417.

Llop, M. (2013): “Water reallocation in the input-output model”, *Ecological Economics*, 86, 21-27.

Mattila, T. (2012): “Any sustainable decoupling in the Finnish economy? A comparison of the pathways and sensitivities of GDP and ecological footprint 2002-2005”, *Ecological Indicators*, 16, 128-134.

Miller, R. E. and Blair, P. D. (2009): *Input-Output Analysis: Foundations and Extensions*, Cambridge University Press, New York.

Mo, W.; Zhang, Q.; Mihelcic, J. R. and Hokanson, D. R. (2011): “Embodied energy comparison of surface water and groundwater supply options”, *Water Research*, 45, 5577-5586.

Skelton, A.; Guan, D; Peters, G. P. and Crawford-Brown, D. (2011): “Mapping flows of embodied emissions in the global production system”, *Environmental Science and Technology*, 45, 10516-10523.

Sonis, M. and Hewings, G. J. D. (1998): “Economic complexity as network complication: Multiregional input-output structural path analysis”, *The Annals of Regional Science*, 32, 407-436.

Sonis, M.; Hewings, G. J. D. and Sulistyowati, S. (2006): “Block structural path analysis: Applications to structural changes in the Indonesian economy”, *Economic Systems Research*, 9 (3), 265-280.

UNEP (2008): *Vital Water Graphics: An Overview of the State of the World’s Fresh and Marine Waters*. 2nd edition. United Nations Environment Programme, Nairobi.

Wood, R. and Lenzen, M. (2009): “Structural path decomposition”, *Energy Economics*, 31, 335-341.

Wood, R.; Lenzen, M.; Dey, C. and Lundie, S. (2006): “A comparative study of some environmental impacts of conventional and organic farming in Australia”, *Agricultural Systems*, 89, 324-348.

WWDR (2012): *The United Nations World Water Development Report 4. Managing Water under Uncertainty and Risk*. The United Nations Educational, Scientific and Cultural Organization, Paris.