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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 seeks to propose a methodology to improve the estimation of the impacts of these variations or supply shocks. Within the methodological context of input-output (IO) analysis, this paper introduces a practical procedure that includes price mechanisms that allow us to consider all sectoral linkages (backward and forward), thereby avoiding double counting. Therefore, the proposed method will improve impact assessments derived from supply shocks.

Keywords

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

Notes:

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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. For instance, relevant studies can be found on the analysis of the economic impacts of specific industries (Kinnaman, 2011; Malik et al. 2014), environmental impacts (Lenzen et al., 2003; Ferng, 2003; Suh, 2004; Suh and Kagawa, 2005; Hertwich, 2011), impact assessments that use IO tables in physical units (Giljum and Hubacek, 2004; Dietzenbacher, 2005), or impacts that are linked to disasters or attacks (Santos and Haimes, 2004; Andrijcic and Horowitz, 2006; Okuyama, 2007).

Building on the framework of IO models, this work focuses on assessing impacts that are linked to productive sectors whose activity or production levels are highly dependent on uncontrollable factors (e.g., the weather), natural restrictions (e.g., limitations on the availability of natural resources) or political decisions (e.g., production limitations due to quotas and/or regulated prices). These types of 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?

To address this type of analysis, scholars can use models that estimate the impacts of disasters. In these models, the consequences of disorder caused by a natural and/or human-made disaster are studied. As noted by Okuyama and Santos (2014), the direct impacts are linked to the loss of physical and human capital. Such damage can cause business interruptions and production and/or consumption losses, which can potentially spread to other firms via backward and/or forward linkages. Direct effects represent damage to stocks, while indirect effects represent damage to production and consumption flows. The inoperability input-output model (IIM) was developed to analyze the wide-ranging economic impacts of disasters. The conceptual and theoretical foundations of the original IIM (Haimes and Jiang, 2001) were presented in physical terms. Santos and Haimes (2004) developed a process in which IO data could be utilized to study the effects of inoperability across interdependent economic systems. Since then, methodological extensions and practical applications of the IIM have been published (a brief description of these works can be found in Santos et al., 2014). However, in a recent paper, Oosterhaven (2015) presented a critical view on IIM's suitability for capturing the diverse impacts of disasters. First, the IIM completely ignores the potential positive impacts that can be derived from, for example, technical and/or substitution effects (in the case of replaceable inputs) or from post-disaster reconstruction programs. Second, although it considers only a subset of a disaster's negative effects, the IIM is not well suited to estimate these impacts because the exogenous final demand is the driving force in the IIM, while most disasters generate a shock on the supply side of the economy.

To overcome these limitations, some authors (Roberts, 1994) have proposed replicating previous methodology using the Ghosh model's forward perspective (Ghosh, 1958). As Dietzenbacher (2002) indicated, this type of model has been frequently used to empirically analyze the supply-side effects on the output of an economy (Kurz et al., 1998, includes an exhaustive revision of this perspective). However, other authors have questioned this solution, deeming it implausible (Oosterhaven, 1988, 1989). After reviewing the literature, we have concluded that the model should be used only for descriptive analyses and not for causal interpretations or applications, which could potentially lead to meaningless results. Subsequently, the Ghosh model has been interpreted as a pricing model (Dietzenbacher, 1997). Nevertheless, the discussion regarding the theoretical consistency and validity of the Ghosh model continues, as evidenced in some more recent works (Guerra and Sancho, 2011; Oosterhaven, 2012).

Critical authors with supply-driven IO models have proposed other ways of estimating forward production effects. For example, Oosterhaven (1988) developed an interesting alternative model that applies to situations in which resources are scarce. Based on exogenous change in primary inputs, this alternative model uses intraregional output coefficients (from the supply-driven IO model) and reciprocal technical coefficients to estimate the forward production effects on processing sectors. Aiming to consider the possible forward and backward effects simultaneously, Rose and Wei (2013) developed Oosterhaven's idea to estimate the total economic consequences of a seaport disruption. They used the demand-driven IO model to capture the impacts on suppliers up the supply chain and a modified version of the supply-driven IO model to capture impacts on customers down the supply chain. This modified supply-driven IO model was able to avoid some of the criticism related to the use of this type of model. However, as Oosterhaven (1989) previously concluded, markets and prices need to be introduced into IO models to integrate demand and supply effects in a satisfactory manner.

