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A methodological approach to quantifying socioeconomic impacts linked to supply shocks

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Abstract

Input-output models are commonly used to assess socioeconomic impacts. These models typically evaluate exogenous variations in demand-related elements; however, they do not fully capture the associated effects of backward and forward sectoral linkages simultaneously. An analysis from the supply perspective is of greater interest to economic sectors that exploit natural resources because their activity is subject to natural variations or political factors beyond the producers' direct control. This paper proposes a methodology to improve the estimation of the impacts of these variations or supply shocks. Within the methodological context of input-output analysis, a practical procedure is introduced including price mechanisms that allow us to consider all sectoral linkages (backward and forward). Therefore, the proposed method will improve impact assessments derived from supply shocks linked to environmental events.

Keywords

Input-output; impact assessment; supply shock; socioeconomic impacts

Highlights

Assessing impacts linked to natural, climatic and environmental events

Novel procedure for better estimates of economic impacts linked to supply shocks

Input-output methodology and socio-economic impacts assessment

1. Introduction

Since Leontief's first contributions (Leontief 1936, 1941), the input-output (IO) analysis has undergone substantial development (Rose and Miernyk 1989, Kurz et al 1998). According to experts in the field, its future is quite promising (Dietzenbacher et al 2013). A relevant part of the theoretical extensions and practical applications of IO models are related to impact assessment (Perminova et al 2016). For instance, relevant studies can be found on the analysis of the economic impacts of specific industries (Kinnaman 2011, Egilmez et al 2013, Malik et al 2014, Richardson et al 2014), environmental impacts (Lenzen et al 2003, Ferng 2003, Suh 2004, Suh and Kagawa 2005, Hertwich 2011, Huysman et al 2016, Yang et al 2017, Ivanova et al 2017, Zi et al 2017), impact assessments that use IO tables in physical units (Giljum and Hubacek 2004, Dietzenbacher 2005), or impacts that are linked to disasters or attacks (Haimes and Jiang 2001, Santos and Haimes 2004, Andrijcic and Horowitz, 2006, Okuyama 2007, Hallegate 2008, Okuyama and Santos 2014, Santos et al 2014, Marin and Modica 2017).

Building on the framework of IO models, this work focuses on assessing socioeconomic impacts that are linked to productive sectors whose activity or production levels are highly dependent on environmental or climatic factors, natural restrictions or political decisions. For instance, unexpected events like a prolonged droughts, torrential rains or frosts could cause a significance decrease in the volume of the annual harvests. Other management scenarios can be also assessed like the extension of parks, forest reserves or a fire that could reduce the area of the forest that could be exploited for obtaining wood. Evermore, another examples can be an oil spill in the ocean, the enlargement of a marine reserve with fishing restrictions or the use of a quota management system that limit the allowed annual resources to be harvested. According to these examples, the production restrictions often affect activities in primary sectors (agriculture, forestry or fishing). Therefore, the production level is largely determined by these exogenous factors rather than by changes in the final demand for such products (which tends to be relatively stable due to the products' low-income elasticity). When an event limits production (i.e. a supply shock), how can we estimate the resulting socioeconomic impacts?

In most of the works cited above, the input-output models applied have followed the classical perspective where the final demand is the driving force of the economy, but for the cases of our interest it is advisable to use the perspective from the supply side (Oosterhaven 2017). For the analysis of socioeconomic impacts from the supply perspective it has been proposed to use the Gosh model (Dietzenbacher 2002), but despite its reinterpretation (Guerra and Sancho 2011), its theoretical consistency for this purpose is still questioned (Oosterhaven 2012). Rose and Wei (2013) estimated the consequences of a seaport disruption by using the demand-driven model to capture impacts on suppliers up the supply chain and a modified version of the supply-driven model to capture impacts on customers down the supply chain. In order to consider both forward and backward impacts, other authors have used computable general equilibrium models to analyze the consequences of changes in transport costs (Mansen and Jensen-Butler 2004) or linked to natural disasters (Rose et al 2011). Despite the efforts made within the input-output framework, the simultaneous estimation of forward and backward impacts linked to supply shock has not yet been satisfactorily resolved.

The current paper aims to introduce a practical methodological proposal that combines elements of various IO approaches (the IO model of prices and the mixed IO model of demand) in order to improve socioeconomic impact assessments that are derived from initial shocks in the supply's output of a given sector. More specifically, it proposes a novel stepwise procedure for studying simultaneously the effects on both; the backward and the forward sectoral linkages by considering markets and prices into the IO model. This proposal is designed to analyze those cases where the variation of the production is out of the producer' control, without any reduction of the productive capacity (infrastructures, facilities, etc.), neither the possibility of obtaining alternative products in the short term.

To explain this approach, the paper is organized as follows. In section 2, the basic elements of IO analysis are summarized because they will be used throughout the rest of the paper. For those who are familiar with these elements, this section presents the notation used. In section 3, the new methodological proposal for assessing socioeconomic impacts that are linked to initial supply shocks is introduced. This innovative procedure is based on a sequential combination of known elements in the field of IO analysis. In section 4 the conclusions are summarized. Finally, with the aim of demonstrating the potential application of the methodological proposal, it has been included an Appendix with a hypothetic numeric example.

