Economic Systems Research

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/cesr20

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ECONOMIC SYSTEMS RESEARCH
https://doi.org/10.1080/09535314.2020.1804331

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ABSTRACT
The literature of inter-regional social accounting matrices (SAM) focuses on quantity-oriented models that determine the transmission of income impacts. This paper develops a price version to identify the channels of price transmission at the inter-regional (or inter-country) level. The method proposed divides the total multiplier effects into intra-regional price multipliers (i.e. the cost impacts within a region), open loop inter-regional price multipliers (i.e. the cost impacts from one region on another by quantifying all the within-region impacts), and closed loop inter-regional price multipliers (i.e. the circular cost impacts transiting through the accounts in the other region and returning to the starting region). In addition, the intra-regional multipliers are divided into the intra-account, the inter-account and the cross-account (circular) effects. The empirical application, which uses a bi-regional SAM that distinguishes the United States (USA) and China (CHN), highlights the importance of the within-region interdependences for explaining price impacts.

ARTICLE HISTORY
Received 1 April 2020
In final form 29 July 2020

KEYWORDS
Price impacts; inter-regional and intra-regional price transmission; cost linkages; social accounting matrix

1. Introduction

The issue of economic interdependence among (individual) economic units has been the cornerstone of applied quantitative economics since its beginnings. Defining the circuits of economic influence and capturing the transmission of impacts are central issues in the disciplines of regional science, economics of trade, economic growth, economic geography and environmental economics, among others. Researchers in these fields have developed a consistent set of methods and tools that provide a broad knowledge about the way in which economies interrelate and how the underlaying mechanisms of economic influence operate.

Within the specific topic of economic impact analysis, a strand of the literature is based on input–output (IO) modelling and focuses on representing both inter-regional and intra-regional linkages inherent to economic systems.[1] From its origins, inter-regional IO modelling has studied the feedback size on activities placed in a region coming from

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Supplemental data for this article can be accessed here. https://doi.org/10.1080/09535314.2020.1804331

[1] Within this line of research, the pioneering contributions go back to Isard (1951), Chenery (1953) and Moses (1955).

an inflow in that region or in another region, which are due to the linkages materialised through bilateral trade relations.[2] More recently, there has been a large number of contributions on both sub-national regions and regional blocks of national economies. The majority of these analyses provide quantity-oriented applications for analysing shocks coming from (exogenous) demand inflows.[3] According to the quantity approach, prices are assumed to be constant and the input–output framework is used to identify the production impacts in one region (economy) due to exogenous inflows that occurred in any of the regions (economies) defined in the model.

After the generalisation of the inter-regional input–output framework, a new generation of models emerged that are based on the structure of social accounting matrices (SAMs).[4] In particular, SAMs have been used to analyse the income generation process by extending the production relations inherent to the input–output relations with the personal and factorial income processes. From the pioneering contributions of Stone (1978) and Pyatt and Round (1979), contributions in this field have been applied to a large set of both national and regional economies. A common feature of the initial SAM contributions is the adoption of a closed economy perspective of the income and production interdependences; therefore, the role initially attributed to the external sector was residual.

Round (1985) made a next step forward in social accounting research by incorporating the regional dimension in the SAM model. Round's paper defined the income linkages between different economic systems and presented an empirical application based on a bi-regional social accounting matrix for Malaysia. In particular, Round's contribution identified the regional constituting parts of a multiplier matrix when production, consumption and factors of production are endogenously incorporated in the SAM framework. Examples of this approach can also be found in D'Antonio et al. (1988) for the Italian regions of Mezzogiorno and Centre-North, Roberts (1998) for the rural and urban areas in the Grampian region (North East of Scotland), Psaltopoulos et al. (2006) for the Greek areas of Archanes (Crete), N. Kazantzakis and Heraklion, and Hyytiä (2014) for the Finnish regions of South-Ostrobothnia and North-Karelia.

In parallel to the quantity-oriented SAM model, Roland-Holst and Sancho (1995) developed the dual price version of the SAM framework and provided a decomposition of the SAM price multipliers into different channels of price transmission. Since this initial price-oriented contribution, only a few papers have used the SAM model to analyse the cost-linkages and the transmission channels of price impacts. Moreover, to the best of this author's knowledge, all the SAM price models developed so far have been applied to individual economies[5] and there is no contribution that uses the inter-regional SAM approach to define the cost price transmission processes among different regions and/or blocks of

[2] See the Miller's early results on this issue (Miller, 1966, 1969). See also Miller and Blair (2009) for a systematisation and update of the advances done so far on regional input–output modelling.

[3] Among the wide set of applications, see for instance Akita (1993) for an inter-regional study of the Japanese economy, Ichimura and Wang (2003) for a bi-regional application to China, and Llano (2009) for an inter-regional model of the Spanish regions.

[4] A SAM is an extension of the input–output table, that not only includes information about the revenues and payments made by production activities but also by the institutional sectors of the economy (consumers, government, capital account and the rest of the world). See Pyatt (1988) for details about the structure of social accounting matrices.

[5] See Akkemik (2011) for Turkey; Llop and Pié (2011), Llop (2012), and Llop (2018) for the Catalan economy; and Saari et al. (2016) for Malaysia.

economies.[6] Considering this shortage in the regional science literature, the present paper aims to fill this gap and adapts the inter-regional SAM model to define price formation and price transmission at the inter-regional level. In particular, the proposed approach identifies the existing linkages between two areas in the world: the United States of America (USA) and China (CHN), which are used for illustrative purposes. The division of total price impacts distinguishes between the intra-regional and inter-regional price multipliers between the two countries. The intra-regional multipliers individually show the intra-account impacts (i.e. the cost shocks among accounts belonging to the same part of the circular flow of income within each economy), the inter-account impacts (i.e. the cost shocks among accounts belonging to different parts of the circular flow of income within each economy) and the cross-account price multipliers due to the circular interactions among the model's components and materialised within the economy. Finally, the inter-regional price impacts are divided into closed loop multipliers, showing the impacts starting and ending within an economy, and open loop multipliers, showing the price impacts of one region upon the other. The proposed decomposition of multipliers makes it possible to determine the relative importance of different types of interdependencies governing price formation in open economies.