Changes in prices, supply constraints and possibilities of substituting inputs, imports and exports may be considered in the computable general equilibrium (CGE) model. This model has also been used to analyze the impacts of disasters (Rose and Liao, 2005 and Rose at al., 2011). Although developments and applications of the CGE model are beyond the scope of this study, the contributions of Mansen and Jensen-Butler (2004) may be of special interest to scholars in the field of IO models and impact assessments. Their paper examined the nature of the links between a regional economy and activities at the sub-regional level through the perspective of a disaggregated sub-regional CGE model, discussed related operational problems and developed a concrete application to analyze the economic effects of changing transport costs and bridge tolls in Denmark. The model is based on two interrelated circles: a real Keynesian circuit and a dual cost-price circuit. In the application, three types of locations (place of production, place of residence and place of demand) were considered to calculate the changes in transport costs through trade, shopping, tourism and commuting. The variations in transport costs result in changes in the relevant prices (for demand, production and imports and exports), which have an impact on disposable income, private consumption, foreign trade, GDP and employment. Therefore, this analysis incorporates the influence of supply-side conditions on production (e.g., the links between prices and disposable income) in the first step, but it does not consider the consequences of changes in prices of goods on the demand for those goods.

Hallegate (2008) proposed an IO model to assess the indirect effects of disasters at the regional scale and applied it to the landfall resulting from Hurricane Katrina in Louisiana. This model considers changes in production capacity due to productive capital losses (an assessment of the consequences of a shock on the supply side) and adaptive behavior in the aftermath of disasters (producers and consumers can respond to a lack of input, for instance, by finding alternative suppliers). The disaster can reduce productive capacity and generate an imbalance with demand, leading to increases in commodity prices. This author noted that commodity prices respond linearly to the level of underproduction and assumed a single parameter of price inflation for the whole economy in applying these prices. In addition, local demand and exports were modified based on both the macroeconomic situation and their price elasticity (also considered unique for the whole economy in their application). In the sensitivity analysis of that model, the author concluded that price dynamics do not strongly feed back into the model dynamics (inflation in all sectors remains negligible, except in the construction sector) and that, for reasonable values of demand elasticity, no large qualitative changes are observed, showing that this parameter is not essential.

The current paper aims to introduce a practical methodological proposal that combines elements of various IO approaches to improve socioeconomic impact assessments that are derived from initial shocks in the supply's output in a given sector. More specifically, it proposes a novel procedure for studying the effects of forward sectoral linkages by considering markets and prices in the IO model. This proposal is tailored to support decision making, as it provides an assessment of potential impacts under different circumstances (e.g., before setting fishing quotas, limits on dairy or livestock production, and regulated energy prices). Evaluating the potential impacts of unexpected changes in production conditions (e.g., due to climatic events that temporarily reduce or stop production in some sectors) may also be useful.

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. Section 4 contains a synopsis and discussion of the proposed methodological procedure. This discussion attempts to explain the rationale and economic logic behind the assumptions made in the different phases of the procedure. Finally, section 5 summarizes the conclusions.

2. 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:

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

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

where **A** is the input coefficients matrix in the case of open economies (Oosterhaven and Hewings, 2014); **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:

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

where **L**=(**I**-**A**)$^{-1}$ is known as the Leontief inverse matrix of the total requirements (l_{ij}). From this matrix, we can obtain the simple output multipliers, $m(o)_j$:

$$m(o)_j = \sum_{i=1}^{n} l_{ij} \quad (4)$$

This indicator explains the direct and indirect impacts that variations of a certain sector's final demand can have on the overall economic system.

The price model based on monetary data (Miller and Blair, 2009) can be represented in matrix form:

$$\mathbf{x'} = \mathbf{i'}\,\mathbf{Z} + \mathbf{v'} \quad (5)$$

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 (5), we obtain the following:

$$\mathbf{i}' = \mathbf{i}'\,\mathbf{A} + \mathbf{v}'_{\mathbf{c}} \quad (6)$$

where $v'_c = v'\,\hat{x}^{-1}$ = [v_1/x_1, …, v_n/x_n]. If $\tilde{p}_j$ denotes the base-year index prices, $\tilde{p}'$ = [$\tilde{p}_1, \ldots, \tilde{p}_n$], then the IO price model can be written as follows:

$$\tilde{\mathbf{p}}' = \tilde{\mathbf{p}}'\mathbf{A} + \mathbf{v}'_{\mathbf{c}} = \mathbf{v}'_{\mathbf{c}}\,(\mathbf{I} - \mathbf{A})^{-1} = \mathbf{v}'_{\mathbf{c}}\,\mathbf{L} \quad (7)$$