2. Methods: Basic input-output models and output multipliers

By accepting the assumptions of standard IO models (Oosterhaven 1996, and Miller and Blair 2009), we can define the more conventional demand-driven IO model, which is formulated in matrix algebra notation as follows:

$$\mathbf{x} = \mathbf{A}\mathbf{x} + \mathbf{f} \qquad (1)$$

$$(\mathbf{I} - \mathbf{A})\,\mathbf{x} = \mathbf{f} \qquad (2)$$

where **A** is the input coefficients matrix; **x** and **f** are the column vectors of total output and final demand, respectively; and **I** is the identity matrix. The matrix that results from solving (**I-A**) is known as the Leontief matrix. From the previous expressions, we can yield the following:

$$\mathbf{x} = (\mathbf{I}-\mathbf{A})^{-1}\,\mathbf{f} = \mathbf{L}\,\mathbf{f} \qquad (3)$$

where **L**=(**I**-**A**)$^{-1}$ is known as the Leontief inverse matrix of the total requirements (l_{ij}).

The accounting equations that form the starting-point for price model based on monetary data (Miller and Blair 2009) can be represented in matrix form:

$$\mathbf{x}' = \mathbf{i}'\,\mathbf{Z} + \mathbf{v}' \qquad (4)$$

where x', i' and v' are, respectively, the row vector of total output, the row vector of ones and the row vector of the total value-added expenditures by each sector. If we represent $\hat{x}$ as the diagonalized matrix of total outputs and substitute Z = A $\hat{x}$ in expression (4) and post-multiply both sides by $\hat{x}^{-1}$, we obtain the following:

$$i' = i'\,\mathbf{A} + \tilde{\mathbf{v}}'_{\mathbf{c}} \qquad (5)$$

where $\tilde{v}'_{\mathbf{c}} = v'\hat{x}^{-1} = [v_1/x_1, \dots, v_n/x_n]$.

If $\tilde{p}_j$ denotes the base-year price index, $\widetilde{\mathbf{p}'} = [\tilde{p}_1, \dots, \tilde{p}_n]$, from (5) we can write:

$$\widetilde{\mathbf{p}'} = \widetilde{\mathbf{p}}'\,\mathbf{A} + \widetilde{\mathbf{v}}'_{\mathbf{c}} = \widetilde{\mathbf{v}}'_{\mathbf{c}}\,(\mathbf{I}-\mathbf{A})^{-1} = \widetilde{\mathbf{v}}'_{\mathbf{c}}\,\mathbf{L} \qquad (6)$$

By assuming that the coefficients of **A** are fixed values, this model is useful in determining how the price indexes vary due to exogenous changes in the primary input coefficients (This price model is known as the *cost-push IO price model*, in which the quantities are fixed and the prices change, Oosterhaven 1996 and Dietzenbacher 1997).

In the standard demand-side IO models, the final demand elements are typically exogenous components, and each sector's outputs are endogenous. In certain cases, the total output of one or more sectors may be determined exogenously, while the outputs of the remaining sectors continue to be specified endogenously. A mixed type of IO model may be appropriate to address these special circumstances (Miller and Blair 2009, Dietzenbacher and Miller 2015). This type of model has often been applied in empirical studies on agricultural and natural resource economics (e.g., Johnson and Kulshreshtha 1982, Papadas and Dahl 1999, Eiser and Roberts 2002, Leung and Pooley 2002).

Assume that total output for k sectors in a regional economy is determined exogenously ($\mathbf{x}'^{ex} = [x_1,\ldots,x_k]$) and that final demands are determined endogenously ($\mathbf{f}'^{en} = [f_1,\ldots,f_k]$); in addition, the other sectors (n–k) are assumed to remain exogenous their final demands ($\mathbf{f}'^{ex} = [f_{k+1},\ldots,f_n]$) and endogenous in their outputs ($\mathbf{x}'^{en} = [x_{k+1},\ldots,x_n]$). For simplicity, we can partition the elements of matrix **A** as follows:

$$\mathbf{A} = \begin{pmatrix} \mathbf{A}_{11} & \mathbf{A}_{12} \\ \mathbf{A}_{21} & \mathbf{A}_{22} \end{pmatrix} \tag{7}$$

Matrix $\mathbf{A}_{11}$ contains the elements of the first k rows and columns of **A**; matrix $\mathbf{A}_{12}$ contains the elements of the first k rows and the last n–k columns; matrix $\mathbf{A}_{21}$ contains the elements of the last n–k rows and the first k columns; and matrix $\mathbf{A}_{22}$ contains the elements of the last n–k rows and the columns of **A**. The same notation criteria can be used for the partitioned matrices of **I** and **L**. From (2), we can express the IO system as follows:

$$\begin{bmatrix} (\mathbf{I}_{11} - \mathbf{A}_{11}) & -\mathbf{A}_{12} \\ -\mathbf{A}_{21} & (\mathbf{I}_{22} - \mathbf{A}_{22}) \end{bmatrix} \begin{bmatrix} \mathbf{x}^{ex} \\ \mathbf{x}^{en} \end{bmatrix} = \begin{bmatrix} \mathbf{f}^{en} \\ \mathbf{f}^{ex} \end{bmatrix} \tag{8}$$

