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An extension of the hypothetical extraction method to determine key regions: backward and forward dependencies

Paz Rico Belda[1*], Francisco G. Morillas-Jurado[2], Bernardí Cabrer-Borrás[1] and Luis Tormo García[1]

*Correspondence: Paz.Rico@uv.es

[1] Departament d'Análisis Econòmica, Facultat d'Economia, Universitat de València, Campus dels Tarongers, s/n, 46022 Valencia, Spain
[2] Departament d'Economia Aplicada, Facultat d'Economia, Universitat de València, Campus dels Tarongers, s/n, 46022 Valencia, Spain

Abstract
The study of the linkages between regions to identify key economic regions generally uses the hypothetical extraction method proposed by Dietzenbacher et al. (Econ Syst Res 5(2):185–206, 1993). This approach assumes a partial hypothetical extraction (PHEM), as it excludes only intermediate input flows. We use an extension of the hypothetical extraction method (Tormo et al. in Econ Syst Res 36(2):292–318, 2024. 10.1080/09535314.2022.2157249), referred to as full extraction (FHEM), as the extraction of a region also affects final demand and value-added flows. In this study, the FHEM is compared with the PHEM, both from a theoretical point of view, based on the decomposition proposed by Rose and Casler (Econ Syst Res 8(1):33–62, 1996), and from an empirical point of view, applying it to Spanish regions. The results show that, in equilibrium, full backward and full forward dependencies are similar and the PHEM does not adequately quantify the relevance of regions since it varies depending on whether they are analysed from the demand or supply side.

Keywords: Interregional input–output model, Hypothetical extraction method, Backward dependence, Forward dependence and EUREGIO

JEL Classification: C67, D57, R15

1 Introduction

Input–output (IO) analysis has a long tradition and has been widely applied in both theoretical and empirical studies, ranging from environmental and disaster impact assessments to analyses of trade shocks, economic crises, and, more recently, the regional effects of Brexit and COVID-19 (Stone 1984; Rose and Miernyk 1989; Suh and Kagawa 2005; Chen et al. 2017; Prades-Illanes and Tello-Casas 2020). This wide range of applications underscores the continued relevance of IO analysis, as noted by Dietzenbacher et al. (2013). Following this approach, the study of the linkages between sectors and/or regions to identify key sectors and/or regions generally uses the hypothetical extraction method (HEM).[1]

Initially, the HEM was applied to sectors in uniregional input–output (IO) tables; Miller and Lahr (2001) distinguished six different cases. The generalization the HEM to several regions was proposed by Dietzenbacher et al. (1993) in multi-regional IO tables, and as Dietzenbacher and Lahr (2013) point out, several extensions of the HEM have been presented over time. Specifically, the regional HEM assumes, hypothetically, the extraction of a region from the productive system, and estimates the effect of this extraction by measuring the difference between the production of the system with and without the extracted region. The production of a region, before and after extraction, can be measured using Leontief model (1951, 1974). The difference reflects the backward dependence. Similarly, using the model of Ghosh (1958, 1968), the forward dependence can be obtained.

The extraction proposed by Dietzenbacher et al. (1993) supposes a partial extraction (PHEM) as it does not eliminate all the transactions that the extracted region has with the other regions, but does so partially, excluding only the transactions of intermediate inputs and ignoring the fact that the extraction of a region must suppose the elimination of the final demand, on the demand side, and of values added, on the supply side. However, by using the classic HEM, which considers variations in both final demand and value-added flows, the contribution made by a region to the economy-wide total output can be estimated (Temurshoev and Oosterhaven 2014) and, thus, the importance of the region recognised.

The main objective of this study is to demonstrate the usefulness of a full extraction method to determine the key regions of an economy by justifying and applying it. We refer to this method as FHEM (Tormo et al. 2024). This methodology excludes the demand for final goods from the extracted region, in addition to intermediate input transactions, and assumes that the extracted region stops generating and inducing primary inputs. This methodology is appropriate for quantifying economic effects in a context where a region or sector is "collapsed".[2] The FHEM can also analyse which countries are most affected by a stoppage of foreign trade between them.

In this study, the FHEM is compared with the PHEM, both from a theoretical point of view, based on the decomposition proposed by Rose and Casler (1996), and from an empirical point of view, applying it to Spanish regions. The decomposition allows us to verify that, in equilibrium, full backward and full forward dependencies are similar. As Altimiras-Martin (2024) points out, the Leontief and Ghosh models provide the same information from different perspectives. The FHEM enables identification of the most economically relevant regions of the Spanish economy, analysing their push and pull effect. In the case of forward dependence, the matrix of value-added flows between

[1] The HEM, initially developed by Strassert (1968) and applied empirically in uniregional models by Schultz (1977), can be considered an alternative to the classical analysis of multipliers.

[2] A clear example occurred in Spain when, after the confinement due to the COVID19 pandemic, the tourism sector collapsed, and its economic activity hibernated. In fact, throughout that period, there were no transactions (flows) of intermediate goods and services and no demand for final goods and services.

regions needs to be calculated. The accounting procedure used to obtain the interregional value-added flows is an additional contribution of this paper.

Following the introduction, the rest of the paper is organised as follows. Section two presents the database and explains the applied methodology. Section three analyses the main results, and the final section presents the conclusions.

2 Data and methodology

2.1 Data

The EUREGIO database, developed by the Tinbergen Institute, is a set of global IO tables with regional and sectoral disaggregation. This database collects the productive structure and trade relations of the WIOD for the period 2000–2010. The table is broken down into 249 administrative regions at the NUTS2 level, from 24 EU countries, 16 non-EU countries, and a block that brings together countries from the rest of the world, making a total of 266 regions. The statistical information is organised into eleven IO tables, one for each year. A simplified version of this database is presented in Table 4 of Appendix A. Thissen et al. (2018) provide an exhaustive description of the characteristics and construction of this database.

To identify the key regions of the Spanish economy, smaller IO tables are built through an aggregation and disaggregation procedure. First, the 14 industries are grouped, then the 4 sectors of final demand, and lastly, the 4 components of value added. Below, the 266 EUREGIO regions are grouped into 21 regions. Of these, 19 regions correspond to Spain,[3] one region includes the rest of the NUTS2 in the EU, and another region covers the rest of the world. The result of this aggregation and disaggregation process is a symmetric IO Table (21×21) (see Table 5 of Appendix C).

There are different algorithms used to estimate the matrix of regional flows of value added. Choosing one or other method depends on the available information for breaking down value added. Among a variety of procedures, the following are of note: (A) The RAS method (Stone and Brown 1962), used when only the aggregate row and column values of the value-added matrix are known; (B) The imputed values estimation method, which is applied when only the aggregated row vector of the value added, and the column vector of production are known (Tormo et al. 2024). (C) The accounting method used when the production and intermediate consumption matrices provide enough information to estimate the value-added flows. This method disaggregates value-added values based on the known structure of production. This study uses the accounting approach, taking into consideration the formulation proposed by the European Parliament (2013) and Eurostat (1995), as outlined in Appendix B.

2.2 Methodology

The methodology used is based on the HEM, which involves the partial or full extraction of a region and determining the effect that this has on the productive activity of the system. The difference in production *with* and *without* the region quantifies its importance,

[3] The 17 Spanish regions and the two autonomous cities of Ceuta and Melilla. This study focuses on the Spanish regions, excluding Ceuta and Melilla, as is common in most studies, given their limited economic and demographic weight. Moreover, Ceuta and Melilla are Spanish enclaves located on the north coast of Africa, outside the Iberian Peninsula.

measured as backward dependence or forward dependence, depending on whether the applied model is the Leontief demand model or the Ghosh supply model, respectively.

2.2.1 HEM: backward dependence

In a regional IO table with N regions, the initial production is determined by the Leontief model:

$$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}.\mathbf{F}.\mathbf{e} = (\mathbf{I} - \mathbf{A})^{-1}.\mathbf{f} = \mathbf{L}.\mathbf{f} \tag{1}$$

Without loss of generality, extraction from Region *1* will be considered. Following Henderson and Searle (1981) and Dietzenbacher et al. (1993), the technical coefficient matrix $\mathbf{A}$ is partitioned, as are the production vectors $\mathbf{x}$, $\mathbf{F}$ is a final demand matrix, $\mathbf{e}$ is a vector of adequate dimension of unitary values and the demand vector $\mathbf{f}$. By definition, $\mathbf{L} = (\mathbf{I} - \mathbf{A})^{-1}$ is he Leontief matrix.