Or its equivalent form can be expressed in column vectors:

$$\tilde{\mathbf{p}} = \mathbf{A}'\tilde{\mathbf{p}} + \mathbf{v}_{\mathbf{c}} = \left(\mathbf{I} - \mathbf{A}'\right)^{-1}\mathbf{v}_{\mathbf{c}} = \mathbf{L}'\,\mathbf{v}_{\mathbf{c}} \quad (8)$$

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

$$\mathbf{A} = \begin{pmatrix} \mathbf{A_{11}} & \mathbf{A_{12}} \\ \mathbf{A_{21}} & \mathbf{A_{22}} \end{pmatrix} \qquad (9)$$

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:

$$\begin{bmatrix} (\mathbf{I_{11}} - \mathbf{A_{11}}) & -\mathbf{A_{12}} \\ -\mathbf{A_{21}} & (\mathbf{I_{22}} - \mathbf{A_{22}}) \end{bmatrix} \begin{bmatrix} \mathbf{x^{ex}} \\ \mathbf{x^{en}} \end{bmatrix} = \begin{bmatrix} \mathbf{f^{en}} \\ \mathbf{f^{ex}} \end{bmatrix} \qquad (10)$$

Rearranging (10) provides the following:

$$\begin{bmatrix} -\mathbf{I_{11}} & -\mathbf{A_{12}} \\ \mathbf{0} & (\mathbf{I_{22}} - \mathbf{A_{22}}) \end{bmatrix} \begin{bmatrix} \mathbf{f^{en}} \\ \mathbf{x^{en}} \end{bmatrix} = \begin{bmatrix} -(\mathbf{I_{11}} - \mathbf{A_{11}}) & \mathbf{0} \\ \mathbf{A_{21}} & \mathbf{I_{22}} \end{bmatrix} \begin{bmatrix} \mathbf{x^{ex}} \\ \mathbf{f^{ex}} \end{bmatrix} \qquad (11)$$

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, (11) can be expressed as follows:

$$\begin{bmatrix} \mathbf{f^{en}} \\ \mathbf{x^{en}} \end{bmatrix} = \mathbf{M^{-1}}\,\mathbf{N} \begin{bmatrix} \mathbf{x^{ex}} \\ \mathbf{f^{ex}} \end{bmatrix} = \begin{bmatrix} (\mathbf{I_{11}} - \mathbf{A_{11}}) - \mathbf{A_{12}}\,\mathbf{L_{22}}\,\mathbf{A_{21}} & -\mathbf{A_{12}}\,\mathbf{L_{22}} \\ \mathbf{L_{22}}\,\mathbf{A_{21}} & \mathbf{L_{22}} \end{bmatrix} \begin{bmatrix} \mathbf{x^{ex}} \\ \mathbf{f^{ex}} \end{bmatrix} \quad (12)$$

where $\mathbf{L_{22}} = (\mathbf{I_{22}}\text{-}\mathbf{A_{22}})^{-1}$.

$\mathbf{M^{-1}N}$ 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 $\mathbf{L_{22}A_{21}}$ 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 ($\Delta f_2=\ldots=\Delta f_n = 0$), these 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). Therefore, the multipliers calculated through the aforementioned methods do not consider the possible impacts of the existence of forward linkages. The inability 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 scheme and basic assumptions of IO models, as synthesized in section 2.

In the case of this methodological proposal, it is important to highlight that the supply shock that we analyze is not linked to a disaster involving a reduction in productive capacities; thus, no inflationary process deriving from underproduction is generated (as contemplated in Hallegate, 2008). This proposal is not based on the problematic supply-driven IO model or on the sophisticated combination of a supply and demand IO model (the idea of Oosterhaven, 1988, which was later applied by Rose and Wei, 2013) because this approximation uses a combination of fixed technical coefficients and flexible trade coefficients, and a series of case-specific assumptions must be applied to obtain a decent estimate (Oostehaven, 2015). We assume that, in the short and medium term, the input coefficients remain stable after the supply shock because no technical or trade substitution possibilities exist (unlike in the CGE models or the model that Madsen and Jensen-Butler, 2013, proposed for foreign trade).