Rearranging (8) provides the following:

$$\begin{bmatrix} -\mathbf{I}_{11} & -\mathbf{A}_{12} \\ \mathbf{0} & (\mathbf{I}_{22} - \mathbf{A}_{22}) \end{bmatrix} \begin{bmatrix} \mathbf{f}^{en} \\ \mathbf{x}^{en} \end{bmatrix} = \begin{bmatrix} -(\mathbf{I}_{11} - \mathbf{A}_{11}) & \mathbf{0} \\ \mathbf{A}_{21} & \mathbf{I}_{22} \end{bmatrix} \begin{bmatrix} \mathbf{x}^{ex} \\ \mathbf{f}^{ex} \end{bmatrix} \tag{9}$$

If we use **M** to denote the matrix that pre-multiplied to endogenous variables and **N** to denote the matrix that pre-multiplied to exogenous variables, (9) can be expressed as follows:

$$\begin{bmatrix} \mathbf{f}^{en} \\ \mathbf{x}^{en} \end{bmatrix} = \mathbf{M}^{-1}\,\mathbf{N} \begin{bmatrix} \mathbf{x}^{ex} \\ \mathbf{f}^{ex} \end{bmatrix} = \begin{bmatrix} (\mathbf{I}_{11} - \mathbf{A}_{11}) - \mathbf{A}_{12}\,\mathbf{L}_{22}\,\mathbf{A}_{21} & -\mathbf{A}_{12}\,\mathbf{L}_{22} \\ \mathbf{L}_{22}\,\mathbf{A}_{21} & \mathbf{L}_{22} \end{bmatrix} \begin{bmatrix} \mathbf{x}^{ex} \\ \mathbf{f}^{ex} \end{bmatrix} \tag{10}$$

where $\mathbf{L}_{22} = (\mathbf{I}_{22}\text{-}\mathbf{A}_{22})^{-1}$.

$\mathbf{M}^{-1}\mathbf{N}$ is a multiplier matrix that relates the exogenous variables ($\mathbf{x}^{ex}$ and $\mathbf{f}^{ex}$) to their corresponding endogenous variables ($\mathbf{f}^{en}$ and $\mathbf{x}^{en}$). The $\mathbf{L}_{22}\mathbf{A}_{21}$ matrix elements are similar to output-to-output multipliers. For instance, if we assume k = 1 and no changes in the values of the other exogenous variables ($\Delta f_2 = \ldots = \Delta f_n = 0$), $\mathbf{L}_{22}\mathbf{A}_{21}$ is a vector and its elements reflect changes in the endogenous outputs ($[x_2,\ldots,x_n]$) that are derived from a unitary change in the exogenous output (x_1 in our example).

3. Methodological proposal for assessing supply shock impacts

Exogenous variation in the output of a sector will affect the sectors that supply intermediate products to that sector. Furthermore, an exogenous shock to the production of a sector may have a significant impact on other sectors of the economy that are provisioned by that sector's output (or intermediate inputs). The inability of traditional IO models to capture the forward and backward effects simultaneously is particularly manifest in a regional economy with many sectors whose production is subject to frequent exogenous shocks and that have strong forward linkages, such as input suppliers, with other sectors of the same economy. The following methodological proposal aims to address this aforementioned problem while maintaining the general framework and basic assumptions of IO models, as synthesized in section 2.

The rationale of this proposal is that an exogenous shock in the volume of the output of one or more sectors (initial moment or period 0) will cause changes in the prices of the outputs of the sectors directly affected, but also in the prices of the other sectors' outputs. These variations in prices will affect the production's volumes and final demands. The process of adjustment in prices and volumes occurs simultaneously and continuously over the time, until a new equilibrium is reached (in the final moment or period 1). The changes are expressed in prices of period 0 and can be translated into current prices (period 1) to reflect the variations in value. The comparison of the final output value (in period 1) with the initial (in period 0) will provide a measure of the economic impact related to the supply shock. In order to estimate the final equilibrium values, we propose a methodological procedure that needs to follow some specific sequential steps detailed as follow:

Step 1

As a baseline, an exogenous supply shock to the production of a certain sector of an economy ($\Delta q_i^1 / q_i^0$) is considered to potentially alter the price of this sector's output.

Step 2

According to the supply, demand and market price information, the inverse of price elasticity of this exogenous output can be estimated $[Es_i^{-1} = (\Delta p_i/p_i)/(\Delta q_i/q_i)]$. Subsequently, the possible price variation in period 1 (Δp_i^1) can be calculated through the concrete forecasting of supply amount variation in period 0 for the following period (Δq_i^1):

$$\Delta p_i^1 / p_i^0 = Es_i^{-1} \ (\Delta q_i^1 / q_i^0) \qquad (11)$$

In addition, this output price variation can affect the prices of other outputs in the same economy, particularly if these outputs are used as intermediate inputs into other productive sectors.