The rest of the paper is organised as follows. The next section describes the model of SAM price multipliers. Section 3 describes the structure of the bi-regional SAM subsequently used to obtain price multipliers and its decomposition into different circuits of influence. The final section draws some conclusions.

2. A two-region model of prices

The analysis is based on a SAM that distinguishes two regions (countries) plus a consolidated exogenous account. Table 1 schematically shows an aggregate version of the SAM used in the inter-regional price model.

In Table 1, the transactions of the two regions differentiate the endogenous and the exogenous transactions:[7] $\mathbf{T}_{11}$ and $\mathbf{T}_{22}$ are block matrices containing the endogenous transfers within regions 1 and 2, respectively, and blocks $\mathbf{T}_{12}$ and $\mathbf{T}_{21}$ show the endogenous inter-regional transactions. The exogenous account in Table 1 includes the expenditure ($\mathbf{T}_{13}$ and $\mathbf{T}_{23}$) and income ($\mathbf{T}_{31}$ and $\mathbf{T}_{32}$) of the capital account, the government and the rest of the world. Finally, block $\mathbf{T}_{33}$ includes the transactions among the exogenous components of the model.

Following the inter-regional multiplier decomposition of Round (1985), the two-region price model is constructed based on the structure shown in Table 1 and adopting the hypothesis of a constant structure in the income and payments of accounts. In particular, reading down the columns of Table 1 and using matrix notation, prices for the endogenous components are defined as:[8]

$$\mathbf{p} = \mathbf{pA} + \mathbf{v}$$

[6] Xue et al. (2019) used a two-region SAM to analyse the price impacts of carbon pricing in China. Their analysis, which focused on distinguishing the total, global and direct influence on prices, defined an aggregate cost transmission process at the regional level.

[7] The approach follows the traditional assumption of SAM quantity-based models (Pyatt & Round, 1979), which consider sectors, households and factors of production endogenously.

[8] See Roland-Holst and Sancho (1995) and Llop (2012) for details.

Table 1. Aggregate bi-regional SAM.

		Endogenous Accounts			
		Region 1	Region 2	Exogenous Account	Total
Endogenous Accounts	Region 1	T_{11}	T_{12}	T_{13}	y_1
	Region 2	T_{21}	T_{22}	T_{23}	y_2
Exogenous Account		T_{31}	T_{32}	T_{33}	y_3
Total		y_1	y_2	y_3	

$$= \mathbf{v}[\mathbf{I} - \mathbf{A}]^{-1} = \mathbf{vM}, \tag{1}$$

where prices have been explicitly (and endogenously) determined.[9] Note that this is the fundamental difference with the quantity-oriented model, which assumes constant (and unitary) prices for all the accounts. In expression (1), $\mathbf{M} = [\mathbf{I} - \mathbf{A}]^{-1}$ is the matrix of price multipliers and $\mathbf{A}$ is the matrix of normalised coefficients, with the following (constant) structure:[10]

$$\mathbf{A} = \begin{bmatrix} \mathbf{A}_{11} & \mathbf{A}_{12} \\ \mathbf{A}_{21} & \mathbf{A}_{22} \end{bmatrix},$$

where $\mathbf{A_{ij}}$ represents the column coefficients calculated by dividing the transactions in the SAM ($\mathbf{T_{ij}}$) by the corresponding column total ($\mathbf{y_j}$). In addition, $\mathbf{p} = \begin{bmatrix} \mathbf{p}_1 & \mathbf{p}_2 \end{bmatrix}$ denotes the row vector of prices for endogenous accounts and $\mathbf{v} = \mathbf{p}_3\bar{\mathbf{A}}$ is the row vector of exogenous costs (i.e. imports from the rest of the world and taxation costs), where $\bar{\mathbf{A}} = \begin{bmatrix} \mathbf{A}_{31} & \mathbf{A}_{32} \end{bmatrix}$ shows the coefficients of the exogenous components and $\mathbf{p}_3$ is the price for exogenous costs. Note that the SAM price model reflects the cost transmission so that matrix $\mathbf{M}$ is read horizontally across the rows. This is different to the SAM quantity model, in which the identification of income impacts implies that $\mathbf{M}$ is read vertically down the columns.[11]

Following the definitions above, expression (1) can also be written as:

$$\begin{bmatrix} \mathbf{p}_1 & \mathbf{p}_2 \end{bmatrix} = \begin{bmatrix} \mathbf{p}_1 & \mathbf{p}_2 \end{bmatrix} \begin{bmatrix} \mathbf{A}_{11} & \mathbf{A}_{12} \\ \mathbf{A}_{21} & \mathbf{A}_{22} \end{bmatrix} + \mathbf{p}_3 \begin{bmatrix} \mathbf{A}_{31} & \mathbf{A}_{32} \end{bmatrix},$$

or alternatively:

$$\begin{bmatrix} \mathbf{p}_1 & \mathbf{p}_2 \end{bmatrix} = \begin{bmatrix} \mathbf{p}_1 & \mathbf{p}_2 \end{bmatrix} \begin{bmatrix} (\mathbf{I} - \mathbf{A}_{11})^{-1} & 0 \\ 0 & (\mathbf{I} - \mathbf{A}_{22})^{-1} \end{bmatrix} \left[\begin{bmatrix} 0 & \mathbf{A}_{12} \\ \mathbf{A}_{21} & 0 \end{bmatrix} + \mathbf{p}_3 \begin{bmatrix} \mathbf{A}_{31} & \mathbf{A}_{32} \end{bmatrix} \right],$$

$$\begin{aligned} \begin{bmatrix} \mathbf{p}_1 & \mathbf{p}_2 \end{bmatrix} = \begin{bmatrix} \mathbf{p}_1 & \mathbf{p}_2 \end{bmatrix} & \begin{bmatrix} 0 & (\mathbf{I} - \mathbf{A}_{22})^{-1}\mathbf{A}_{12} \\ (\mathbf{I} - \mathbf{A}_{11})^{-1}\mathbf{A}_{21} & 0 \end{bmatrix} \\ & + \mathbf{p}_3 \begin{bmatrix} \mathbf{A}_{31} & \mathbf{A}_{32} \end{bmatrix} \begin{bmatrix} (\mathbf{I} - \mathbf{A}_{11})^{-1} & 0 \\ 0 & (\mathbf{I} - \mathbf{A}_{22})^{-1} \end{bmatrix}. \end{aligned}$$