As a baseline, an exogenous supply shock to the production of a certain sector of an economy is considered to potentially alter the price of this sector's output. According to the supply, demand and market price information, the inverse of price elasticity of supply 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 year 1 (Δp_i^1) can be calculated through the concrete forecasting of supply amount variation in year 0 for the following year (Δq_i^1):

$$\Delta p_i^1 = Es_i^{-1}\, p_i^0\, (\Delta q_i^1 / q_i^0) \qquad (13)$$

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. We assume that, with fixed input coefficients, 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 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 index prices can be constructed ($\tilde{\boldsymbol{p}}'^{ex} = [\tilde{p}_1,\ldots,\tilde{p}_k]$). For the remaining (n–k) sectors of the economy, the ratio value added per unit of output will be the exogenous variables ($\mathbf{v_c}'^{ex} = [v_{c\ k+1},\ldots, v_{c\ n}]$). From equation (8), we can write the following:

$$\begin{bmatrix} \tilde{\boldsymbol{p}}^{\mathbf{ex}} \\ \tilde{\boldsymbol{p}}^{\mathbf{en}} \end{bmatrix} = \begin{bmatrix} \mathbf{A'}_{11} & \mathbf{A'}_{21} \\ \mathbf{A'}_{12} & \mathbf{A'}_{22} \end{bmatrix} \begin{bmatrix} \tilde{\boldsymbol{p}}^{\mathbf{ex}} \\ \tilde{\boldsymbol{p}}^{\mathbf{en}} \end{bmatrix} + \begin{bmatrix} \mathbf{v_c}^{\mathbf{en}} \\ \mathbf{v_c}^{\mathbf{ex}} \end{bmatrix} \qquad (14)$$

Following the steps in the previous mixed IO quantity model (equations 10-12), we obtain the following:

$$\begin{bmatrix} -\mathbf{I}_{11} & -\mathbf{A'}_{21} \\ \mathbf{0} & (\mathbf{I}_{22} - \mathbf{A'}_{22}) \end{bmatrix} \begin{bmatrix} \mathbf{v_c}^{\mathbf{en}} \\ \tilde{\boldsymbol{p}}^{\mathbf{en}} \end{bmatrix} = \begin{bmatrix} -(\mathbf{I}_{11} - \mathbf{A'}_{11}) & \mathbf{0} \\ \mathbf{A'}_{12} & \mathbf{I}_{22} \end{bmatrix} \begin{bmatrix} \tilde{\boldsymbol{p}}^{\mathbf{ex}} \\ \mathbf{v_c}^{\mathbf{ex}} \end{bmatrix} \qquad (15)$$

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 (15), we obtain the following:

$$\begin{bmatrix} \mathbf{v_c}^{\mathbf{en}} \\ \tilde{\boldsymbol{p}}^{\mathbf{en}} \end{bmatrix} = \dot{\mathbf{M}}^{-1}\,\dot{\mathbf{N}} \begin{bmatrix} \tilde{\boldsymbol{p}}^{\mathbf{ex}} \\ \mathbf{v_c}^{\mathbf{ex}} \end{bmatrix} = \begin{bmatrix} (\mathbf{I}_{11} - \mathbf{A'}_{11}) - \mathbf{A'}_{21}\,\mathbf{L'}_{22}\,\mathbf{A'}_{12} & -\mathbf{A'}_{21}\,\mathbf{L'}_{22} \\ \mathbf{L'}_{22}\,\mathbf{A'}_{12} & \mathbf{L'}_{22} \end{bmatrix} \begin{bmatrix} \tilde{\boldsymbol{p}}^{\mathbf{ex}} \\ \mathbf{v_c}^{\mathbf{ex}} \end{bmatrix} \qquad (16)$$

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

According to exogenous price variation in year 1 ($\tilde{\boldsymbol{p}}^{ex\ 1}$ known) and assuming $\mathbf{v_c}^{ex\ 1} = \mathbf{v_c}^{ex\ 0}$, the system (16) estimates $\mathbf{v_c}^{en\ 1}$ and $\tilde{\boldsymbol{p}}^{en\ 1}$. 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.