The matrices and vectors in Eq. (1) can be partitioned by obtaining the following relationship[4]:

$$\mathbf{x} = \begin{bmatrix} \mathbf{x}^1 \\ \mathbf{x}^{\mathbf{R}} \end{bmatrix} = \left\{ \begin{bmatrix} \mathbf{I} & 0 \\ 0 & \mathbf{I} \end{bmatrix} - \begin{bmatrix} \mathbf{A}^{11} & \mathbf{A}^{1\mathrm{R}} \\ \mathbf{A}^{\mathrm{R}1} & \mathbf{A}^{\mathrm{RR}} \end{bmatrix} \right\}^{-1} \cdot \begin{bmatrix} \mathbf{F}^{11} & \mathbf{F}^{1\mathrm{R}} \\ \mathbf{F}^{\mathrm{R}1} & \mathbf{F}^{\mathrm{RR}} \end{bmatrix} .\mathbf{e} = \begin{bmatrix} \mathbf{L}^{11} & \mathbf{L}^{1\mathrm{R}} \\ \mathbf{L}^{\mathrm{R}1} & \mathbf{L}^{\mathrm{RR}} \end{bmatrix} \cdot \begin{bmatrix} \mathbf{f}^1 \\ \mathbf{f}^{\mathbf{R}} \end{bmatrix} = \mathbf{L}.\mathbf{f} \tag{2}$$

where the superscripts 11, 1R, R1 and RR refer to the blocks in which they are partitioned to separate the intra-regional and inter-regional flows of Region *1*. And $\mathbf{f}^1$ is the final demand of Region *1* and $\mathbf{f}^{\mathrm{R}} = [f_{i,21}]_{i=2,\ldots,21}$ is the column vector of final demands of the other regions. Using Table 5 in Appendix C, $\mathbf{f}^1$ denotes the sum of the values in row (a), while the elements of $\mathbf{f}^{\mathrm{R}}$ are obtained by adding, row by row, the rest of the values in the rows of the final demand matrix.

When extracting a region, the elements of the row and column corresponding to this region are equal to zero, except for the element of the main diagonal. By extracting Region 1, the resulting technical coefficient matrix $\overline{\mathbf{A}}$.

Using the Leontief model again, the production after extraction, $\overline{\mathbf{x}}^{\mathrm{L}}$, is obtained; For this, two situations are considered with respect to the vector of final demand. In the first situation, the final demand vector is the same as in (2) and this gives:

$$\overline{\mathbf{x}}^{\mathrm{L}} = \left\{ \begin{bmatrix} \mathbf{I} & 0 \\ 0 & \mathbf{I} \end{bmatrix} - \begin{bmatrix} \overline{\mathbf{A}}^{11} & 0 \\ 0 & \overline{\mathbf{A}}^{\mathrm{RR}} \end{bmatrix} \right\}^{-1} \cdot \begin{bmatrix} \mathbf{f}^1 \\ \mathbf{f}^{\mathbf{R}} \end{bmatrix} = \begin{bmatrix} \overline{\mathbf{L}}^{11} & 0 \\ 0 & \overline{\mathbf{L}}^{\mathrm{RR}} \end{bmatrix} \cdot \begin{bmatrix} \mathbf{f}^1 \\ \mathbf{f}^{\mathbf{R}} \end{bmatrix} = \overline{\mathbf{L}}.\mathbf{f} \tag{3}$$

The backward dependence of Region *1* is the difference between the production before and after the extraction and, is obtained by subtracting Eqs. (2) and (3):

$$\mathbf{x} - \overline{\mathbf{x}}^{\mathrm{L}} = \left(\mathbf{L} - \overline{\mathbf{L}}\right).\mathbf{f} \tag{4}$$

Equation (4) corresponds to the PHEM and enables the partial economic effect after the hypothetical extraction of Region *1* to be obtained.

[4] See Herderson and Searle (1981) and Miller and Lahr (2001) for a comprehensive presentation of the operation of partitioned matrices.

In the second situation, the final demand vector is modified. The modification (see Table 5 of Appendix C) consists in making all the values of the column and row of the final demand matrix of Region *1* zero, except the element of the main diagonal. Therefore, the production is obtained through Eq. (5):

$$\overline{\overline{\mathbf{x}}}^{\mathrm{L}} = \begin{bmatrix} \overline{\mathbf{L}}^{11} & 0 \\ 0 & \overline{\mathbf{L}}^{\mathrm{RR}} \end{bmatrix} \cdot \begin{bmatrix} \overline{\mathbf{F}}^{11} & 0 \\ 0 & \overline{\mathbf{F}}^{\mathrm{RR}} \end{bmatrix} .\mathbf{e} = \begin{bmatrix} \overline{\mathbf{L}}^{11} & 0 \\ 0 & \overline{\mathbf{L}}^{\mathrm{RR}} \end{bmatrix} \cdot \begin{bmatrix} \overline{\mathbf{f}}^{1} \\ \overline{\mathbf{f}}^{\mathrm{R}} \end{bmatrix} = \overline{\mathbf{L}}.\overline{\mathbf{f}} \tag{5}$$

The backward dependence with full extraction of Region *1* can be determined by the difference between Eqs. (2) and (5):

$$\mathbf{x} - \overline{\overline{\mathbf{x}}}^{\mathrm{L}} = \mathbf{L}.\mathbf{f} - \overline{\mathbf{L}}.\overline{\mathbf{f}} \tag{6}$$

Finally, the backward dependence can be decomposed using the structural decomposition proposed by Rose and Casler (1996). Given two levels of production, $\mathbf{x}$ and $\overline{\overline{\mathbf{x}}}^{L}$, the variation in production can be decomposed into three components:

$$\mathbf{x} - \overline{\overline{\mathbf{x}}}^{\mathrm{L}} = \left(\mathbf{L} - \overline{\mathbf{L}}\right).\mathbf{f} + \mathbf{L}.\left(\mathbf{f} - \overline{\mathbf{f}}\right) + \left(\mathbf{L} - \overline{\mathbf{L}}\right).\left(\mathbf{f} - \overline{\mathbf{f}}\right) \tag{7}$$

Equation (7) shows that the variation in production, after the extraction of a region, breaks down into three terms. The first term captures the variation in production as interregional flows of intermediate inputs change, interpreted as a partial extraction (PHEM). The second term is a consequence of the variation in final demand, which could be considered as another partial extraction. Finally, the third term collects the interaction between both effects. The decomposition in (7) is very important, and it demonstrates that the proposed method generalises the PHEM.

2.2.2 HEM: forward dependence

Using the Ghosh supply model, the initial production level is determined by the equation:

$$\mathbf{x}' = \mathbf{e}.\mathbf{V}.(\mathbf{I} - \mathbf{B})^{-1} = \mathbf{v}.(\mathbf{I} - \mathbf{B})^{-1} = \mathbf{v}.\mathbf{G} \tag{8}$$

where $\mathbf{x}'$ is the row vector of total output, $\mathbf{v}$ is the row vector of value added,[5] $\mathbf{B}$ is the matrix of distribution coefficients and $\mathbf{G} = (\mathbf{I} - \mathbf{B})^{-1}$ is the Ghosh matrix.

In a similar way to the procedure presented in the backward analysis, the extraction of Region *1* is considered, which in the IO table occupies the first position (see Table 5 of Appendix C). The initial production can be defined as:

$$\mathbf{x}' = \begin{bmatrix} \mathbf{v}^{1} & \mathbf{v}^{\mathrm{R}} \end{bmatrix} . \begin{bmatrix} \mathbf{G}^{11} & \mathbf{G}^{1\mathrm{R}} \\ \mathbf{G}^{\mathrm{R}1} & \mathbf{G}^{\mathrm{RR}} \end{bmatrix} = \mathbf{v}.\mathbf{G} \tag{9}$$

[5] The file vector $\mathbf{v}$ is obtained from: $\mathbf{v} = \mathbf{e}'.\mathrm{V} = \begin{pmatrix} 1 & \dots & 1 \end{pmatrix} . \begin{pmatrix} \mathrm{v}_{11} & \cdots & \mathrm{v}_{1n} \\ \vdots & \ddots & \vdots \\ \mathrm{v}_{c1} & \cdots & \mathrm{v}_{cn} \end{pmatrix}$, where the vector e has been defined previously.

If Region *1* is extracted, all row and column elements of Region *1*, except for the element on the main diagonal, are set equal to zero in matrix **B**.