[9] Expression (1) does not consider the role of foreign exchange rates which may affect inter-country cost shocks, especially in dynamic analysis of price impacts in which the value of national currencies can evolve differently.

[10] The fixed structure of prices defined in expression (1) does not allow to adapt the role played by countries in the global market in response to price modifications that, for instance, may set aside a country out of the world market rather than causing a shock to its customers.

[11] Roland-Holst and Sancho (1995).

By using $\mathbf{B}_{21} = (\mathbf{I}-\mathbf{A}_{11})^{-1}\mathbf{A}_{21}$ and $\mathbf{B}_{12} = (\mathbf{I}-\mathbf{A}_{22})^{-1}\mathbf{A}_{12}$, it follows that:

$$\begin{bmatrix}\mathbf{p}_1 & \mathbf{p}_2\end{bmatrix} = \begin{bmatrix}\mathbf{p}_1 & \mathbf{p}_2\end{bmatrix}\begin{bmatrix}0 & \mathbf{B}_{12}\\ \mathbf{B}_{21} & 0\end{bmatrix} + \mathbf{p}_3\begin{bmatrix}\mathbf{A}_{31} & \mathbf{A}_{32}\end{bmatrix}\begin{bmatrix}(\mathbf{I}-\mathbf{A}_{11})^{-1} & 0\\ 0 & (\mathbf{I}-\mathbf{A}_{22})^{-1}\end{bmatrix}.$$

Solving for prices:

$$\begin{bmatrix}\mathbf{p}_1 & \mathbf{p}_2\end{bmatrix} = \mathbf{p}_3\begin{bmatrix}\mathbf{A}_{31} & \mathbf{A}_{32}\end{bmatrix}\underbrace{\begin{bmatrix}(\mathbf{I}-\mathbf{A}_{11})^{-1} & 0\\ 0 & (\mathbf{I}-\mathbf{A}_{22})^{-1}\end{bmatrix}}_{\mathbf{M}_1}\underbrace{\begin{bmatrix}0 & -\mathbf{B}_{12}\\ -\mathbf{B}_{21} & 0\end{bmatrix}^{-1}}_{\mathbf{M}_\mathbf{r}}, \tag{2}$$

where the total multipliers have been split into two different blocks. $\mathbf{M}_\mathbf{r}$ is the *inter-regional multiplier matrix* that shows the cost connection between the two regions of the model. Next, this inter-regional block ($\mathbf{M}_\mathbf{r}$) is transformed as:

$$\begin{bmatrix}\mathbf{p}_1 & \mathbf{p}_2\end{bmatrix} = \mathbf{p}_3\begin{bmatrix}\mathbf{A}_{31} & \mathbf{A}_{32}\end{bmatrix}\underbrace{\begin{bmatrix}(\mathbf{I}-\mathbf{A}_{11})^{-1} & 0\\ 0 & (\mathbf{I}-\mathbf{A}_{22})^{-1}\end{bmatrix}}_{\mathbf{M}_1}$$

$$\times\underbrace{\begin{bmatrix}(\mathbf{I}-\mathbf{B}_{12}\mathbf{B}_{21})^{-1} & (\mathbf{I}-\mathbf{B}_{12}\mathbf{B}_{21})^{-1}\mathbf{B}_{12}\\ (\mathbf{I}-\mathbf{B}_{21}\mathbf{B}_{12})^{-1}\mathbf{B}_{21} & (\mathbf{I}-\mathbf{B}_{21}\mathbf{B}_{12})^{-1}\end{bmatrix}}_{\mathbf{M}_\mathbf{r}},$$

$$\begin{bmatrix}\mathbf{p}_1 & \mathbf{p}_2\end{bmatrix} = \mathbf{p}_3\begin{bmatrix}\mathbf{A}_{31} & \mathbf{A}_{32}\end{bmatrix}\underbrace{\begin{bmatrix}(\mathbf{I}-\mathbf{A}_{11})^{-1} & 0\\ 0 & (\mathbf{I}-\mathbf{A}_{22})^{-1}\end{bmatrix}}_{\mathbf{M}_1}\underbrace{\begin{bmatrix}\mathbf{I} & \mathbf{B}_{12}\\ \mathbf{B}_{21} & \mathbf{I}\end{bmatrix}}_{\mathbf{M}_2}$$

$$\times\underbrace{\begin{bmatrix}(\mathbf{I}-\mathbf{B}_{12}\mathbf{B}_{21})^{-1} & 0\\ 0 & (\mathbf{I}-\mathbf{B}_{21}\mathbf{B}_{12})^{-1}\end{bmatrix}}_{\mathbf{M}_3}.$$

Compactly, this expression can be written as:

$$\mathbf{p} = \mathbf{v}\mathbf{M}_1\mathbf{M}_2\mathbf{M}_3, \tag{3}$$

where the price indices have been divided into three matrices containing different circuits of cost transmission.

From expression (3), block $\mathbf{M}_1$ is the *intra-regional multiplier matrix* showing the price impacts originated in one specific region and completely materialised within that region. Note that this matrix is block diagonal, as it contains the price effects started and concluded within an economy without any link with the other region.