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 that are demanded by other n–k sectors is prioritized; consequently, the impact on the quantity needed to supply the final demand of k sectors with exogenous output depends on the magnitude of the supply shock suffered and of 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 the standard IO models, by assuming fixed values for input coefficients, we implicitly assume that the price elasticity of demand is equal to -1 (de Boer, 1997). However, 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 year 1 (Δd_i^1). Additionally, these variations in the demanded quantity of endogenous outputs can be estimated through the observed information according to the price elasticity of the demand for these products [$Ed_i = (\Delta d_i / d_i)/(\Delta p_i / p_i)$].

$$\Delta d_i^1 \,/\, d_i^0 \;=\; Ed_i \,(\Delta p_i^1 \,/\, p_i^0) \qquad (17)$$

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.

If we operate with prices in the initial year (year 0), 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 year 1 and $f_i^{ex\,1(0)}$ as the value of the exogenous demands for year 1, both expressed in monetary units of year 0, we obtain the following:

$$x_i^{ex\,1(0)} \;=\; x_i^{ex\,0}\,[1 + (\Delta q_i^1 \,/\, q_i^0)] \qquad ; \qquad f_i^{ex\,1(0)} \;=\; f_i^{ex\,0}\,[1 + (\Delta d_i^1 \,/\, d_i^0)] \quad (18)$$

By understanding the predicted values for the exogenous variables ($x_i^{ex\,1(0)}$ and $f_i^{ex\,1(0)}$), we can estimate a mixed IO model using the endogenous variables ($f_i^{en\,1(0)}$ and

$x_i^{en\,1(0)}$). Therefore, assuming that the values of the input coefficients remain fixed, according to the system of equations (12), we obtain the following:

$$\begin{bmatrix} \mathbf{f}^{en\,1(0)} \\ \mathbf{x}^{en\,1\,(0)} \end{bmatrix} = \mathbf{M}^{-1}\,\mathbf{N} \begin{bmatrix} \mathbf{x}^{ex\,1(0)} \\ \mathbf{f}^{ex\,1(0)} \end{bmatrix} = \begin{bmatrix} (\mathbf{I}_{11} - \mathbf{A}_{11}) - \mathbf{A}_{12}\,\mathbf{L}_{22}\,\mathbf{A}_{21} & -\mathbf{A}_{12}\,\mathbf{L}_{22} \\ \mathbf{L}_{22}\,\mathbf{A}_{21} & \mathbf{L}_{22} \end{bmatrix} \begin{bmatrix} \mathbf{x}^{ex\,1(0)} \\ \mathbf{f}^{ex\,1(0)} \end{bmatrix} \quad (19)$$

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

Notably, to estimate the impact of the initial supply shock on the outputs of the other sectors, we must consider the variations in the exogenous final demands. 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).

As estimated with the aforementioned method, each sector's total output is expressed in monetary units of the initial year (at year-0 prices). However, the estimated price indices are known for year 1 and linked to the initial supply shock: $\tilde{\boldsymbol{p}}^{ex\ 1}$ from equation (13) and $\tilde{\boldsymbol{p}}^{en\ 1}$ from equation (16). If these indices are used to calculate the variation in prices in percentage terms from one year to another ($\Delta\%p_j$), the results can be expressed in monetary terms for year 1 (x_j^1) with a simple operation:

$$x_j^1 = x_j^{1(0)}\left(1 + \Delta\%p_j\right) \quad (20)$$

Applying a similar operation to the intermediate outputs [$z_{ij}^1 = z_{ij}^{1(0)}\,(1 + \Delta\%p_i)$] and final demand in each sector [$f_j^1 = f_j^{1(0)}\left(1 + \Delta\%p_j\right)$], we can rebuild a new IO table for year 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 year-1 prices, and to compare it with the initial situation valued at year-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.