After extraction, the production level, considering the same vector of value added as in (9), is obtained:

$$\overline{\mathbf{x}}^{G\prime} = \left[\mathbf{v}^1 \mathbf{v}^R\right] . \begin{bmatrix} \overline{\mathbf{G}}^{11} & 0 \\ 0 & \overline{\mathbf{G}}^{RR} \end{bmatrix} = \mathbf{v}.\overline{\mathbf{G}} \tag{10}$$

The forward dependence of Region *1* is the difference between the production levels reached before and after extraction, that is, the subtraction of Eqs. (9) and (10):

$$\mathbf{x}' - \overline{\mathbf{x}}^{G\prime} = \mathbf{v}.\mathbf{G} - \mathbf{v}.\overline{\mathbf{G}} = \mathbf{v}.(\mathbf{G} - \overline{\mathbf{G}}) \tag{11}$$

Equation (11) quantifies the partial forward effect attributable to the inputs. If it is assumed that the extracted region stops generating and inducing value added, this forward effect would be biased. Isolating Region *1* implies that the column vector of value added generated by this region is zero. Likewise, the row vector of imputed value added is also a null vector (see Table 5 of Appendix C). Therefore, when extracting Region *1*, the level of production reached is:

$$\overline{\overline{\mathbf{x}}}^{G\prime} = \left[\overline{\mathbf{v}}^1 \overline{\mathbf{v}}^R\right] . \begin{bmatrix} \overline{\mathbf{G}}^{11} & 0 \\ 0 & \overline{\mathbf{G}}^{RR} \end{bmatrix} = \overline{\mathbf{v}}.\overline{\mathbf{G}} \tag{12}$$

where $\overline{\mathbf{v}}^1$ and $\overline{\mathbf{v}}^R$ are the row vectors of the value added of the extracted region and of the other regions, respectively, modified as indicated.

The forward dependence with full extraction is the difference between Eqs. (9) and (12). Like the backward dependence, the full forward effect can be decomposed into:

$$\mathbf{x}' - \overline{\overline{\mathbf{x}}}^{G\prime} = \mathbf{v}.(\mathbf{G} - \overline{\mathbf{G}}) + (\mathbf{v} - \overline{\mathbf{v}}).\mathbf{G} + (\mathbf{v} - \overline{\mathbf{v}}).(\mathbf{G} - \overline{\mathbf{G}}) \tag{13}$$

The first element of the second term of Eq. (13) shows the change in production due to the partial extraction of the intermediate inputs, while the second element is the consequence of the variation in value added and the third element collects the interaction between both changes.

It should be noted that in an equilibrium situation, when the full extraction of a region is carried out, the results through the Leontief model are similar to those obtained through the Ghosh model (Davar 2011). In other words, the results of the full backward dependence, Eq. (7), will be similar to the results of the full forward dependence, Eq. (13). This would imply the same classification of the key regions from both perspectives, whereas, with Dietzenbacher et al. (1993), the classification varies according to whether it is done on the demand side or on the supply side.

2.2.3 Definition of indicators: backward and forward

Equations (4) and (6) allow the backward, partial and full dependencies, respectively, to be obtained for each region. As indicated by Dietzenbacher et al. (1993), the results obtained are presented in a **D** (NxN)[6] matrix, which is referred to as the *backward extraction matrix.*

The elements of matrix **D**, BE_j^i (i denotes column and j row), measure the backward dependence or pull effect, which includes the decrease in production in affected Region j after extracting Region i. In essence, the backward dependence is calculated as the difference of the production of Region j, before (x_j) and after $\left(\overline{\mathrm{x}}_j^{i,L}\right)$ the extraction of Region i:

$$BE_j^i = \mathrm{x}_j - \overline{\mathrm{x}}_j^{i,L} \tag{14}$$

From the elements of matrix **D**, other indicators are derived that quantify backward dependence from different points of view:

i. Regional dependence. This shows the backward dependence of Region i from the set of regions and is obtained by aggregating all backward dependencies:

$$BE_R^i = \sum_{j \neq i}^{N} BE_j^i = \sum_{j \neq i}^{N} \left(\mathrm{x}_j - \overline{\mathrm{x}}_j^{i,L}\right) \tag{15}$$

ii. Interregional feedback. The element of the main diagonal, BE_i^i, measures the backward dependence of the other regions on Region i.
iii. Overall effect. This is the sum of the regional dependence and the interregional feedback and includes the effect of extracting Region i from the system.[7] This is expressed as:

$$BE_T^i = BE_i^i + BE_R^i \tag{16}$$

All these indicators are expressed in absolute terms. As suggested by Dietzenbacher et al. (1993), these can be calculated in relative terms, considering the production level of the region that is extracted.

The empirical results of the Ghosh supply model are presented in the matrix **S** (NxN), which is referred to as the *forward extraction matrix*.[8] As with the backward dependence, different forward indicators can be obtained from the elements of matrix **S**: (i) regional dependence; (ii) interregional feedback; and (iii) total dependence. Analogous to backward dependence, the forward analysis in monetary units can be complemented in relative terms.

3 Empirical results: dependence between Spanish regions

This section analyses the backward and forward dependencies of the Spanish regions, comparing the results obtained from the PHEM and the FHEM. Equations (4) and (6) are used to calculate the partial and full backward dependencies, respectively, while

[6] In this case it is a matrix of 21 × 21 regions. The extracted regions appear in columns and the affected regions appear in rows.

[7] The sum of the elements of each column of matrix **D** gives the total backward dependence of the extracted region.

[8] Matrix **S** is analogous to matrix **D**. Therefore, the sum of the elements of each column of matrix **S** gives the total forward dependence.

Table 1 Backward dependencies

Name	Acronym	Output		Partial extraction				Full extraction			
				BE_R		IF		BE_R		IF	
Andalusia	AND	*4*	174,264	*11*	19,501	*7*	30,464	*10*	45,944	*6*	61,044
Aragon	ARA	*10*	86,243	*8*	25,053	*9*	25,828	*11*	35,480	*9*	44,389
Asturias	AST	*13*	57,854	*15*	15,164	*14*	13,971	*15*	22,888	*14*	24,295
Balearic Islands	BAL	*12*	59,485	*12*	17,778	*15*	13,179	*13*	28,303	*12*	27,774
Canary Islands	CAN	*9*	91,179	*10*	21,861	*11*	17,461	*12*	31,503	*11*	40,517
Cantabria	CNT	*16*	31,306	*16*	10,677	*16*	8,858	*16*	16,062	*16*	15,470
Castile and Leon	CYL	*7*	139,444	*5*	37,481	*6*	30,688	*8*	51,724	*7*	54,859
Castile-La Mancha	CYM	*8*	95,464	*6*	35,653	*10*	25,487	*7*	52,268	*8*	45,300
Catalonia	CAT	*2*	230,718	*13*	17,573	*3*	60,693	*6*	55,044	*3*	95,066
Valencian Community	CV	*3*	225,112	*2*	54,967	*2*	63,789	*2*	86,715	*2*	97,450
Extremadura	EXT	*15*	42,898	*9*	22,426	*13*	14,066	*4*	57,172	*15*	22,606
Galicia	GAL	*6*	149,739	*7*	33,919	*5*	37,576	*9*	47,257	*5*	62,291
Community of Madrid	MAD	*1*	378,191	*1*	95,981	*1*	139,762	*1*	118,995	*1*	201,775
Region of Murcia	MUR	*11*	79,944	*3*	43,845	*8*	29,477	*3*	81,808	*10*	44,135
Navarre	NAV	*14*	46,742	*14*	16,650	*12*	15,098	*14*	23,823	*13*	24,863
The Basque Country	PV	*5*	172,691	*4*	43,347	*4*	55,444	*5*	55,572	*4*	83,628
Rioja	RIO	*17*	18,906	*17*	9,773	*17*	6,814	*17*	13,023	*17*	10,849

Year 2009 (millions of euros)

Source: Compiled by the authors and INE

The column with the numbers in italics refers to the ranking of each region

BE_R Regional backward effect, *IF* Interregional feedback

Eqs. (11) and (13) enable calculation of the full and partial forward dependencies, respectively.[9]

Before proceeding with the analysis, it is useful to provide a brief overview of the Spanish regions. The regions differ significantly in terms of economic specialization. In general terms, the Community of Madrid and Catalonia are the largest economies, characterized by highly diversified and service-oriented structures. The Basque Country and Navarre stand out for their advanced manufacturing and high income levels. The Valencian Community combines a strong tourism sector with a significant industrial base (particularly ceramics, textiles, and automotive). Andalusia, and the Canary and Balearic Islands are strongly associated with tourism. Castile and Leon, Castile-La Mancha, La Rioja, and Extremadura remain predominantly agricultural, with increasing development in renewable energy, while Aragon, although still marked by agriculture, has a notable manufacturing presence, particularly in automotive. The Region of Murcia is intensive in agriculture, with a growing industrial and logistics sector. Galicia, Cantabria and Asturias maintain important industrial and maritime activities.