Block $\mathbf{M}_2$ is the *inter-regional 'open loop' multiplier matrix* and shows the price impacts that the local accounts have on the other region. The cost transmission in this matrix is channelled through elements $\mathbf{B}_{21}$ and $\mathbf{B}_{12}$, which contain the cross price effects from one region to the other and vice versa, and thus the main diagonal is compounded by identity matrices.

Element $\mathbf{M}_3$ is the *inter-regional feedback 'closed loop' multiplier matrix* containing the price impacts in one region coming from the cost shocks originated in the same region. This matrix is block diagonal as it captures the feedback effects due to inter-regional channels. That is, the price impacts in $\mathbf{M}_3$ are those started and received in one region once all the interactions with the other region have concluded.

The intra-regional price multipliers, $\mathbf{M}_1$, can be further decomposed to reveal the importance of different cost linkages within each region, in a similar way to Roland-Holst and Sancho (1995). By dividing the structural coefficients $\mathbf{A}_{11}$ and $\mathbf{A}_{22}$ into different groups of accounts, the intra-regional multiplier matrix can be transformed to the following multiplicative decomposition (Pyatt & Round, 1979):[12]

$$\mathbf{M}_1 = \mathbf{M}_1^1 \mathbf{M}_1^2 \mathbf{M}_1^3, \tag{4}$$

where total price impacts within the economy are divided into three different components: $\mathbf{M}_1^1$, which captures the impact resulting from the linkages within a particular type of account within a specific region (or *intra-account multipliers*), $\mathbf{M}_1^2$, which shows the within-regional price effects resulting from *inter-account multipliers*, and finally, $\mathbf{M}_1^3$, which contains the *cross-account multipliers* of the circular interactions corresponding to the intra-regional components of the model.

By inserting expression (4) into expression (3), it follows that:

$$\mathbf{p} = \mathbf{v}(\mathbf{M}_1^1 \mathbf{M}_1^2 \mathbf{M}_1^3)\mathbf{M}_2 \mathbf{M}_3, \tag{5}$$

or alternatively:

$$\begin{bmatrix} \mathbf{p}_1 & \mathbf{p}_2 \end{bmatrix} = \mathbf{p}_3 \begin{bmatrix} \mathbf{A}_{31} & \mathbf{A}_{32} \end{bmatrix} \underbrace{\underbrace{\begin{bmatrix} (\mathbf{I}-\mathbf{C}_{11})^{-1} & 0 \\ 0 & (\mathbf{I}-\mathbf{C}_{22})^{-1} \end{bmatrix}}_{\mathbf{M}_1^1} \underbrace{\begin{bmatrix} \mathbf{I}+\mathbf{D}_{11}+\mathbf{D}_{11}^2 & 0 \\ 0 & \mathbf{I}+\mathbf{D}_{22}+\mathbf{D}_{22}^2 \end{bmatrix}}_{\mathbf{M}_1^2} \underbrace{\begin{bmatrix} (\mathbf{I}-\mathbf{D}_{11}^3)^{-1} & 0 \\ 0 & (\mathbf{I}-\mathbf{D}_{22}^3)^{-1} \end{bmatrix}}_{\mathbf{M}_1^3}}_{\mathbf{M}_1} \underbrace{\begin{bmatrix} \mathbf{I} & \mathbf{B}_{12} \\ \mathbf{B}_{21} & \mathbf{I} \end{bmatrix}}_{\mathbf{M}_2} \underbrace{\begin{bmatrix} (\mathbf{I}-\mathbf{B}_{12}\mathbf{B}_{21})^{-1} & 0 \\ 0 & (\mathbf{I}-\mathbf{B}_{21}\mathbf{B}_{12})^{-1} \end{bmatrix}}_{\mathbf{M}_3}, \tag{6}$$

where $\mathbf{C}_{11}$ and $\mathbf{C}_{22}$ are the coefficients in the block diagonal of $\mathbf{A}_{11}$ and $\mathbf{A}_{22}$, respectively, and zeros elsewhere.[13] Also in expression (6), $\mathbf{D}_{11} = (\mathbf{A}_{11} - \mathbf{C}_{11})(\mathbf{I} - \mathbf{C}_{11})^{-1}$, and $\mathbf{D}_{22} = (\mathbf{A}_{22} - \mathbf{C}_{22})(\mathbf{I} - \mathbf{C}_{22})^{-1}$.

[12] Following the traditional procedure in the quantity-oriented SAM model of multipliers, the price analysis considers the sectors of production, factors and consumers separately.

[13] Note that the three categories of endogenous accounts (i.e. sectors of production, value added and consumers) define three different blocks within the intra-regional coefficient matrices $\mathbf{A}_{11}$ and $\mathbf{A}_{22}$.

Figure 1. Decomposition of price multipliers.

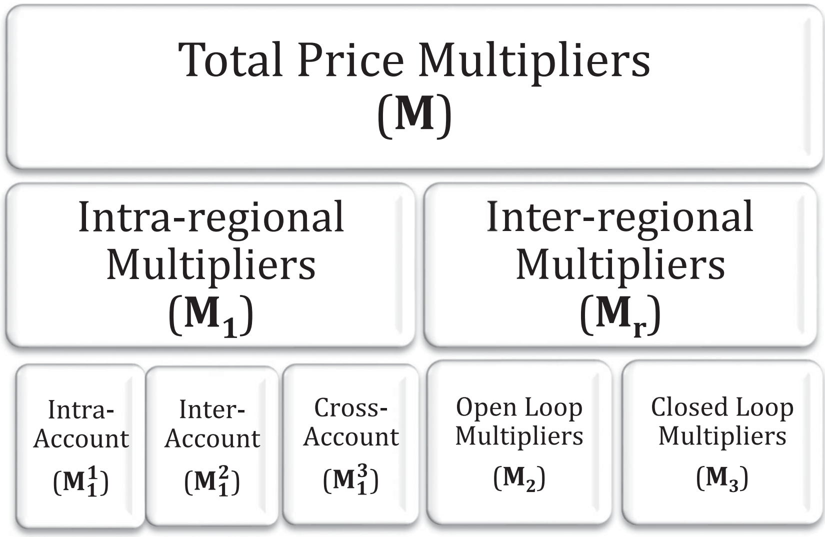

Figure 1 schematically illustrates the division of total price multipliers into different components that identify the various channels of price transmission. Following the model definition above, this figure shows two possible decompositions of the total cost impacts; First, the division into intra-regional (internal) and inter-regional (external) price impacts, according to expression (2); Second, the division of the inter-regional multipliers into the open loop effects (one region on the other) and the closed loop effects (feedback effects), which is completed with the division of the intra-regional multipliers into inter-account, intra-account and cross-account effects, according to expression (6). All these individual components clarify the nature and the origin of the various effects involved in the transmission throughout the interconnected network of cost impacts, which sheds light on the complexity of the spatial dimension of the economic system.