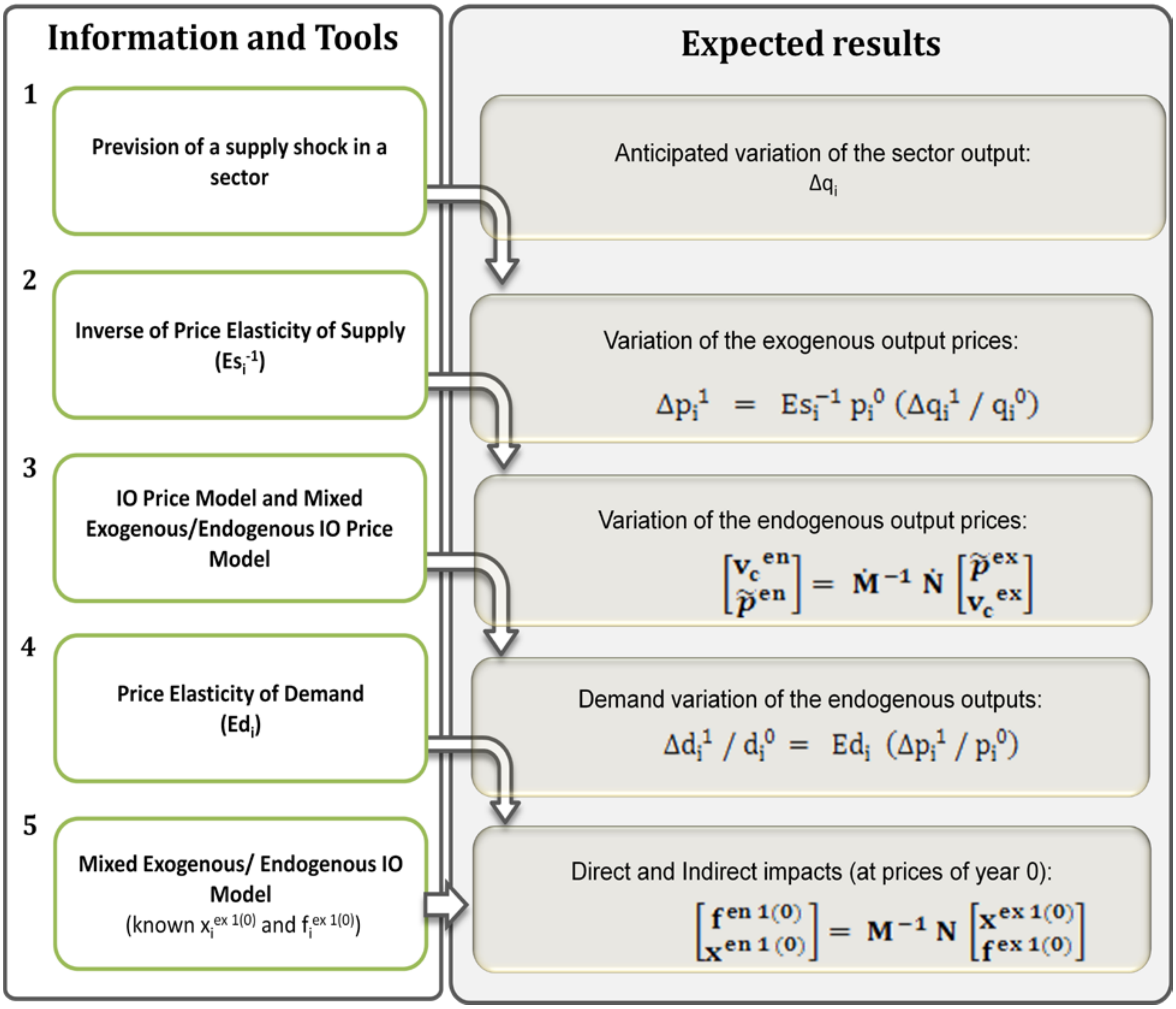

Figure 1. Proposed procedure for assessing economic impacts

4. DISCUSSION OF THE METHODOLOGICAL PROPOSAL

The complexity of assessing the impacts related to exogenous shocks primarily affects the primary sectors that directly exploit natural resources (e.g., agriculture, fisheries, and forestry). These sectors have a high degree of uncertainty in their medium- and long-term production forecasts (e.g., due to atmospheric or climatic events, fires, and spills at sea), or they are strongly regulated (e.g., via fish quotas or prices fixed by the government). In addition, some industrial sectors in these economies may use these raw materials for their production (e.g., the agro-industry, forestry industries, canned food, and processed fish products) or to directly satisfy the final demand (e.g., restaurants). In these cases, the productive activity is also affected by changes in the supply of their main raw materials.