[9] To obtain the different effects, different *ad-hoc* scripts have been programmed in the R Core Team Software (2020).

3.1 Empirical results: backward dependence

Table 1 shows the partial and full backward dependencies for the year 2009,[10] and the ranking that corresponds to each of the regions according to their production, their regional backward effect and their interregional feedback. As seen in Eq. (7), the difference between the results of the two extractions is the pull effect of the final demand.[11] This difference depends on the relevance of the final demand of Region *i* in Region *j*, and helps to explain why not all regions are affected equally. For example, in Andalusia the total partial and full backward dependencies[12] amount to 49,965 and 106,988 million euros, respectively. This means that the dependence on the final demand from the other regions is 57,023 million euros. Thus, 46.7% of the backward full dependence is due to the input component and the remaining 53.3% to the final demand component and the interaction effect. Therefore, the backward full dependence is 2.1 times greater than the partial one. However, in the Community of Madrid the dependence on the demand for final goods is much lower, accounting for a weight of 26.5% of the full dependence, so the latter represents only 1.2 times that of partial dependence. On average, the dependence of full extraction is about 1.6 times greater than that obtained with partial extraction, which means that the dependence of the inputs is 59.02% that of full extraction. Therefore, given the notable difference in the results, this leads to different conclusions when quantifying the backward dependence of a region by full or partial extraction.

With respect to ranking of the regions, it is interesting to highlight the result obtained for some regions, such as Catalonia, Extremadura, and Region of Murcia. Catalonia is the second region of importance in terms of production. The PHEM places Catalonia in thirteenth position, but the FHEM places it in sixth position, which indicates that Catalonia's dependence on final demand from other regions is significant. Regarding the ranking of the interregional feedback effect, which measures the dependence of the other regions on Catalonia, the Catalan region presents a position in line with its size. Similarly, the position of Extremadura in the regional backward dependence ranking is very different in the two procedures. While the PHEM places it in ninth place, the FHEM places it in fourth, so Extremadura's dependence on final demand from other regions is high. Regarding the interregional feedback effect, Extremadura goes from thirteenth position, with the first procedure, to fifteenth, with the second, which indicates that the dependence of the other regions on the final demand of Extremadura is not very relevant. The Region of Murcia, given its size, has a high regional pull effect, ranking third with both procedures.

[10] The PHEM and FHEM methods have been applied to the eleven years of the 2000–2010 period, which is collected by the EUREGIO database, using both the Leontief model and the Ghosh model. However, for clarity of presentation, it was decided to show the comparison for just one year, and the last year was discarded since, as Prades-Illanes and Tello-Casas (2020) point out for Catalonia and Andalusia, the commercial relations, both with the outside world and with other regions of Spain, seem to be underestimated. This does not seem to occur, or to be so evident, for the year 2009, so the comparison was carried out using this year.

[11] Specifically, it has been found that the full backward dependence breaks down into the variation in production due to changes in inputs (partial extraction), the variation in production due to changes in the demand for final goods, and an interaction term between both. Therefore, the difference between the full dependence and the partial dependence includes the variation in production due to final demand itself and the interaction term.

[12] The total backward dependence is the sum of the regional BE_R and the interregional feedback IF, so, in each of the extractions, this is the sum of the two columns. In Table 1, (19,501 + 30,464 = 49,965) and (45,944 + 61,044 = 106,988), respectively.

Table 2 Backward dependencies, full extraction

Affected region	Extracted region								
	AND	**ARA**	**AST**	**BAL**	**CAN**	**CNT**	**CYL**	**CYM**	**CAT**
AND	**49,763**	1,516	1,107	1,395	1,735	0,740	2,186	2,069	3,117
ARA	1,950	**38,001**	0,945	1,225	1,191	0,548	2,065	2,152	2,444
AST	0,823	0,646	**21,084**	0,528	0,593	0,389	1,143	0,934	1,470
BAL	2,120	1,087	0,288	**22,719**	0,684	0,323	0,678	0,982	1,814
CAN	1,521	1,340	0,781	1,204	**34,273**	0,632	1,316	1,489	2,246
CNT	0,504	0,364	0,289	0,247	0,259	**13,485**	0,683	0,588	0,896
CYL	1,913	1,462	0,985	1,158	1,656	0,710	**45,518**	2,054	2,645
CYM	1,707	1,304	0,683	0,865	1,061	0,560	1,760	**36,747**	2,323
CAT	2,966	2,568	1,422	2,329	2,197	0,888	3,136	3,057	**74,826**
CV	4,347	3,609	1,937	2,424	2,743	1,307	4,826	4,615	5,240
EXT	1,552	1,099	0,974	0,467	0,516	0,343	2,002	2,115	1,511
GAL	2,081	1,731	1,060	1,248	1,622	0,718	2,516	2,315	3,265
MAD	10,099	6,727	4,719	4,972	7,067	2,893	11,274	10,566	10,605
MUR	2,841	2,280	0,842	1,863	1,877	0,683	3,127	3,470	3,608
NAV	0,967	0,765	0,455	0,600	0,488	0,316	1,056	0,996	1,311
PV	4,266	2,661	1,554	1,882	2,137	1,117	4,448	3,516	4,249
RIO	0,403	0,426	0,150	0,208	0,165	0,167	0,473	0,444	0,604
Ceuta	0,393	0,008	0,010	0,024	0,015	0,009	0,009	0,013	0,060
Melilla	0,011	0,026	0,101	0,030	0,017	0,049	0,013	0,046	0,142
Rest of NUTS UE	32,304	18,794	11,311	9,214	14,347	7,004	21,981	16,030	41,558
Rest of the world	14,068	9,145	6,855	4,691	7,057	3,893	12,398	8,696	21,769
Output	149,287	72,339	47,974	48,792	77,501	25,878	117,066	76,726	193,852
National BE	40,465	29,617	18,303	22,669	26,022	12,391	42,710	41,420	47,547
Exterior BE	46,372	27,939	18,166	13,904	21,404	10,897	34,379	24,726	63,327
Interregional feedback	49,763	38,001	21,084	22,719	34,273	13,485	45,518	36,747	74,826

Affected region	Extracted region							
	CV	**EXT**	**GAL**	**MAD**	**MUR**	**NAV**	**PV**	**RIO**
AND	3,694	1,717	2,011	5,927	2,521	0,982	2,382	0,363
ARA	4,204	1,611	1,781	6,912	2,667	1,065	1,995	0,713
AST	2,044	0,933	0,810	3,723	1,511	0,463	1,143	0,338
BAL	2,325	1,143	0,830	3,243	1,907	0,475	1,031	0,268
CAN	3,539	1,183	2,291	4,569	2,063	0,854	2,096	0,320
CNT	1,385	0,908	0,394	2,822	1,422	0,283	0,754	0,265
CYL	3,772	1,390	1,904	6,946	1,944	0,982	2,409	0,625
CYM	3,694	1,735	1,423	7,335	2,736	0,795	1,834	0,485
CAT	5,162	2,479	3,047	9,416	3,612	1,307	3,636	0,519
CV	**84,319**	2,292	4,138	14,427	4,316	1,968	5,331	0,983
EXT	2,406	**22,243**	1,685	3,658	2,150	0,442	0,934	0,381
GAL	4,583	1,444	**50,264**	8,916	2,524	1,087	2,814	0,601
MAD	17,122	5,167	10,906	**156,738**	8,388	4,123	14,124	1,774
MUR	6,489	1,872	2,941	6,954	**42,151**	1,012	2,406	0,530
NAV	2,187	1,137	0,804	3,967	1,792	**20,893**	1,494	0,562
PV	6,377	2,095	3,706	11,355	3,236	2,130	**68,228**	0,951
RIO	0,993	0,691	0,281	1,856	0,998	0,409	0,743	**9,112**
Ceuta	0,041	0,141	0,008	0,091	0,161	0,009	0,013	0,027
Melilla	0,038	0,155	0,022	0,187	0,038	0,014	0,021	0,027
Rest of NUTS UE	38,559	20,677	25,734	75,175	29,184	9,838	29,053	4,189

Table 2 (continued)

Affected region	Extracted region							
	CV	**EXT**	**GAL**	**MAD**	**MUR**	**NAV**	**PV**	**RIO**
Rest of the world	20,747	11,228	13,770	38,942	15,450	5,206	17,119	2,377
Output	189,324	33,696	123,078	316,971	62,824	38,133	142,219	15,426
National BE	70,055	28,092	38,984	102,304	43,985	18,401	45,160	9,733
Exterior BE	59,307	31,905	39,504	114,117	44,634	15,044	46,172	6,566
Interregional feedback	84,319	22,243	50,264	156,738	42,151	20,893	68,228	9,112

Average values for the period 2000–2010 (millions of euros)

Source: Compiled by the authors

BE Backward effect

Tables 2 and 6 of Appendix C show the mean values of the backward dependence with full extraction, in both absolute and relative terms. As seen in Table 2, the larger regions present higher backward dependence. However, in relative terms, the dependence of the smaller regions (Rioja, Cantabria and Extremadura) exceeds that of the larger regions (see Table 6). These results corroborate those obtained by Dietzenbacher et al. (1993) in their analysis of EU countries. Nonetheless, the Region of Murcia can be considered an exception since, as mentioned before, given its size, it presents a high backward dependence in both absolute and relative terms.