3. The bi-regional SAM

Table 2 shows the structure of the bi-regional SAM that includes two countries: China and the United States of America.[14] The database, which has a base year of 2014, was constructed relying heavily on data available in the World Input Output Database (WIOD).[15] In particular, the inter-country input–output tables and factor requirements were obtained directly from the WIOD. In its original form, the WIOD covers 56 sectors of 43 countries plus a model for the Rest of the World (ROW). The original data source was aggregated to isolate the two areas of interest (i.e. the USA and China), while sectoral disaggregation was limited to 16 activities.[16]

[14] The complete database is in the Supplementary Material.
[15] See Timmer et al. (2015) for a description of the WIOD construction process.
[16] The complete list of accounts in the bi-regional SAM are detailed in the Supplementary Material.

Table 2. Structure of the bi-regional SAM.

		CHINA			USA				
		Industries	Factors	Households	Industries	Factors	Households	Exogenous	Total
CHINA	Industries	CHN domestic intermediate consumption		CHN domestic consumption	USA intermediate consumption from CHN		USA consumption from CHN	CHN exports to ROW, CHN investment, CHN government consumption	Total CHN output
	Factors	CHN value added							Total CHN factor payments
	Households		CHN value added payments for factor services					Transfers from CHN government	Total CHN households' income
USA	Industries	CHN intermediate consumption from USA			USA domestic intermediate consumption		USA domestic consumption	USA Exports to ROW, USA investment, USA government consumption	Total USA output
	Factors				USA value added				Total USA factor payments
	Households			CHN consumption from USA		USA value added payments for factor services		Transfers from USA government	Total USA households' income
Exogenous		Indirect taxes, CHN imports from ROW		CHN private savings, CHN taxes on income	Indirect taxes, USA imports from ROW		USA private savings, USA taxes on income		Total public revenues, total saving, total imports from ROW
Total		Total CHN output	Total factor payments through CHN	Total CHN households' expenditure	Total USA output	Total factor payments through USA	Total USA households' expenditure	Total public consumption, total investment, total exports to ROW	

Unlike the IO tables, the structure of a SAM is not limited to the production system because it shows the complete circular flow of income by adding the income transactions of the rest of the economic agents (consumers, government and foreign agents). This additional information covering the transactions inherent to the institutional agents was obtained from various heterogenous statistical sources. Due to restrictions in data availability, it was not possible to disaggregate households by social group or show different categories of factors. Therefore, the SAM has a limited institutional structure (i.e. a single account for households and a single account for factors).[17]

For the USA, the personal current taxes and the public transfers to households are available in the Federal Reserve Bank of St. Louis.[18] The American private and public savings were calculated residually, given that the rest of the elements in the capital account (i.e. the USA investment) were directly available from the WIOD.

The Chinese personal taxes were obtained with an indirect calculation. First, the State Taxation Administration of the People's Republic of China publishes the total tax revenue in local currency.[19] Second, the International Monetary Fund (2020) publishes the proportion of Chinese taxes on income in relation to total tax revenues. By applying the proportion of income taxation to total tax revenue, personal taxation is obtained indirectly. Finally, the resulting variable was converted into American dollars using the WIOD exchange rates. The public transfers to Chinese households in 2014 were obtained from the 'CHIP dataset'[20] and the corresponding value was converted to American dollars by using the WIOD exchange rates. The rest of the Chinese variables (public and private saving) were calculated residually by preserving the balance between total investment and total saving sources in the social accounting matrix.

4. Empirical results

4.1. Total price impacts

The information provided by the model reflects the impacts on endogenous prices in each country (i.e. production prices, consumption prices and the prices for value added) resulting from the exogenous cost shocks received, such as changes in the costs of imports from the ROW or in the taxation system. At the empirical level, the values in matrix $\mathbf{M}$ (expression (1)) can be directly interpreted as percentage price increases given that the model assumes unitary benchmark prices.

Table 3 shows the total price multipliers, focusing on the maximum bilateral impacts of an exogenous cost shock in the account in the left column. The values in this table are in net terms, once the initial and exogenous shock has been subtracted from the total impacts, and show the additive decomposition of multipliers (matrices $\mathbf{N}_1$, $\mathbf{N}_2$, and $\mathbf{N}_3$).[21] For instance, a dollar of cost increase in the exogenous components of the Chinese chemical sector (Sector 5) would have the highest impact on the prices of Chinese health and social activities

[17] Due to the lack of data in the two countries, all value added has been allocated to consumers although other agents and institutions receive part of this income. This means that the SAM will contain an overestimation of household income.

[18] https://fred.stlouisfed.org.

[19] www.chinatax.cn/eng/.

[20] China Institute for Income Distribution (2020).

[21] The net multipliers, initially defined by Pyatt and Round (1979) and Round (2003), facilitate the interpretation of the contribution of the decomposed components to total effects.

Table 3. Total and inter-regional price multipliers.