Step 3

The price change of outputs due to a supply shock will influence the prices of other outputs that are generated in other sectors of the economy, depending on the sector's relative importance as an intermediate input in those industries. The main contribution of this methodological proposal is that a mixed IO price model is used to evaluate how a product's price variation can affect the prices of other products. In this model, we assume that the same k sectors generate outputs whose prices are determined exogenously by the existence of direct regulations on supply or on prices. For sectors with exogenous prices, their vector of price indexes can be constructed ($\tilde{\boldsymbol{p}}'^{\text{ex}} = [\tilde{p}_1,\ldots,\tilde{p}_k]$). For the remaining (n–k) sectors of the economy, the ratio value added per unit of output will be the exogenous variables ($\widetilde{\mathbf{v}}'^{\mathbf{ex}\,\mathbf{1}}_{\mathbf{c}} = [v_{c\ k+1},\ldots, v_{c\ n}]$). From equation (6), we can write the following:

$$\begin{bmatrix} \tilde{\boldsymbol{p}}^{\text{ex}} \\ \tilde{\boldsymbol{p}}^{\text{en}} \end{bmatrix} = \begin{bmatrix} \mathbf{A'}_{11} & \mathbf{A'}_{21} \\ \mathbf{A'}_{12} & \mathbf{A'}_{22} \end{bmatrix} \begin{bmatrix} \tilde{\boldsymbol{p}}^{\text{ex}} \\ \tilde{\boldsymbol{p}}^{\text{en}} \end{bmatrix} + \begin{bmatrix} \tilde{\mathbf{v}}_{\mathbf{c}}^{\mathbf{en}} \\ \tilde{\mathbf{v}}_{\mathbf{c}}^{\mathbf{ex}} \end{bmatrix} \qquad (12)$$

Following the steps in the previous mixed IO quantity model (equations 8-10), we obtain the following:

$$\begin{bmatrix} -\mathbf{I}_{11} & -\mathbf{A'}_{21} \\ \mathbf{0} & (\mathbf{I}_{22}-\mathbf{A'}_{22}) \end{bmatrix} \begin{bmatrix} \tilde{\mathbf{v}}_{\mathbf{c}}^{\mathbf{en}} \\ \tilde{\boldsymbol{p}}^{\mathbf{en}} \end{bmatrix} = \begin{bmatrix} -(\mathbf{I}_{11}-\mathbf{A'}_{11}) & \mathbf{0} \\ \mathbf{A'}_{12} & \mathbf{I}_{22} \end{bmatrix} \begin{bmatrix} \tilde{\boldsymbol{p}}^{\mathbf{ex}} \\ \tilde{\mathbf{v}}_{\mathbf{c}}^{\mathbf{ex}} \end{bmatrix} \qquad (13)$$

If we use $\dot{\mathbf{M}}$ to denote the matrix that pre-multiplied to endogenous variables and $\dot{\mathbf{N}}$ to denote the matrix that pre-multiplied to exogenous variables, from (13), we obtain the following:

$$\begin{bmatrix} \tilde{\mathbf{v}}_{\mathbf{c}}^{\mathbf{en}} \\ \tilde{\boldsymbol{p}}^{\mathbf{en}} \end{bmatrix} = \dot{\mathbf{M}}^{-1}\,\dot{\mathbf{N}} \begin{bmatrix} \tilde{\boldsymbol{p}}^{\mathbf{ex}} \\ \tilde{\mathbf{v}}_{\mathbf{c}}^{\mathbf{ex}} \end{bmatrix} = \begin{bmatrix} (\mathbf{I}_{11}-\mathbf{A'}_{11}) - \mathbf{A'}_{21}\,\mathbf{L'}_{22}\,\mathbf{A'}_{12} & -\mathbf{A'}_{21}\,\mathbf{L'}_{22} \\ \mathbf{L'}_{22}\,\mathbf{A'}_{12} & \mathbf{L'}_{22} \end{bmatrix} \begin{bmatrix} \tilde{\boldsymbol{p}}^{\mathbf{ex}} \\ \tilde{\mathbf{v}}_{\mathbf{c}}^{\mathbf{ex}} \end{bmatrix} \qquad (14)$$

where $\mathbf{L}'_{22} = (\mathbf{I}_{22}-\mathbf{A}'_{22})^{-1}$.

Under usual conditions:

- The input coefficients remain stable after the supply shock in the short and medium term due to the inexistence of technical or trade substitution. Therefore, the input coefficients will remain stable if the initial supply shock is not extreme.

- And assuming $\tilde{\mathbf{v}}_{\mathbf{c}}^{\mathbf{ex}\,\mathbf{1}} = \tilde{\mathbf{v}}_{\mathbf{c}}^{\mathbf{ex}\,\mathbf{0}}$. This assumption is reasonable for those sectors which have a slight weight on the overall economy, such as agriculture or fishing. Therefore, a slight change in the levels of these sectors' outputs hardly can result in significant variation in the average cost of wages or the average return of capital employed in the economy.

And according to exogenous price variation ($\tilde{\mathbf{p}}^{\mathbf{ex}\,\mathbf{1}}$ known), the system (14) estimates $\tilde{\mathbf{v}}^{\mathbf{en}\,\mathbf{1}}$ and $\tilde{\mathbf{p}}^{\mathbf{en}\,\mathbf{1}}$. Moreover, this mixed IO price model allows us to estimate the relative change in the prices due to exogenous changes in the price levels of one or more sectors of the economy.

We consider the price variations in relation to the initial situation (initial moment or period 0) and exclusively associated to the supply shock under consideration (i.e., no additional factors are assumed to be capable to influence the modification of these products' prices). The new price indexes for endogenous outputs, as obtained through this mixed model ($\tilde{\boldsymbol{p}}^{en1}$), provide valuable information regarding each sector's sensitivity to exogenous supply shocks in other sectors. If $\tilde{p}_j^1 > \tilde{p}_i^1$ (with $k < i,j \leq n$), the outputs generated by the sectors subject to supply shocks have greater relative relevance in the cost structure of industry j and in determining the price of the output of sector j. Consequently, sector j is more sensitive than sector i in terms of potential exogenous supply shocks.