As Pérez et al. (2009) point out, small regions with a high degree of trade openness are characterised by high dependence, that is, a high relative pull capacity, while large regions with a high self-sufficiency capacity have a high dependence or pull capacity in absolute terms, but a low one in relative terms. As an example, the pull effect from La Rioja to Community of Madrid is 1,774 million euros and the pull effect from Community of Madrid to La Rioja is 1,856 million euros. In absolute terms, the difference is 82 million euros, but if analysed in relative terms, the backward dependence of Community of Madrid is 0.6%, while that of La Rioja is 11.5% (Table 6). Regarding the interregional feedback effect, the data show that it is low, in relative terms, in line with the results of Llano (2009). The Community of Madrid is the region with the highest interregional feedback, followed by the Valencian Community, the Basque Country and Catalonia. La Rioja and Cantabria present a reduced feedback effect, which highlights the low dependence of the other regions on them.

Table 6 shows that the Community of Madrid is highly dependent so, in relative terms, the pull effect that Community of Madrid generates is less than the pull effect it experiences.

In conclusion, the Community of Madrid is the most relevant region given its high pull capacity, in absolute terms. However, it is also the region upon which other regions are most dependent, as indicated by the high interregional feedback. The Community of Madrid is followed in importance, according to its pull capacity, by the Valencian Community, Catalonia, and the Basque Country.

3.2 Empirical results: forward dependence

Table 3 shows the partial and full forward dependencies for the year 2009. The difference between them reflects the push effect of value-added flows,[13] as has been observed

[13] Specifically, the difference reflects the push effect of value-added flows, strictly speaking, and the interaction effect between the variation of intermediate inputs and that of value added.

Table 3 Forward dependencies

	Output		Partial extraction				Full extraction			
			FER		IF		FER		IF	
AND	*4*	17,4264	*5*	31,952	*11*	21,379	*10*	46,572	*6*	61,044
ARA	*10*	86,243	*8*	22,702	*8*	33,227	*11*	35,889	*9*	44,389
AST	*13*	57,854	*14*	10,951	*12*	21,056	*15*	23,273	*14*	24,295
BAL	*12*	59,485	*15*	10,839	*14*	19,348	*13*	28,677	*12*	27,774
CAN	*9*	91,179	*13*	12,808	*10*	26,776	*12*	31,992	*11*	40,517
CNT	*16*	31,306	*16*	7,931	*16*	11,884	*16*	16,218	*16*	15,470
CYL	*7*	139,444	*9*	22,516	*5*	49,831	*8*	52,286	*7*	54,859
CYM	*8*	95,464	*10*	21,709	*7*	37,574	*7*	52,748	*8*	45,300
CAT	*2*	230,718	*2*	67,294	*9*	28,712	*6*	55,579	*3*	95,066
CV	*3*	225,112	*3*	53,816	*2*	73,182	*2*	87,142	*2*	97,450
EXT	*15*	42,898	*11*	16,095	*13*	20,220	*5*	56,789	*15*	22,606
GAL	*6*	149,739	*7*	27,545	*4*	53,880	*9*	48,049	*5*	62,291
MAD	*1*	378,191	*1*	140,696	*1*	133,133	*1*	119,064	*1*	201,775
MUR	*11*	79,944	*6*	31,704	*6*	40,761	*3*	81,259	*10*	44,135
NAV	*14*	46,742	*12*	13,735	*15*	18,948	*14*	24,036	*13*	24,863
PV	*5*	172,691	*4*	45,016	*3*	67,255	*4*	56,857	*4*	83,628
RIO	*17*	18,906	*17*	7,661	*17*	8,248	*17*	12,873	*17*	10,849

Year 2009 (millions of euros)

Source: Compiled by authors and INE

The column with the numbers in italics refers to the ranking of each region

FE_R Regional forward effect, *IF* Interregional feedback

in the decomposition of Eq. (13). The divergence between partial and full extraction depends on the relevance of the value-added flows from Region *i* to Region *j*.

Regarding the ranking, the Community of Madrid is once again in first position in terms of forward dependence, followed by the Valencian Community. Andalusia presents one of the highest changes, dropping from fifth position in the PHEM to tenth in the FHEM. This variation suggests that the value-added flows from Andalusia to other regions are less important than its flows of intermediate input.

When comparing the results of the backward dependencies (Table 1) with the forward dependencies (Table 3), in most regions, the partial forward dependencies are significantly higher than the partial backward dependencies. This indicates that the regions are more dependent on the other regions as buyers of their outputs than on the other regions as sellers of their inputs. Therefore, the push effect is greater than the pull effect. However, the differences in full extraction are smaller than in partial extraction because, in equilibrium, when the extraction of all flows is considered, the full backward and forward dependences are the same. These results are in line with the formulation set out in Miller and Blair (2022) and Altimiras-Martin (2024).

Table 7 shows that, as with backward dependence, the smaller regions demonstrate a smaller forward dependence in absolute terms. On the contrary, the larger regions such as the Community of Madrid, the Valencian Community, Catalonia, and the Basque

Country present the highest push effects. Interestingly, the Region of Murcia exhibits, given its size, high forward dependence. In relative terms (see Table 8), as observed with backward dependence, the highest forward dependence corresponds to the smallest regions. This means that these regions are more dependent on others as buyers of their production.

Table 8 of Appendix C offers a detailed study of the relative forward dependencies for the Community of Madrid. When this region is extracted, it is verified that it maintains a high dependence on the largest regions, such as the Valencian Community and Basque Country, and those closest to it, such as Castile-La Mancha and Castile and Leon. However, when other regions are extracted individually, practically all of them present a greater dependence on the Community of Madrid than the Community of Madrid has on them. The push effect that the Community of Madrid receives from the other regions, in relative terms, is greater than the push effect it generates. Note that the differences between the backward and forward results are, as expected, very small.

4 Conclusion and policy recommendations

The aim of this paper is to justify and apply a method to adequately quantify the relevance of regions, whether analysed from the demand side or the supply side. The proposed method ensures the ranking of the regions remains consistent, regardless of whether they are analysed from the demand or supply perspective. In general, applying this method requires first estimating the matrix of interregional value-added flows using the accounting procedure, which is an additional contribution of this paper.

This study compares, theoretically and empirically, the regional PHEM, formulated by Dietzenbacher et al. (1993), with the FHEM proposed by Tormo et al. (2024), using both the supply model and the demand model.

The difference between the two methods lies in the flows that they consider. Thus, in the Leontief model, the PHEM assumes that the extracted region does not generate demand for intermediate inputs, while the FHEM assumes that the isolated region does not generate transactions in either intermediate inputs or final demand. The reasoning is similar in the Ghosh model, where the PHEM only assumes that the extracted region does not offer intermediate inputs, while the FHEM assumes that the extracted region neither generates nor induces value added.

To determine regions key is common to use backward and forward dependencies. This paper stablishes that the FHEM fully quantifies these dependencies. Moreover, this paper shows that full extraction can be broken down into three terms. Particularly, the first term corresponds to partial extraction, which, on the demand side, is the effect derived from intermediate inputs. The second term covers the effect caused by the extraction of the final demand, and the third term reflects the interaction between the two previous effects. On the supply side, the full dependence decomposition is similar, with three terms: the first corresponds to the partial extraction, due to the intermediate inputs; the second captures the effect of the variation in value added; and the third component summarises the interaction between these two effects. This decomposition makes it possible to quantify the deviation of partial extraction with respect to full extraction, which depends on the productive structure of each region.