Cost increase originated in account *i*	Price impact materialised in account *j*									
	CHINA					USA				
CHINA		M – I	N_1	N_2	N_3		M – I	N_1	N_2	N_3
1. Agriculture	4. Food industry	0.6769	0.6768	0	0.0001	7. Automobiles	0.0084	0	0.0084	0
2. Coke, petroleum, fuel	5. Chemical products	0.2142	0.2142	0	0.0000	5. Chemical products	0.0053	0	0.0053	0
3. Electricity, gas, steam, water	2. Coke, petroleum, fuel	0.9286	0.9285	0	0.0001	7. Automobiles	0.0155	0	0.0155	0
4. Food industry	4. Food industry	0.5750	0.5749	0	0.0001	7. Automobiles	0.0094	0	0.0094	0
5. Chemical products	14. Health, social activities	0.5656	0.5654	0	0.0002	5. Chemical products	0.0207	0	0.0207	0
6. Machinery	6. Machinery	0.9577	0.9574	0	0.0003	7. Automobiles	0.0549	0	0.0549	0
7. Automobiles	7. Automobiles	0.6328	0.6327	0	0.0001	7. Automobiles	0.0164	0	0.0164	0
8. Other manufacturing	8. Other manufacturing	0.6817	0.6814	0	0.0003	8. Other manufacturing	0.0287	0	0.0287	0
9. Construction	9. Construction	0.0549	0.0548	0	0.0001	7. Automobiles	0.0006	0	0.0006	0
10. Commerce	7. Automobiles	0.2660	0.2659	0	0.0001	7. Automobiles	0.0106	0	0.0106	0
11. Transportation	11. Transportation	0.1742	0.1742	0	0.0000	7. Automobiles	0.0056	0	0.0056	0
12. Financial services	11. Transportation	0.1339	0.1339	0	0.0000	7. Automobiles	0.0048	0	0.0048	0
13. Education	13. Education	0.0790	0.0790	0	0.0000	7. Automobiles	0.0014	0	0.0014	0
14. Health, social activities	14. Health, social activities	0.0529	0.0529	0	0.0000	7. Automobiles	0.0018	0	0.0018	0
15. Public administration	15. Public administration	0.0158	0.0158	0	0.0000	7. Automobiles	0.0003	0	0.0003	0
16. Other services	10. Commerce	0.3555	0.3554	0	0.0001	7. Automobiles	0.0117	0	0.0117	0
17. Value added	12. Financial services	1.3854	1.3852	0	0.0002	7. Automobiles	0.0543	0	0.0543	0
18. Households	17. Value added	1.4364	1.4362	0	0.0002	7. Automobiles	0.0543	0	0.0543	0

Cost increase originated in account *i*	Price impact materialised in account *j*									
	USA					CHINA				
USA		M – I	N_1	N_2	N_3		M – I	N_1	N_2	N_3
1. Agriculture	4. Food industry	0.4088	0.4087	0	0.0001	4. Food industry	0.0086	0	0.0086	0
2. Coke, petroleum, fuel	11. Transportation	0.1865	0.1864	0	0.0001	5. Chemical products	0.0016	0	0.0016	0
3. Electricity, gas, steam, water	2. Coke, petroleum, fuel	0.4967	0.4966	0	0.0001	5. Chemical products	0.0021	0	0.0021	0
4. Food industry	4. Food industry	0.3311	0.3310	0	0.0001	4. Food industry	0.0036	0	0.0036	0
5. Chemical products	5. Chemical products	0.2618	0.2617	0	0.0001	5. Chemical products	0.0051	0	0.0051	0
6. Machinery	6. Machinery	0.3162	0.3161	0	0.0001	6. Machinery	0.0038	0	0.0038	0
7. Automobiles	7. Automobiles	0.2177	0.2176	0	0.0001	7. Automobiles	0.0024	0	0.0024	0
8. Other manufacturing	8. Other manufacturing	0.2396	0.2395	0	0.0001	8. Other manufacturing	0.0024	0	0.0024	0
9. Construction	15. Public administration	0.0369	0.0369	0	0.0000	4. Food industry	0.0003	0	0.0003	0
10. Commerce	9. Construction	0.4533	0.4532	0	0.0001	4. Food industry	0.0053	0	0.0053	0
11. Transportation	11. Transportation	0.1954	0.1953	0	0.0001	5. Chemical products	0.0032	0	0.0032	0
12. Financial services	12. Financial services	0.5499	0.5498	0	0.0001	4. Food industry	0.0028	0	0.0028	0
13. Education	13. Education	0.0388	0.0388	0	0.0000	4. Food industry	0.0004	0	0.0004	0
14. Health, social activities	14. Health, social activities	0.2293	0.2292	0	0.0001	4. Food industry	0.0026	0	0.0026	0
15. Public administration	11. Transportation	0.1041	0.1041	0	0.0000	4. Food industry	0.0012	0	0.0012	0
16. Other services	16. Other services	0.9220	0.9218	0	0.0002	4. Food industry	0.0104	0	0.0104	0
17. Value added	12. Financial services	2.1029	2.1025	0	0.0004	4. Food industry	0.0248	0	0.0248	0
18. Households	17. Value added	2.1803	2.1799	0	0.0004	4. Food industry	0.0248	0	0.0248	0

(Sector 14), which is quantified as 0.5656 dollars. In the American accounts, this cost shock would produce the highest impact on the prices of the USA Chemical products (Sector 5), which is quantified as 0.0207 dollars (right hand-side in Table 3).

In both economies, the results of the within-country impacts (i.e. from CHN to CHN and from USA to USA) clearly illustrate that the highest influence on agricultural and industrial prices (Sectors 1–8) comes from cost shocks in the domestic industry, and that the highest influence on service prices (Sectors 11–16) comes from cost shocks received by domestic services. In contrast, the highest (open) price multipliers from one country to the other (right-hand-side in Table 3) are limited to industrial activities, showing that cost shocks in domestic sectors have the highest impact on foreign industrial prices of the other country. Specifically, the USA Automobiles industry (Sector 7) and the Chinese Food industry (Sector 4) are the most sensitive to price rises in foreign sectors.