Step 4

In our methodological approach, we assume that the change in prices of outputs involves changes in production and in final demand, but the estimation of these effects differs based on the type of sector.

For the case of k sectors that are affected by a supply shock, we assume that companies, at least in the short and medium term, react by keeping supply commitments to industries that depend on their raw materials. The supply of intermediate inputs is prioritized. Consequently, the impact on the required quantity to supply the final demand of k sectors with exogenous output depends on the magnitude of the supply shock as well as the evolution of demand for n–k sectors.

In the case of the n–k sectors that are not directly affected by a supply shock, variations in final demand depend on the price elasticity of demand for their products. In this proposal, we assume that elasticity may differ by product. This information is exogenous to the IO model; thus, we assume that the change in these final demands is determined exogenously. That is, the variations in the prices of n–k endogenous outputs imply changes in their final demand in period 1 ($\Delta \mathrm{d_i}^1$). Additionally, these variations in the demanded quantity of endogenous outputs can be estimated through the observed information according to the price elasticity for these products [$\mathrm{Ed_i} = (\Delta \mathrm{d_i}/\mathrm{d_i})/(\Delta \mathrm{p_i}/\mathrm{p_i})$].

$$\Delta \mathrm{d_i}^1 \,/\, \mathrm{d_i}^0 = \mathrm{Ed_i}\,(\Delta \mathrm{p_i}^1 \,/\, \mathrm{p_i}^0) \qquad (15)$$

The impact on the total output of the n–k sectors is determined both by the supply shock in the k sectors and by exogenous variations in their own final demands.

Step 5

If we operate with prices in the initial period, the expected variations are transferred directly to their monetary values in the quantities of exogenous outputs supplied (Δq_i^1) and in the quantities of endogenous outputs demanded (Δd_i^1). If we denote $x_i^{ex\,1(0)}$ as the value of exogenous outputs for period 1 and $f_i^{ex\,1(0)}$ as the value of the exogenous demands for period 1, both expressed in monetary units of period 0, we obtain the following:

$$x_i^{ex\,1(0)} = x_i^{ex\,0}\,[1 + (\Delta q_i^1 / q_i^0)] \quad ; \quad f_i^{ex\,1(0)} = f_i^{ex\,0}\,[1 + (\Delta d_i^1 / d_i^0)] \quad (16)$$

By understanding the predicted values for the exogenous variables ($x_i^{ex\,1(0)}$ and $f_i^{ex\,1(0)}$), we can estimate the endogenous variables ($f_i^{en\,1(0)}$ and $x_i^{en\,1(0)}$) using a mixed IO model. Therefore, according to the system of equations (10), we obtain the following:

$$\begin{bmatrix} \mathbf{f}^{en\,1(0)} \\ \mathbf{x}^{en\,1\,(0)} \end{bmatrix} = \mathbf{M}^{-1}\,\mathbf{N} \begin{bmatrix} \mathbf{x}^{ex\,1(0)} \\ \mathbf{f}^{ex\,1(0)} \end{bmatrix} = \begin{bmatrix} (\mathbf{I}_{11} - \mathbf{A}_{11}) - \mathbf{A}_{12}\,\mathbf{L}_{22}\,\mathbf{A}_{21} & -\mathbf{A}_{12}\,\mathbf{L}_{22} \\ \mathbf{L}_{22}\,\mathbf{A}_{21} & \mathbf{L}_{22} \end{bmatrix} \begin{bmatrix} \mathbf{x}^{ex\,1(0)} \\ \mathbf{f}^{ex\,1(0)} \end{bmatrix} \quad (17)$$

where $\mathbf{L}_{22} = (\mathbf{I}_{22}\text{-}\mathbf{A}_{22})^{-1}$.

We consider the variations in the exogenous final demands to estimate the impact of the initial supply shock on the outputs of the other sectors. In our model, these variations may be significantly different from zero ($[\Delta f_{k+1}, \ldots, \Delta f_n] \neq 0$), which diverges from the typical assumption in other applications of the mixed IO model (e.g., Papadas and Dahl 1999).

Step 6

As estimated with the aforementioned method, each sector's total output is expressed in monetary units of the initial moment (at period-0 prices). However, the estimated price indexes are known for period 1 and linked to the initial supply shock: $\tilde{\boldsymbol{p}}^{ex\,1}$ from equation (11) and $\tilde{\boldsymbol{p}}^{en\,1}$ from equation (15). If these indices are used to calculate the variation in prices in percentage terms from one period to another ($\Delta\%p_j$), the results can be expressed in monetary terms for period 1 ($x_j^{1(1)}$) with a simple operation:

$$x_j^{1(1)} = x_j^{1(0)}\left(1 + \Delta\%p_j\right) = x_j^{1(0)}\,\tilde{p}_j^1 \quad (18)$$

Applying a similar operation to the intermediate outputs [$z_{ij}^{1(1)} = z_{ij}^{1(0)}\,(1 + \Delta\%p_i)$] and final demand in each sector $[f_j^{1(1)} = f_j^{1(0)} \left(1 + \Delta\%p_j\right)]$, we can rebuild a new IO table for period 1 that is expressed in current monetary units. This step allows us to calculate the value of total impacts in current terms, i.e., the situation valued at period-1 prices, and to compare it with the initial situation valued at period-0 prices.