Within IO analysis schemes, impact assessments are typically based on the assumption that input coefficients and the prices of outputs are stable in the short and medium term. Nevertheless, this price stability seems difficult to assume for some outputs when a supply shock occurs. For instance, a significant decrease in landings of fish, due to an exogenous cause, affects not only the production of the regional processing industries but also the hospitality industry if these industries cannot find replacement supplies for those raw materials. The scarcity of fish products causes an increase in prices that ultimately affects the prices of fish products and the prices of items served at seafood restaurants. If so, the typical assumption of invariability in final demand of the sectors with endogenous output is also affected.

The data on the produced quantities and market prices in primary sectors are generally available through official data sources and surveys. Therefore, we can obtain the measurements on the inverse of the elasticity price of supply ($\mathrm{Es}_{\mathrm{i}}^{-1}$) for those exogenous outputs. Thus, the initial supply shock for a primary product (Δq_i^1) due to exogenous causes can be calculated (step 1). Furthermore, by applying $\mathrm{Es}_{\mathrm{i}}^{-1}$, we can estimate how prices will vary in the next period (step 2).

If this information is included in the proposed mixed price model (step 3), the effects of exogenous output price variation ($\widetilde{\boldsymbol{p}}^{ex\ 1}$) on endogenous output prices ($\widetilde{\boldsymbol{p}}^{en\ 1}$) can be estimated. Remarkably, we consider price variations in relation to the initial situation (moment or year 0) and exclusively associate them with the supply shock under consideration (i.e., no additional factors are assumed to be capable of influencing the modification of these products' prices).

To apply this mixed pricing model, two basic assumptions should be explained in detail.

On the one hand, we assumed stability in the relations of value added per unit of exogenous output ($\mathbf{v_c}^{ex\ 1} = \mathbf{v_c}^{ex\ 0}$) to calculate the price indices. This assumption is reasonable for the sectors examined here. Agricultural and fishing sectors often have a slight relative weight on the overall economy. 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.

On the other hand, assuming that, in the short term, no real changes are required in the physical demand of the different intermediate inputs per unit of output seems equally reasonable, as can be illustrated in a brief example. After an initial shock in the supply of a fish product (e.g., tuna fish), in the short term, the canning industry will continue to demand a similar amount of tuna per can and will continue using the same facilities and working hours per unit produced as those used in previous years. A similar situation will occur in restaurants. The dishes will require the same amount of tuna fish and the same kitchen, chefs and waiters per customer. In both cases, the changes are related to the costs of production (variation in the price of raw tuna fish), which will be reflected in the final price of the tuna can or in the price of dinner at the restaurant. Therefore, if the initial supply shock is not extreme, the input coefficients will remain stable.

The new index prices 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 $k < i,j \leq n$), then sector j has a greater relative dependence on sector i in relation to the supplies of intermediate outputs of the sectors with exogenous prices. In other words, 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.

The historical information on market behavior allows us to determine the price elasticity of demand ($\mathrm{Ed_i}$) for each type of output (step 4). Through price variations ($\tilde{\boldsymbol{p}}^{en\,1}$), we can estimate quantitative changes in the final demand for these products in year 1 ($\Delta \mathrm{d_i}^1$). A significant change in the price of a product (e.g., fish) due to an exogenous shock (government restrictions on allowed catches) will affect the amount of output that is earmarked for final demand and the amount of final demand in other sectors that use these products as intermediate inputs (e.g., fish processing industry or restaurants).

Notably, both the initial supply shock (Δq_i^1) and the estimated final demand variation ($\Delta \mathrm{d_i}^1$) are discussed in physical terms (in our example, tons of fish). Applying equation (18), these variations in supply and demand allow us to obtain the new values of exogenous outputs ($\mathrm{x_i}^{\mathrm{ex}\,1(0)}$) and exogenous demand ($\mathrm{f_i}^{\mathrm{ex}\,1(0)}$) in monetary terms for the initial year (year 0). As discussed in step 3, we do not assume constant prices in this scheme. Put simply, once the changes in physical terms are estimated (Δq_i^1 and $\Delta \mathrm{d_i}^1$), we propose to calculate their value in real monetary terms by using the base-year prices (in our case, year-0 prices).