In addition, figures in Table 3 help to unveil a different response of sectoral costs in quantitative terms. In particular, Chinese agricultural and industrial costs are more responsive than the American ones after receiving unitary cost impacts, while American service costs (with the exception of Education) are more responsive than Chinese services after the unitary cost shocks received. The divergence in the sectoral reaction suggests differences in the competitiveness of domestic production. Moreover, the asymmetric price impacts on sectors could affect the production system of the two countries differently in relation to changes in trade policies, cost increases in imported goods or changes in taxation, for instance.

4.2. Inter-regional price impacts

In order to gain further insights into the underlying price connections between the two countries, Table 3 shows the inter-regional decomposition of the price multipliers. The first part of this table contains the cost linkages originated in China and materialised in China (left-hand side) and the USA (right-hand side) respectively. The second part of Table 3 shows the corresponding impacts of the cost increases originated in the USA.

The $\mathbf{N}_1$ multipliers, which show the price impacts of the intra-regional linkages triggered wholly within each country, show that the greatest impact is produced within each country and at a great distance from the inter-regional impacts. An interesting piece of evidence of the multipliers' decomposition is, therefore, the strength of the intra-regional multipliers ($\mathbf{N}_1$), and the weakness of the inter-regional multipliers ($\mathbf{N}_2$ and $\mathbf{N}_3$) for explaining total price impacts. Surprisingly, the vast proportion of cost impacts under exogenous shocks arise from within-country linkages, whereas the bilateral linkages seem to have an extremely limited influence. In summary, since trade between China and the USA is relatively low in relation to domestic output, the multipliers in the two economies show small inter-regional open effects ($\mathbf{N}_2$) and negligible inter-regional feedback effects ($\mathbf{N}_3$).

From Table 3, the highest inter-regional impacts of cost shocks in the Chinese production system are on the USA automobile production (Sector 7) after a price rise in the Chinese machinery sector (Sector 3), which amounts to 0.0549. For the opposite price linkages, the highest ability to increase Chinese costs is the repercussions of a cost push impact in the USA's other services (Sector 16) on the Chinese food industry (Sector 4), which amounts to 0.0104. A unitary cost shock in the USA value added and households (Sectors 17 and 18) would increase the costs of the Chinese food industry by 0.0248 dollars. This gives some insight into the weakness and nature of linkages between the two countries. Finally, the rest of the inter-regional impacts are clearly below these values.

4.3. Intra-regional price impacts

The SAM price model makes it possible to divide the intra-regional multipliers ($\mathbf{N}_1$) into inter-account, intra-account and cross-account multipliers. Table 4 shows the results of this decomposition for the maximum bilateral multipliers. In the two countries, Table 4 shows that inter-account multipliers ($\mathbf{N}_1^2$) are null for those shocks originated and materialised within the same group of accounts (i.e. the production sectors) and intra-account multipliers ($\mathbf{N}_1^1$) are null for those shocks originated in one part of the system and materialised in another part of the system (i.e. from sectors to value added and consumers, from value added to households and sectors and, finally, from households to sectors and value added). The third component ($\mathbf{N}_1^3$) (cross-account multipliers) captures the feedback between value added, private consumption and sectoral production.

For China, the intra-regional multipliers are clearly dominated by the intra-account components, and this means that sectoral relations themselves are the highest source of cost impact in the Chinese production system. The exceptions are the value added (Account 17) and households (Account 18) that cause the highest impact due to the inter-account linkages ($\mathbf{N}_1^2$).

For the USA, the highest price influence is also due to the $\mathbf{N}_1^1$ (intra-account) multipliers. However, the results in this economy show some interesting exceptions, including the service activities (commerce -Sector 10, education -Sector 13, health and social services -Sector 14, public administration -Sector 15, and other services -Sector 16), where the highest cost shocks are explained by the cross-account impacts ($\mathbf{N}_1^3$). Again, for value added (Account 17) and households (Account 18) the highest intra-regional cost shock is due to the relations between the different blocks ($\mathbf{N}_1^2$).

The comparison of the intra-regional impacts indicates that services spread the cost shocks differently in the two countries. The American (direct) intra-account links are less important than the (indirect) cross-account and the Chinese intra-account relations make the circuit more prone to transmit price impacts.

Since the SAM allocates all value added (Account 17) to households (Account 18), in the two countries the inter-account multipliers show that the influence of the households cost inflows to value added is unitary. Moreover, the value added cost shocks are causing an (almost) equal inter-account effect to financial services (Account 12) in the two countries,[22] and the cross-account multipliers for value added (Account 17) and households (Account 18) in the USA are much larger than those for CHN showing a higher inter-regional feedback price impacts in the USA.

[22] Although Table 4 shows equal values for these multipliers in CHN and the USA, differences occur from the fifth decimal.

Table 4. Intra-regional decomposition of the price multipliers.