Table 4 EUREGIO IO matrix

	R_1 $\mathbf{S}_1 - \mathbf{S}_{14}$	(R_j) $\mathbf{S}_1 - \mathbf{S}_{14}$	R_{266} $\mathbf{S}_1 - \mathbf{S}_{14}$	R_1 $\mathbf{F}_1 - \mathbf{F}_4$	(R_j) $\mathbf{F}_1 - \mathbf{F}_4$	R_{266} $\mathbf{F}_1 - \mathbf{F}_4$	$\mathbf{x}$
R_1 $\mathbf{S}_1 - \mathbf{S}_{14}$							
(R_i) $\mathbf{S}_1 - \mathbf{S}_{14}$		z_{ij}^{hk}			f_{ij}^{hm}		x_i^h
R_{266} $\mathbf{S}_1 - \mathbf{S}_{14}$							
$\mathbf{VA}_1$ | $\mathbf{VA}_4$		$\mathrm{v}_{i/j}(c)$					
$\mathbf{x}'$		x_j^k					

The results show that full backward and forward dependencies, in equilibrium, are very similar. These findings are in line with the formulation set out in Miller and Blair (2022) and Altimiras-Martin (2024) suggesting that the ranking of regions remains the same whether the analysis is conducted from the demand or supply side. This consistency supports the goodness of the FHEM.

To quantify the differences between FHEM and PHEM in a real case, we conducted an empirical analysis using the global IO tables from EUREGIO.

The study verifies that the weight of partial extraction over full extraction varies depending on the productive structure of each region. The results obtained with FHEM are more coherent than those with PHEM. Therefore, ignoring the effect of the final demand or value added could lead to errors when quantifying the dependence and importance of regions. Full extraction, from both the demand and the supply side, identifies the key regions, as both approaches produce similar results.

In summary, the FHEM proposed and used in this paper enables a rigorous and precise study of interregional dependencies. In its application to the Spanish regions, the results confirm that the PHEM underestimates interregional dependencies.

This methodology is useful for identifying which region or country would be most adversely affected by the cessation of bilateral trade. The cessation of trade between two regions would not only "eliminate" intermediate inputs but also the final demand and value added that are generated and induced.

Beyond the methodological contribution, the results also have clear policy implications. The FHEM provides policymakers with a more precise identification of key regions within Spain's interregional economic structure. In particular, the Community of Madrid, Catalonia, the Valencian Community, and the Basque Country emerge as key drivers of national production, while smaller regions such as La Rioja and Extremadura show a high degree of relative dependence, making them more vulnerable to external shocks. This knowledge can guide the allocation of structural funds, the design of regional development strategies, and the promotion of sectoral diversification. Moreover, ignoring these dependencies could lead to misallocation of resources, reinforcing regional disparities instead of reducing them. Although the empirical application focuses on Spain, the FHEM can be extended to other countries, providing policymakers a rigorous tool to improve regional cohesion and respond to future shocks.

Appendix A: EUREGIO IO table

As indicated, EUREGIO is a regional symmetric IO table with regional and sectoral breakdown that consists of (Table 4):

(a) A matrix of intermediate goods or inputs: **Z**
(b) A matrix of final goods: **F**
(c) A column vector of total productions:**x**
(d) A matrix of value added: **VA**

The subscripts refer to the region (R) of origin (*i*) and the region of destination (*j*) and the superscripts to the production sector (**S**) that delivers/sells (*h*) and the production sector that uses/buys (*k*).

h: Production sector[14] [$h=1, 2, \ldots, 14$].
k: User sector [$k=1, 2, \ldots, 14$].
i: Region of production sector [$i=1, 2, 3, \ldots, 266$] region of origin.
j: Region of user sector [$j=1, 2, 3, \ldots, 266$ or region of destination.

z_{ij}^{hk} Goods produced by sector *h* of Region *i* that are used as inputs in sector *k* of Region *j*

f_{ij}^{hm} Final goods produced by sector *h* of Region *i* that are purchased by final sector *m* of Region *j*, *m* being the sectors of final demand: [$m=1, 2, 3, 4$]

1. Private expenditure
2. Public expenditure
3. Gross fixed capital formation
4. Change in stocks

$v_{i/j}(c)$ Value added generated in the production sector of good k of Region j, with c being the different components of value added: [$c=1, 2, 3, 4$]:

1. Wages
2. Gross production surplus
3. Taxes and subsidies on products
4. Trade margin

x_i^h Total production of the sector producing the good h in Regioni

[14] Identified as sector producing the good.

Such that:

(1) $\mathbf{Z} = \left[z_{ij}^{hk}(c)\right]$ the square matrix [(266×14)(266×14)] of inputs. Where z_{ij}^{hk} is the value of the inputs that sector h of Region i delivers to sector k of Region j.
(2) $\mathbf{F} = \left[f_{ij}^{hm}\right]$ the matrix [(266×14)×4] of final demand. Where f_{ij}^{hm} is the value of the goods that sector h of Region i delivers to the final sector m of Region j.
(3) $\mathbf{VA} = \left[v_{i//j}(c)\right]$ the matrix [4× (266×14)] of the value added of sector k of Region j. Where c is the value added component.
(4) $\mathbf{x} = \left[x_i^h\right]$ the column vector [(266×14)×1] of the total production of sector h of Region i.
(5) $\mathbf{x}' = \left[x_j^k\right]$ the row vector [1× (266×14)] of the total production of sector k of Region j.

Appendix B: Estimation of the matrix of value-added flows through the accounting procedure

The process of disaggregating the row vector of values added in the matrix of interregional flows of values added is obtained through an accounting procedure. Specifically, the value added can be obtained as the difference between the production matrix and the intermediate consumption matrix (Eurostat 1995 and European Parliament 2013).

In the regional economy, the intermediate consumption flow matrix,**Z**, and the demand flow matrix for final goods, **F,** provide the production matrix. From the element-by-element sum of both matrices, the square matrix of interregional production can be obtained, which we call **X**, such that **Z** + **F** =**X,** or in scalar form: $[z_{i,j}] + [f_{i,j}] = [x_{i,j}]$.

Once the square matrix of interregional production is obtained, **X,** the matrix of interregional value-added flows can be calculated, **V**, through the following relation: $\mathbf{V} = \mathbf{X}' - \mathbf{Z}$, or in scalar form: $\left[z_{i,j}\right] + \left[v_j^i\right] = [x_{j,i}]$

The schematic representation of the system in table form is:

$\mathbf{Z} = [z_{i,j}]$	+	$\mathbf{F} = [f_{i,j}]$	=	$\mathbf{X} = [x_{i,j}]$
+				
$\mathbf{V} = [v_j^i]$				
=				
$\mathbf{X}' = [x_{j,i}]$				

Note: $\mathbf{Z} = [z_{i,j}]$ is an inputs matrix (21x21)
$\mathbf{F} = [f_{i,j}]$ is a final demand matrix (21x21)
$\mathbf{V} = [v_j^i]$ is a value-added flows matrix (21x21).
$\mathbf{X} = [x_{i.j}]$ is a total production matrix (21x21).

Appendix C: Additional tables and figures

See Tables 5, 6, 7 and 8.

Table 5 IO matrix of 21 regions (units: billons of euros)

			Intermediate input matrix **Z**			Final demand matrix **F**			Production matrix **X**		
			(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
			R_1	(R_j)	R_{21}	R_1	(R_j)	R_{21}	R_1	(R_j)	R_{21}
Intermediate input matrix **Z**	(a)	R_1	$z_{1,1}$	$z_{1,j}$	$z_{1,21}$	$f_{1,1}$	$f_{1,j}$	$f_{1,21}$	$x_{1,1}$	$x_{1,j}$	$x_{1,21}$
	(b)	(R_i)	$z_{i,1}$	$z_{i,j}$	$z_{i,21}$	$f_{i,1}$	$f_{i,j}$	$f_{i,21}$	$x_{i,1}$	$x_{i,j}$	$x_{i,21}$
	(c)	R_{21}	$z_{21,1}$	$z_{21,j}$	$z_{21,21}$	$f_{1,21}$	$f_{21,1}$	$f_{21,21}$	$x_{21,1}$	$x_{21,j}$	$x_{21,21}$
Value added matrix **V**	(d)	R_1	v_1^1	v_j^1	v_{21}^1						
	(e)	(R_i)	v_1^i	v_j^i	v_{21}^i						
	(f)	R_{21}	v_1^{21}	v_j^{21}	v_{21}^{21}						
Production matrix **X'**	(g)	R_1	$x_{1,1}$	$\dots$	$x_{21,1}$						
	(h)	(R_i)	$\vdots$	$x_{j,i}$	$\vdots$						
	(k)	R_{21}	$x_{1,21}$	$\dots$	$x_{21,21}$						