Figure 1 synthesizes this methodological proposal. In particular, it represents the stepwise sequence to apply the previous procedure, distinguishing the methodological tools and the information needed from the estimated results obtained from each step.

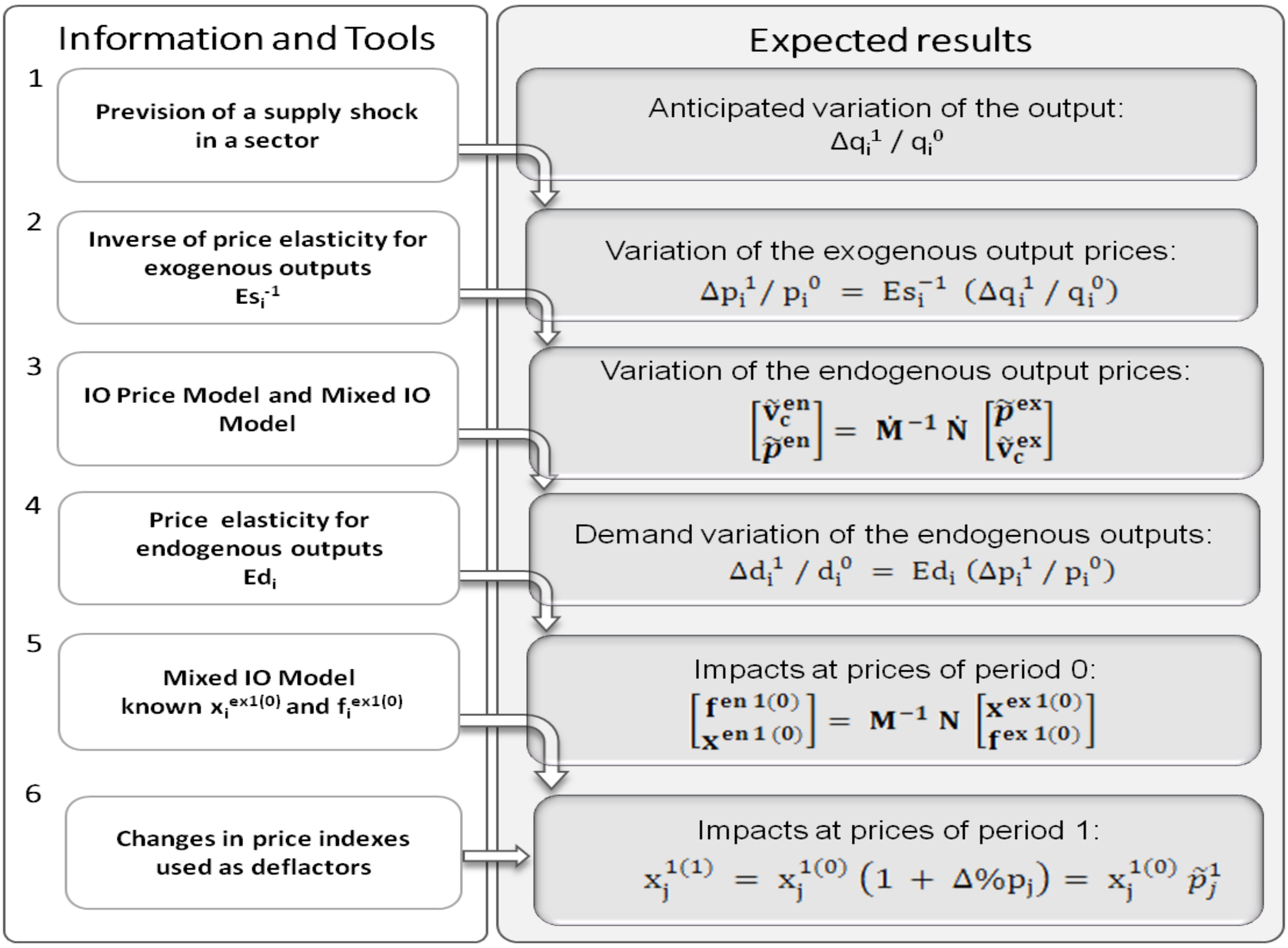

Figure 1. Proposed procedure for assessing economic impacts

5. Conclusions

IO models are widely used to assess socioeconomic impacts in an economy. Normally, the different versions of such models have used a backward linkage perspective. Nevertheless, these usual IO models are insufficient for assessing possible supply shock impacts in sectors with strong forward linkages in their economy (i.e., such as suppliers of raw materials to other activities).

This paper proposes a methodological procedure that aims to address this problem by considering the forward sectoral linkages. To address this problem from a practical perspective, we combine different elements and approaches of IO analysis. We propose a method to assess possible impacts of a potential supply shock in one (or more) of these economic sectors. The impacts derived from the forward linkages are introduced by including market mechanisms into the procedure through variations in the prices of the products that are affected by the initial supply shock. If we use the proposed mixed price IO model, we can see that the variation in the exogenous output price has a greater impact on prices in sectors that use the exogenous output as an intermediate input. By considering the variations in the exogenous demand, we incorporate the forward linkages of those sectors that are subject to exogenous shocks. Therefore, the final demand levels for those sectors with forward linkages will experience a relatively larger impact than the rest. Remarkably, these variations in demand depend on price changes, and they are more pronounced under conditions of high sensitivity to exogenous supply shocks and the high price elasticity (in absolute terms) for these outputs. Therefore, the proposed mixed model simultaneously captures the effects linked to the backward linkages of the sectors with exogenous output (the impact on sectors that supply intermediate inputs) and to the forward linkages of the sectors that depend on the intermediate output of the sectors that are subject to supply shocks.