Cost increase originated in account *i*	Price impact materialised in account *j*				
	CHINA				
CHINA		N_1	N_1^1	N_1^2	N_1^3
1. Agriculture	4. Food industry	0.6768	0.5601	0	0.1167
2. Coke, petroleum, fuel	5. Chemical products	0.2142	0.1879	0	0.0263
3. Electricity, gas, steam, water	2. Coke, petroleum, fuel	0.9285	0.8701	0	0.0584
4. Food industry	4. Food industry	0.5749	0.4270	0	0.1479
5. Chemical products	14. Health, social activities	0.5654	0.5051	0	0.0603
6. Machinery	6. Machinery	0.9574	0.8780	0	0.0794
7. Automobiles	7. Automobiles	0.6327	0.5988	0	0.0339
8. Other manufacturing	8. Other manufacturing	0.6814	0.6014	0	0.0800
9. Construction	9. Construction	0.0548	0.0506	0	0.0042
10. Commerce	7. Automobiles	0.2659	0.1650	0	0.1009
11. Transportation	11. Transportation	0.1742	0.1392	0	0.0350
12. Financial services	11. Transportation	0.1339	0.0924	0	0.0415
13. Education	13. Education	0.0790	0.0475	0	0.0315
14. Health, social activities	14. Health, social activities	0.0529	0.0121	0	0.0408
15. Public administration	15. Public administration	0.0158	0.0129	0	0.0029
16. Other services	10. Commerce	0.3554	0.2094	0	0.1460
17. Value added	12. Financial services	1.3852	0	0.9645	0.4207
18. Households	17. Value added	1.4362	0	1.0000	0.4362
	USA				
USA		N_1	N_1^1	N_1^2	N_1^3
1. Agriculture	4. Food industry	0.4087	0.3761	0	0.0326
2. Coke, petroleum, fuel	11. Transportation	0.1864	0.1409	0	0.0455
3. Electricity, gas, steam, water	2. Coke, petroleum, fuel	0.4966	0.4421	0	0.0545
4. Food industry	4. Food industry	0.3310	0.2543	0	0.0767
5. Chemical products	5. Chemical products	0.2617	0.2192	0	0.0425
6. Machinery	6. Machinery	0.3161	0.2718	0	0.0443
7. Automobiles	7. Automobiles	0.2176	0.1959	0	0.0217
8. Other manufacturing	8. Other manufacturing	0.2395	0.1905	0	0.0490
9. Construction	15. Public administration	0.0369	0.0235	0	0.0134
10. Commerce	9. Construction	0.4532	0.1339	0	0.3193
11. Transportation	11. Transportation	0.1953	0.1323	0	0.0630
12. Financial services	12. Financial services	0.5498	0.3640	0	0.1858
13. Education	13. Education	0.0388	0.0081	0	0.0307
14. Health, social activities	14. Health, social activities	0.2292	0.0111	0	0.2181
15. Public administration	11. Transportation	0.1041	0.0317	0	0.0724
16. Other services	16. Other services	0.9218	0.2893	0	0.6325
17. Value added	12. Financial services	2.1025	0	0.9645	1.1380
18. Households	17. Value added	2.1799	0	1.0000	1.1799

5. Conclusions

The structure of SAMs is a straightforward way to reflect the completeness of the circular flow of income. The SAM model makes it possible to disentangle various channels of interdependence operating within the complex economic interactions captured by the aggregated multipliers. Despite its simplicity, the SAM approach offers a general-equilibrium perspective that can be used to analyse a large set of economic shocks and alternative policy strategies. SAMs are equally useful for reflecting economic interdependences between different economies by adopting a multi-regional perspective able to capture detailed trade and income connections between countries or regions.

This paper extends the literature on SAM methods and proposes a multi-regional price model based on the SAM structure. Specifically, the price model is defined to show the price formation and price transmission mechanisms between two countries: China and the USA. The inter-regional (inter-country) perspective adopted makes it possible to quantify the impacts on all the endogenous accounts of the two regions (countries) caused by any cost shock accrued in a particular account of a specific region (country). In addition, the model is used to divide the total price multipliers into different channels of cost linkages and circuits of influence, at both the intra-regional and inter-regional levels.

The application of the multi-regional SAM price setting illustrates that cost shocks in one country have a low ability to influence sectoral prices of the other country. The results also show that the Chinese industrial activities have a higher response compared to American industry, and the American services have a higher response than the Chinese services. Within each country, the channels belonging to the same category of accounts (intra-account multipliers) have the most relevance for explaining price effects, except the USA services, for which the cross-multipliers are the most important component.

Despite the results presented in this paper, SAM multipliers have some shortcomings that, arising from the model's assumption of linearity, should be taken into account. First, as linear coefficients involve a fixed structure, the SAM model is limited to showing the quantity responses (quantity-oriented version) or, alternatively, the price responses (price-oriented version) but the model does not show a simultaneous interaction between prices and quantities. Second, the linear structure of SAM modelling also determines the cost components in a fixed way, thus neglecting any possible adaptation in the cost structures when prices change. This leads to an overestimation of price responses that place the results in a short-term or rigid situation, where there is no reaction under cost shocks received by accounts. An argument to counterbalance the weaknesses inherent to overestimation of impacts is that some of the responses are absent in the model because some components are assumed to be exogenous. Third, another limitation caused by linearity is that marginal costs are fixed (constant returns-to-scale) and therefore the SAM model neglects capacity constraints. This means that any change in costs is completely materialised in price changes without the possibility of being transmitted to quantity adaptations.

Knowledge of the nature of cost interactions helps to identify the structural sources of interdependences within and between countries or regions. This kind of information has an undeniable policy significance, since it may be useful for monitoring prices within the economy, defining trade policy or determining welfare impacts in inter-related open economies.

Finally, the present paper opens up new areas for future research. The database used has a simple structure in the institutional part of the two countries (regions). Further research, beyond the scope of this paper, would consist in improving the information on households and the government for both economies. Moreover, the use of an alternative structure to the linear definition, in line with Guerra and Sancho (2014), would allow the model's extension with non-linearities able to offer differentiated measures of price effects and volume effects. Additionally, a general-equilibrium framework able to capture the links between quantities (production) and prices (cost functions) would give the option to simultaneously reflect the sphere of production and consumption decisions. Although all these aspects cannot be analysed with the SAM framework, the present analysis does have some important advantages. In particular, the proposed inter-regional decomposition of price effects has clear potential for identifying the structural interdependence of prices among different economic units.

Acknowledgements

The author gratefully acknowledges the financial support of the Spanish Ministry of Economy and Competitiveness and the European Regional Development Fund (grant ECO2016-75204-P AEI/FEDER, UE) and the Rovira i Virgili University (grant PFR2019). I am indebted to three anonymous referees and the editor of the journal for their valuable and constructive comments.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

The author gratefully acknowledges the financial support of the Spanish Ministry of Economy and Competitiveness and the European Regional Development Fund (grant ECO2016-75204-P AEI/FEDER, UE) and the Rovira i Virgili University (grant PFR2019).

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