The shaded cells indicate the elements that correspond to the transactions of Region 1 with the other regions

$\mathbf{Z} = [z_{i,j}]$ is an inputs matrix (21×21)

$\mathbf{F} = [f_{i,j}]$ is a final demand matrix $(21 \times 21)$$\mathbf{f} = [f_i] = \left[\sum_j f_{i,j}\right]$ is a vector of total final demand (21×1)

$\mathbf{V} = [v_j^i]$ is a value-added flows matrix (21×21).$\mathbf{v} = [v_j] = \left[\sum_i v_j^i\right]$ is a vector of total value added (1×21)

$\mathbf{X} = [x_{i,j}]$ is a matrix production $(21 \times 1)$$\mathbf{x} = [x_i] = \left[\sum_j x_{i,j}\right]$ is a vector of total production (21×1)

Source: Compiled by the authors

Table 6 Backward dependencies, full extraction

Affected region	Extracted region								
	AND	ARA	AST	BAL	CAN	CNT	CYL	CYM	CAT
AND	**3.2**	2.1	2.3	2.9	2.3	2.9	1.9	2.7	1.6
ARA	1.3	**2.3**	2.0	2.5	1.5	2.1	1.7	2.8	1.2
AST	0.5	0.9	**1.2**	1.1	0.8	1.5	1.0	1.2	0.7
BAL	1.4	1.5	0.6	**1.3**	0.9	1.2	0.6	1.3	0.9
CAN	1.0	1.8	1.7	2.4	**2.1**	2.4	1.1	2.0	1.1
CNT	0.3	0.5	0.6	0.5	0.3	**0.8**	0.6	0.8	0.5
CYL	1.3	2.0	2.1	2.3	2.1	2.7	**2.8**	2.6	1.4
CYM	1.1	1.8	1.4	1.8	1.4	2.2	1.5	**2.2**	1.2
CAT	2.0	3.5	2.9	4.8	2.8	3.3	2.6	3.9	**4.8**
CV	3.0	5.2	4.2	5.2	3.7	5.2	4.3	6.3	2.8
EXT	1.0	1.5	2.1	0.9	0.7	1.3	1.7	2.8	0.8
GAL	1.4	2.4	2.2	2.5	2.0	2.7	2.1	3.0	1.6
MAD	6.7	9.3	9.9	10.1	9.1	11.1	9.6	13.7	5.4
MUR	1.9	3.1	1.8	3.8	2.4	2.6	2.6	4.5	1.8
NAV	0.6	1.1	1.0	1.2	0.6	1.2	0.9	1.3	0.7
PV	2.8	3.6	3.1	3.7	2.6	4.2	3.7	4.4	2.1
RIO	0.3	0.6	0.3	0.4	0.2	0.6	0.4	0.6	0.3
Ceuta	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Melilla	0.0	0.0	0.2	0.1	0.0	0.2	0.0	0.1	0.1
Rest of NUTS UE	21.7	26.2	23.6	19.0	18.5	27.1	18.8	21.0	21.9
Rest of the world	9.3	12.5	14.0	9.4	9.0	14.8	10.4	11.1	11.2
National BE	27.0	41.0	38.4	46.3	33.4	47.7	36.3	53.8	24.3
Exterior BE	31.0	38.7	37.7	28.4	27.5	41.9	29.2	32.0	33.2
Interregional feedback	3.2	2.3	1.2	1.3	2.1	0.8	2.8	2.2	4.8

Affected region	Extracted region							
	CV	EXT	GAL	MAD	MUR	NAV	PV	RIO
AND	1.9	4.8	1.7	1.9	3.8	2.6	1.7	2.4
ARA	2.2	4.5	1.4	2.2	4.0	2.8	1.3	4.6
AST	1.1	2.6	0.7	1.2	2.3	1.2	0.8	2.2
BAL	1.2	3.2	0.7	1.0	2.9	1.3	0.7	1.7
CAN	1.9	3.3	1.9	1.4	3.1	2.2	1.5	2.0
CNT	0.7	2.5	0.3	0.9	2.2	0.7	0.5	1.7
CYL	2.0	3.8	1.5	2.2	2.9	2.6	1.6	4.0
CYM	1.9	4.8	1.2	2.3	4.1	2.1	1.2	3.1
CAT	2.7	6.8	2.4	2.9	5.4	3.3	2.4	3.3
CV	**5.6**	6.7	3.5	4.7	6.8	5.4	3.8	6.6
EXT	1.3	**1.3**	1.4	1.2	3.3	1.2	0.6	2.5
GAL	2.4	4.0	**3.1**	2.8	3.8	2.8	1.9	3.8
MAD	8.9	14.7	8.8	**11.0**	12.8	10.8	9.6	11.5
MUR	3.3	5.3	2.4	2.2	**2.5**	2.6	1.6	3.4
NAV	1.1	3.2	0.6	1.3	2.7	**1.2**	1.0	3.6
PV	3.2	5.8	2.9	3.5	4.8	5.4	**4.2**	6.0
RIO	0.5	1.9	0.2	0.6	1.5	1.1	0.5	**0.5**
Ceuta	0.0	0.4	0.0	0.0	0.3	0.0	0.0	0.2
Melilla	0.0	0.4	0.0	0.1	0.1	0.0	0.0	0.2
Rest of NUTS UE	20.3	61.2	21.0	23.9	46.2	25.9	20.3	27.2
Rest of the world	10.8	32.8	11.0	12.2	24.2	13.4	11.6	15.2
National BE	36.3	78.7	31.7	32.2	66.8	48.1	30.8	62.8
Exterior BE	31.1	94.0	32.1	36.1	70.3	39.4	31.9	42.4
Interregional feedback	5.6	1.3	3.1	11.0	2.5	1.2	4.2	0.5

Average values for the period 2000–2010 (%)
Source: Compiled by the authors

BE Backward effect

Bold values indicate the interregional feedback for each region

Table 7 Forward dependencies, full extraction

Affected region	Extracted region								
	AND	**ARA**	**AST**	**BAL**	**CAN**	**CNT**	**CYL**	**CYM**	**CAT**
AND	**49,763**	1,463	1,078	1,361	1,705	0,717	2,129	2,002	3,013
ARA	1,974	**38,001**	0,960	1,248	1,212	0,555	2,106	2,191	2,440
AST	0,869	0,678	**21,084**	0,555	0,628	0,403	1,207	0,994	1,509
BAL	2,221	1,166	0,336	**22,719**	0,760	0,355	0,792	1,094	1,909
CAN	1,690	1,473	0,862	1,311	**34,273**	0,685	1,510	1,682	2,426
CNT	0,505	0,366	0,293	0,252	0,262	**13,485**	0,685	0,589	0,893
CYL	2,261	1,716	1,150	1,354	1,896	0,808	**45,518**	2,453	3,012
CYM	1,945	1,480	0,797	1,000	1,218	0,627	2,046	**36,747**	2,570
CAT	2,465	2,234	1,216	2,092	1,925	0,749	2,656	2,583	**74,826**
CV	4,451	3,697	1,984	2,500	2,829	1,332	4,984	4,771	5,321
EXT	1,533	1,089	0,972	0,461	0,506	0,337	1,999	2,113	1,460
GAL	2,268	1,872	1,155	1,358	1,750	0,769	2,756	2,546	3,436
MAD	9,784	6,505	4,600	4,822	6,903	2,789	11,031	10,305	10,164
MUR	2,800	2,255	0,831	1,846	1,858	0,670	3,120	3,461	3,528
NAV	0,978	0,775	0,463	0,614	0,500	0,321	1,074	1,009	1,312
PV	4,336	2,711	1,586	1,922	2,196	1,134	4,554	3,599	4,267
RIO	0,411	0,432	0,155	0,213	0,169	0,170	0,480	0,450	0,611
Ceuta	0,398	0,011	0,011	0,026	0,018	0,010	0,014	0,017	0,063
Melilla	0,013	0,027	0,102	0,032	0,019	0,049	0,015	0,047	0,143
Rest of NUTS UE	30,198	17,404	10,393	8,145	13,052	6,407	19,728	13,830	39,054
Rest of the world	13,854	9,022	6,779	4,577	6,913	3,834	12,082	8,360	21,502
Output	149,287	72,339	47,974	48,792	77,501	25,878	117,066	76,726	193,852
National FE	40,903	29,950	18,554	22,968	26,355	12,478	43,156	41,908	48,077
Exterior FE	44,052	26,426	17,172	12,722	19,965	10,241	31,810	22,190	60,557
Interregional feedback	49,763	38,001	21,084	22,719	34,273	13,485	45,518	36,747	74,826