The previous procedure is valid for assessing slight variations in supply shocks. Particularly, in the cases when occur a variation in the production of a sector without any reduction in the productive capacity (infrastructures, facilities, etc.), neither the possibility of obtaining alternative products in the short term. Otherwise, a traumatic supply shocks, such as major attacks or disasters (human or environmental), require a different type of analysis. The assumptions and approximations used in this process may have little predictive capacity (because a shock is analyzed in isolation from other phenomena). However, we understand that this method has great advantages in analyzing and comparing estimated economic impacts in diverse scenarios. Therefore, the proposed method can support decision making, which is particularly relevant for sectors that are linked to the exploitation of natural resources. An accurate valuation of the socioeconomic impacts could be useful to decision-makers for developing strategies of adaptation or mitigation and, therefore, being in a better position to deal with unexpected events or to anticipate potential effects of decisions linked to limit the harvesting of natural resources.

Appendix: A hypothetical example

The applicability of the proposed method can be demonstrated through a hypothetical numeric example, by analyzing and benchmarking the results obtained with conventional methods and the proposed. Particularly, we suppose an economy with 5 sectors that have the economic flows in monetary units (mu) summarized in the Table A1 as follow:

Table A1. Flow Table for a Five-Sector Economy in monetary units (mu) and Price elasticities

		S1	S2	S3	S4	S5	f	X
		Agriculture	**Food industry**	**Manufacturing**	**Trade & Transport**	**Other services**	**Final Demand**	**Production**
S1	**Agriculture**	0	75	0	0	25	100	200
S2	**Food industry**	0	5	10	25	100	380	520
S3	**Manufacturing**	30	50	300	150	220	2350	3100
S4	**Trade & Transport**	20	50	500	275	220	1435	2500
S5	**Other services**	20	60	400	300	500	2400	3680
v	**Value Added**	130	280	1890	1750	2615		
x	**Production**	200	520	3100	2500	3680		10000
E	**Price elasticity ***	-0.80	-1.50	-1.00	-0.75	-1.25		

* Inverse of the price elasticity of supply (Es^{-1}) for S1 and Price elasticity of demand (Ed) for S2, S3 and S4.

The Agriculture sector (S1) demands intermediate inputs from the sectors S3, S4 and S5. The half of the production value of the agricultural sectors goes to the final demand and, the other half is used as intermediate consumption for processing by the Food industry (S2 sector), and by Other services (S5 sector, including for instance the restaurant services). Based on Table A1, we are able to calculate the input coefficients matrix **(A)** (Table A2) and the Leontief inverse matrix (**L**) (Table A3):

Table A2. The input coefficients matrix (**A**)

	S1	S2	S3	S4	S5
S1	0,00000	0,14423	0,00000	0,00000	0,00679
S2	0,00000	0,00962	0,00323	0,01000	0,02717
S3	0,15000	0,09615	0,09677	0,06000	0,05978
S4	0,10000	0,09615	0,16129	0,11000	0,05978
S5	0,10000	0,11538	0,12903	0,12000	0,13587

Table A3. The Leontief inverse matrix **(L)**

	S1	**S2**	**S3**	**S4**	**S5**
S1	1,00212	0,14810	0,00303	0,00362	0,01300
S2	0,00680	1,01741	0,01149	0,01679	0,03400
S3	0,18875	0,15733	1,13696	0,09074	0,09137
S4	0,15876	0,16850	0,22122	1,15411	0,10170
S5	0,16711	0,19988	0,20238	0,17648	1,19104

We suppose an unexpected environmental or climatic event on the agriculture sector which reduces in 10% the annual harvesting. Therefore, the sector S1 suffers an exogenous supply shock caused by sources that are out of the producers' control. Additionally, in this hypothetic economy, there is not the possibility of substitute these products at least in the short term. Both, food industry (S2) and the restaurants (within the S5) as well as the final consumers, are usually supplied with local agricultural products, and there are no providers to supply alternative products at short term.

In order to estimate the economic impact of this supply shock, we could use the conventional IO model or the Mixed IO model. For both cases, the estimation of the impacts is elaborated under the assumption that there is not variation in prices (this implies a decrease of the S1 production in 20 mu). However, this assumption does not seems realistic when there are not possibilities of substitution at the short term. In these cases, the proposed method can be useful. The stepwise methodological proposal in the hypothetical example can be applied as follows:

Step 1. $\Delta q^{1}_{S1} \,/\, q^{0}_{S1} = -10\%$

Step 2. $\Delta p^{1}_{S1} \,/\, p^{0}_{S1} = Es^{-1}_{S1}\,(\Delta q^{1}_{S1} \,/\, q^{0}_{S1}) = 8.00\%$

Step 3. With $\tilde{\mathbf{p}}^{\mathbf{ex}}_{\mathbf{S1}} = [1.08000]$;

Assuming $\widetilde{\mathbf{v}}'^{\,\mathbf{ex\,1}}_{\mathbf{c\,Si}} = \widetilde{\mathbf{v}}'^{\,\mathbf{ex\,0}}_{\mathbf{c\,Si}} = [\,0.538 \quad 0.610 \quad 0.700 \quad 0.711]$, for i=2,…,5.