The selection of year-0 prices is an important element in estimating these impacts. This decision enables the use of the same input coefficient matrix (**A**) that is used in the mixed IO model (step 5). Here, as in the price model, we assume that technical requirements in physical terms remain unchanged in the short term and that the input coefficients in monetary terms (a_{ij}) at year-0 prices remain unchanged. Therefore, the estimated results obtained through the mixed IO model ($f_i^{en\,1(0)}$ and $x_i^{en\,1(0)}$) are also expressed in monetary units of the initial year (at year-0 prices).

The proposed mixed IO model follows the same backward perspective as that found in standard IO models. Nevertheless, unlike typical assessments of impacts, this proposal considers exogenous final demand variations that are caused by the initial supply shock ($\Delta f_i^{ex\,1(0)} \neq 0$). 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 of demand (in absolute terms) for these outputs. By considering the variations in the exogenous demand that are different from zero, we incorporate the forward linkages of those sectors that are subject to exogenous shocks. Thus, 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. This model also manages to avoid the double counting of impacts.

With this procedure, we estimate the direct and indirect impacts on sectors that are linked to other sectors that suffer due to exogenous supply shocks. However, we likely underestimate the total economic impacts. For this reason, impact assessments typically include induced effects throughout the economy. The incorporation of households in the model tends to overestimate the total economic impacts. In this case, both assessments can be considered minimum and maximum references, and the real impact on the overall economy will be positioned between them (Oosterhaven, Piek and Stelder, 1986).

If the IO table is rebuilt according to the impacts expressed in year-0 prices, the supply relationships per product unit in each sector should remain stable (input coefficients, income per unit of output, etc.). Variation should occur in the sectoral relationships of final demand per unit of output because the new prices should cause relative displacements to the final demand of the sectors less affected by the inflation.

The estimated price increases can be used as deflators to obtain the new IO table at year 1, as valued in current monetary units. This reconstructed table only considers the changes in the levels of prices associated with the initial supply shock to a concrete sector. Once the variables are calculated in current monetary terms, the input coefficients, including those of the other relationships in the basic Leontief model (e.g., the value added per unit of sectoral output), change.

According to the proposed methodological procedure, an impact assessment can be achieved not only in terms of output and final demand but also in terms of value added or employment. The monetary amounts are expressed in terms of prices in the initial year (year 0) and in the final year (year 1), allowing us to conduct comparisons of the variations in real terms and in current or monetary terms. By introducing price variation into the procedure, we allow the possibility of a compensatory reaction in the economic system. Thereby, we avoid—at least in part—the frequent overestimation of impacts derived from the habitual use of the IO multipliers, which are based on fixed relative prices. The results obtained are sensitive to the values assumed for the price elasticity of supply of the good that suffers the exogenous shock. As the elasticity (in absolute terms) increases, the impacts on the entire economy increase because the price variations in the exogenous good more intensively extend to the prices of other goods that are produced in that economy.

5. CONCLUSIONS

IO models are widely used to assess socioeconomic impacts in an economy. Normally, the different versions of such models have analyzed, from a backward linkage perspective, the repercussions on production (endogenous variables) of changes to an element of the final demand (exogenous variables). Furthermore, activities that directly exploit natural resources are often subjected to restrictions (e.g., natural or political drivers) that can determine the production. 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. Building on the economic information available in developed economies (i.e., an IO table and indicators of price elasticities), 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. Therefore, the final demand levels for those sectors with forward linkages will experience a relatively larger impact than the rest.

The previous procedure is valid for assessing slight variations in supply shocks. Traumatic supply shocks, such as major disasters (human or environmental), require a different type of analysis. In this proposal, relative scarcity is addressed in the market through price modifications, but major disasters can turn product scarcity into an absolute (or nearly absolute) shortage. In such cases, market and price mechanisms will not function properly.

Finally, this methodology is valid for providing a socioeconomic impact assessment for a supply shock that directly affects one of an economy's productive sectors because it considers forward and backward sectoral linkages simultaneously. Nevertheless, the proposed method is even more useful for assessing or comparing different options (e.g., the impact of different fishing quotas). 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. The decision makers in these sectors require further information because the main management tool may require limiting production or regulating prices (e.g., maximum price per kW of electric power). For this reason, this methodology may help us explore strategies and scenarios that involve ecological and social information and address biodiversity exploitation dilemmas using complex management approaches, such as the ecosystem-based approach.

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