Affected region	Extracted region							
	CV	**EXT**	**GAL**	**MAD**	**MUR**	**NAV**	**PV**	**RIO**
AND	3,557	1,655	1,951	5,654	2,413	0,950	2,298	0,341
ARA	4,235	1,619	1,819	6,962	2,672	1,075	2,013	0,713
AST	2,115	0,953	0,864	3,798	1,570	0,482	1,200	0,349
BAL	2,501	1,213	0,937	3,470	2,006	0,520	1,155	0,289
CAN	3,852	1,287	2,483	4,843	2,200	0,929	2,310	0,353
CNT	1,381	0,916	0,396	2,867	1,440	0,286	0,761	0,267
CYL	4,351	1,575	2,274	7,549	2,237	1,128	2,787	0,697
CYM	4,098	1,864	1,677	7,829	2,951	0,893	2,087	0,536
CAT	4,338	2,144	2,608	8,154	3,069	1,102	3,139	0,398
CV	**84,319**	2,332	4,278	14,478	4,322	2,004	5,455	0,993
EXT	2,354	**22,243**	1,683	3,555	2,146	0,433	0,914	0,375
GAL	4,898	1,521	**50,264**	9,137	2,653	1,160	3,020	0,632
MAD	16,630	4,955	10,657	**156,738**	8,041	3,968	13,897	1,682
MUR	6,456	1,863	2,923	6,775	**42,151**	0,993	2,373	0,518
NAV	2,202	1,150	0,820	4,016	1,811	**20,893**	1,509	0,564
PV	6,452	2,110	3,808	11,107	3,237	2,158	**68,228**	0,945
RIO	1,004	0,704	0,285	1,921	1,027	0,414	0,755	**9,112**
Ceuta	0,047	0,143	0,013	0,101	0,165	0,010	0,018	0,028
Melilla	0,040	0,157	0,023	0,196	0,040	0,015	0,023	0,027
Rest of NUTS UE	34,919	19,477	23,757	71,009	27,289	8,945	26,867	3,694

Table 7 (continued)

Affected region	Extracted region							
	CV	EXT	GAL	MAD	MUR	NAV	PV	RIO
Rest of the world	20,322	11,107	13,565	38,727	15,271	5,098	16,998	2,302
Output	189,324	33,696	123,078	316,971	62,824	38,133	142,219	15,426
National FE	70,513	28,159	39,498	102,411	44,000	18,519	45,715	9,707
Exterior FE	55,241	30,584	37,321	109,737	42,560	14,043	43,865	5,996
Interregional feedback	84,319	22,243	50,264	156,738	42,151	20,893	68,228	9,112

Average values for the period 2000–2010 (millions of euros)

Source: Compiled by the authors

FE Forward effect

Bold values indicate the interregional feedback for each region

Table 8 Forward dependencies, full extraction

Affected region	Extracted region								
	AND	ARA	AST	BAL	CAN	CNT	CYL	CYM	CAT
AND	**3.2**	2.0	2.3	2.8	2.2	2.8	1.8	2.6	1.6
ARA	1.3	**2.3**	2.0	2.5	1.5	2.1	1.8	2.8	1.2
AST	0.6	0.9	**1.2**	1.1	0.8	1.6	1.0	1.3	0.8
BAL	1.5	1.6	0.7	**1.3**	1.0	1.4	0.7	1.5	1.0
CAN	1.1	2.0	1.8	2.7	**2.1**	2.6	1.3	2.2	1.2
CNT	0.3	0.5	0.6	0.5	0.3	**0.8**	0.6	0.8	0.5
CYL	1.5	2.4	2.4	2.7	2.4	3.1	**2.8**	3.2	1.5
CYM	1.3	2.0	1.7	2.0	1.6	2.4	1.7	**2.2**	1.3
CAT	1.7	3.0	2.5	4.3	2.5	2.8	2.2	3.3	**4.8**
CV	3.1	5.3	4.3	5.3	3.8	5.3	4.4	6.5	2.8
EXT	1.0	1.5	2.1	0.9	0.6	1.3	1.7	2.8	0.7
GAL	1.5	2.6	2.4	2.7	2.2	2.9	2.3	3.3	1.7
MAD	6.5	9.0	9.6	9.8	8.9	10.8	9.4	13.4	5.2
MUR	1.8	3.1	1.7	3.8	2.4	2.6	2.6	4.5	1.8
NAV	0.6	1.1	1.0	1.3	0.6	1.2	0.9	1.3	0.7
PV	2.8	3.6	3.2	3.8	2.7	4.2	3.8	4.5	2.1
RIO	0.3	0.6	0.3	0.4	0.2	0.7	0.4	0.6	0.3
Ceuta	0.3	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Melilla	0.0	0.0	0.2	0.1	0.0	0.2	0.0	0.1	0.1
Rest of NUTS UE	20.2	24.2	21.7	16.7	16.8	24.8	16.9	18.0	20.6
Rest of the world	9.2	12.4	13.9	9.3	8.8	14.7	10.2	10.7	11.1
National FE	27.3	41.4	38.9	46.9	33.9	48.1	36.7	54.4	24.6
Exterior FE	29.4	36.6	35.6	26.0	25.6	39.4	27.1	28.8	31.8
Interregional feedback	3.2	2.3	1.2	1.3	2.1	0.8	2.8	2.2	4.8

Affected region	Extracted region							
	CV	EXT	GAL	MAD	MUR	NAV	PV	RIO
AND	1.9	4.7	1.6	1.8	3.7	2.5	1.6	2.2
ARA	2.2	4.5	1.5	2,2	4.0	2.8	1.4	4.6
AST	1.1	2.6	0.7	1,2	2.4	1.3	0.8	2.3
BAL	1.3	3.4	0.8	1,1	3.0	1.4	0.8	1.9
CAN	2.0	3.6	2.0	1,5	3.3	2.4	1.6	2.3
CNT	0.7	2.5	0.3	0,9	2.2	0.8	0.5	1.7
CYL	2.3	4.3	1.8	2,4	3.4	2.9	1.9	4.5

Table 8 (continued)

Affected region	Extracted region							
	CV	**EXT**	**GAL**	**MAD**	**MUR**	**NAV**	**PV**	**RIO**
CYM	2.1	5.1	1.4	2,5	4.4	2.3	1.4	3.4
CAT	2.2	5.9	2.1	2,5	4.6	2.8	2.1	2.6
CV	**5.6**	6.8	3.6	4,7	6.8	5.4	3.9	6.7
EXT	1.2	**1.3**	1.4	1,1	3.3	1.1	0.6	2.4
GAL	2.5	4.2	**3.1**	2,9	4.0	3.0	2.0	4.0
MAD	8.7	14.1	8.6	**11.0**	12.3	10.4	9.5	10.9
MUR	3.3	5.3	2.4	2.1	**2.5**	2.6	1.6	3.3
NAV	1.1	3.2	0.7	1.3	2.8	**1.2**	1.0	3.6
PV	3.3	5.8	3.0	3.4	4.8	5,5	**4.2**	5.9
RIO	0.5	2.0	0.2	0.6	1.6	1,1	0.5	**0.5**
Ceuta	0,0	0.4	0.0	0.0	0.3	0.0	0.0	0.2
Melilla	0,0	0.4	0.0	0.1	0.1	0.0	0.0	0.2
Rest of NUTS UE	18.4	57.7	19.4	22.6	43.2	23.6	18.8	23.9
Rest of the world	10.6	32.6	10.9	12.2	24.0	13.2	11.6	14.8
National FE	36.6	79.0	32.1	32.3	66.8	48.4	31.2	62.7
Exterior FE	29.0	90.3	30.3	34.7	67.2	36.8	30.4	38.7
Interregional feedback	5.6	1.3	3.1	11.0	2.5	1.2	4.2	0.5

Average values for the period 2000–2010 (%)

Source: Compiled by the authors

FE Forward effect

Bold values indicate the interregional feedback for each region

Author contributions
Luis Tormo García: Conceptualization. Fran Morillas-Jurado: Methodology; Software; Supervision; Validation; Writing-draft; Writing-review and Editing. Paz Rico-Belda: Investigation; Supervision; Validation; Visualization; Writing-draft; Writing-review and Editing. Bernardí Cabrer-Borrás: Conceptualization; Formal analysis; Methodology; Supervision; Writing-review and Editing.

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