Appling the Mixed Price IO model, we obtain:

$\tilde{\mathbf{v}}^{\mathbf{en\,1}}_{\mathbf{c\,S1}} = [0.72983]$; and $\widetilde{\mathbf{p}}'^{\,\mathbf{en\,1}}_{\mathbf{Si}} = [1.01182 \quad 1.00024 \quad 1.00029 \quad 1.00104]$, for i=2,…,5.

Predictably, the sectors S2 and S5 would have more sensitivity in their prices to supply shocks in S1 because they consume the agriculture intermediate outputs.

Step 4. By assuming the values of Ed for the sectors 2 and 5, we obtain:

$\Delta\mathbf{d}_{\mathbf{Si}}^{\mathbf{1}} / \mathbf{d}_{\mathbf{Si}}^{\mathbf{0}} = \mathrm{Ed_i}\ (\Delta \mathrm{p}_{\mathrm{Si}}^{1}/\mathrm{p}_{\mathrm{Si}}^{0}) = [-1.77344\% \quad -0.02420\% \quad -0.02168\% \quad -0.012968\%]$, for i=2,…,5.

Step 5. With $\mathbf{x}_{\mathbf{S1}}^{\mathbf{ex\,1(0)}} = \mathbf{x}_{\mathbf{S1}}^{\mathbf{ex\,0}}\,[1 + (\Delta \mathrm{q}_{\mathrm{S1}}^{1} / \mathrm{q}_{\mathrm{S1}}^{0})] = [180.00]$; and

$\mathbf{f'}_{\mathbf{Si}}^{\mathbf{ex\,1(0)}} = \mathbf{f'}_{\mathbf{Si}}^{\mathbf{ex\,0}}\,[1 + (\Delta \mathrm{d}_{\mathrm{Si}}^{1}/ \mathrm{d}_{\mathrm{Si}}^{0})] = [373.26 \quad 2349.43 \quad 1434.69 \quad 2396.89]$, for i=2,…,5.

Applying the mixed IO model, we obtain:

$\mathbf{f}_{\mathbf{S1}}^{\mathbf{en\,1(0)}} = [81.08]$; and $\mathbf{x}_{\mathbf{Si}}^{\mathbf{en\,1(0)}} = [512.90 \quad 3094.41 \quad 2495.06 \quad 3671.61]$, for i=2,…,5.

Step 6. By known $\tilde{\mathbf{p}}_{\mathbf{S1}}^{\mathbf{ex}}$ y $\tilde{\mathbf{p}}_{\mathbf{Si}}^{\mathbf{en\,1}}$, we can also obtain the values of the output in monetary units for the period 1:

$\mathbf{x}_{\mathbf{Si}}^{\mathbf{1(1)}} = \mathbf{x}_{\mathbf{Si}}^{\mathbf{1(0)}}\,\tilde{\mathbf{p}}_{\mathbf{Si}}^{\mathbf{1}} = [194.40 \quad 518.96 \quad 3095.16 \quad 2495.78 \quad 3675.42]$; for i=2,…,5.

The total economic impact on the economy, linked to the initial supply shock on the S1, could be calculated by comparing the initial and final value of the output. The Table A4 contains the economic impacts estimated by applying the aforementioned IO models. The most affected sector by the initial supply shock would be the S1. Due to the backward approach of the Demand IO models and the Mixed IO models, the estimations only includes the impacts linked to these backward linkages. This is the reason because the Food industry (S2) is affected slightly.

By applying the proposed method, the impacts valued at prices of period 0 (in mu$^{(0)}$) would be highest than the other models (46 mu$^{(0)}$ instead of 30 mu$^{(0)}$). This increase in the impact is concentrated mainly in the Food industry (S2) and in Other services (S5), which are precisely the sectors with the agriculture have forward linkages (see Table A1). Therefore, the proposed method is able to integrate simultaneously the effects in both directions (backward and forward) along the agriculture value chain. Finally, the values of the impacts can be expressed at prices of the period 1 (in mu$^{(1)}$) by using the prices vector estimated after the initial supply shock. In this case, the value of the impacts is monetarily lower due to the compensating effect of the increase of prices.

Tabla A4. Estimated impacts according different IO models

		Demand IO model *	**Mixed IO model**	**New methodological approach**	
		mu$^{(0)}$	**mu$^{(0)}$**	**mu$^{(0)}$**	**mu$^{(1)}$**
S1	Agriculture	-20.04	-20.00	-20,00	-5,60
S2	Food industry	**-0.14**	**-0.14**	**-7,10**	**-1,04**
S3	Manufacturing	-3.78	-3.77	-5,59	-4,84
S4	Trade & Transport	-3.18	-3.17	-4,94	-4,22
S5	Other services	**-3.34**	**-3.34**	**-8,39**	**-4,58**
	Total impacts	**-30.47**	**-30.41**	**-46,02**	**-20,28**

* For this case, we assume that the entire initial shock is absorbed by the final demand.

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