CONFERENCE PAPER

Title: **Harmonising Galicia within FIGARO and measuring feedback: Simplifying gravity equations to embed a region within world in input-output models**

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Abstract:

Interest in multiregional input-output (MRIO) models has increased over the past decades since they provide more detailed maps of economic structures than single region models do. Despite been conceived for the study of subnational economies, lack of trade data in this scale has push regions aside MRIO models. During recent years, several multiscale MRIO models, linking the regions of a country with abroad, have been developed. In this paper we make use of the gravity equation to obtain more accurate estimates for the regions-with-abroad trade while lowering information requirements. To illustrate how our proposal works, we present a modest empirical application considering the region of Galicia (NW Spain).

Keywords: input-output, regional economics, trade, gravity model

JEL codes: C67, R15, F17

1. **Introduction**

1.1. Multiregional input-output models: maps for possible new discoveries

Multiregional input-output (MRIO) models have been a notable development over the past decade (Dietzenbacher et al., 2013; Lahr, Dietzenbacher, & Lenzen, 2020). They yield a more detailed mapping of structural relationships among different industries and economies than do single-region models. Miller and Blair (2009, pp. 69–118) explain MRIO foundations and variants. If models can be considered a sort of mapping of reality, then it follows that we should be able to attain better findings as our models better reflect actual human and environmental interaction across space and sectors (our maps become more accurate).

Table 1 schematically describes an MRIO model composed by $o, d = 1, \cdots, g$ regions where the pair of superscripts o, d denote, respectively, the origin and destination of economic transactions. Note, we use "region" to refer to both national and subnational territorial units.

Table 1. Description of a symmetric MRIO model

	1	$\cdots$	*g*	*1*	$\cdots$	*g*	*Sum*
1	$\mathbf{T}^{11}$	$\cdots$	$\mathbf{T}^{1g}$	$\mathbf{F}^{11}$	$\cdots$	$\mathbf{F}^{1g}$	$\mathbf{x}^{1\bullet}$
$\vdots$	$\vdots$	$\ddots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$	$\vdots$
g	$\mathbf{T}^{g1}$	$\cdots$	$\mathbf{T}^{gg}$	$\mathbf{F}^{g1}$	$\cdots$	$\mathbf{F}^{gg}$	$\mathbf{x}^{g\bullet}$
GVA	$\mathbf{W}^{\bullet 1}$	$\cdots$	$\mathbf{W}^{\bullet g}$	$-$	$\cdots$	$-$	$\mathbf{w}^{\bullet\bullet}$
Sum	$\boldsymbol{x}^{\bullet 1}$	$\cdots$	$\mathbf{x}^{\bullet g}$	$\mathbf{f}^{\bullet 1}$	$\cdots$	$\mathbf{f}^{\bullet g}$	

Source: Own elaboration

Each matrix $\mathbf{T}^{od} = \{t_{ij}^{od}\}$ represents commodity shipments $(i = 1, \ldots, m)$ across industries $(j = 1, \ldots n)$ for each of the g regions. Regional direct requirements matrices show shipments among firms in the same region (*o* = *d*). We consider a symmetric model, where $m = n$ with a given region. But we let *m* and *n* vary across the different types of model regions (province, nation, and rest of world). Analogously, matrices $\mathbf{F}^{od} = \{f_{ij}^{od}\}$

represent commodity shipments to final demand across regions and have dimensions $(m \times q)$, $w$here q denotes the number of final demand sectors (e.g., household consumption, government spending, capital investment, etc.), excluding exports. Matrices $\mathbf{W}^{\bullet o} = \{w_{ij}^{\bullet o}\}$ correspond to each region´s the gross value added (GVA) with $(p \times n)$ dimensions, where p stands for the number of GVA components (e.g., compensation of employees, indirect business taxes, property-type income, etc.). Because GVA is not tradeable, only its origin is considered. In addition, vectors $\mathbf{x}^{\bullet d}$, $\mathbf{x}^{o \bullet}$ and $\mathbf{f}^{\bullet d}$ represent gross output, total final use, and sum of final demand components for each region. The symbol • denotes a sum across the specified matrix dimension.

1.2.Global MRIO models: what about regions?

MRIO models were initially conceived by Isard (1951) to account for linkages among subnational units of a single country. His pioneering work on space economy was followed-up by some extended insights and an application by Leontief (1953) and Isard (1953). Not so long afterward, Leontief and Strout (1963) and Polenske (1970) compiled state-level MRIO tables of the United States. But for reasons of the expense of their compilation; the computational difficulty of implementing them; and work by Miller (1983; 1966), which suggested interregional spill-overs and feedback effects tend to be small, the idea of producing MRIO accounts was generally abandoned. This is despite the enthusiasm shown by Leontief (1980) about the MRIO policy implications and an early call by Duchin (1983) to pursue a well-calibrated world MRIO model.

Since the mid-1980s, the computational intractability of large MRIO models has become a non-issue, due largely to the ever-rising, readily-available computational power available to most researchers. Plus, a global market economy has re-emerged (Sachs & Warner, 1995) generating new-found interest in research on the integration of what had been, for nearly a century, largely national markets. Moreover, Brenner (1999) notes that globalisation has both increased territorial heterogeneity within countries and decoupled regional economic performance and national economic performance. This trend seems to have accelerated since the 2008 financial crisis (Monfort, 2020), and the nature of globalisation appears to be getting more regional, at least in an international sense (Xiao, Meng, Ye, & Li, 2020; Zhang, Tian, Li, Jiang, & Yang, 2022). Combined with ready computation, these trends suggest that Miller's (Miller, 1966, 1969) findings may not be as important as they once were. That is, tracing the links across regions and nations is not just a continuation of MRIO original goals, but is, in itself, an inevitable path to follow when trying to understand how the world economy works. That is, perhaps we should be using MRIO models sub-national research as well as international research these days.

Global MRIO (GMRIO) datasets have been increasingly facilitated thanks to the systematization efforts done by international institutions regarding data collection (Eurostat, 2008; Mahajan et al., 2018). Tukker and Dietzenbacher (2013) identify academic and political interest on environmental issues related with international trade as one of the main motivation for GMRIO model production. Nowadays, a cadre of GMRIO models exists, each of which is focused upon different nations, industry detail, and time coverage. See (Huo et al., 2022) for a recent review.

1.3.Linking regions with the World: looking for nonsurvey solutions

Meng et al. (2013) were among the first to link regional and national IO tables. At about the same time, Feng et al. (2013) linked a Chinese intra-national MRIO to a GTAP international MRIO framework. Even more recently, Towa, Zeller, Merciai, Schmidt and Achten (2022) implemented a hybrid approach to generate multiscale MRIO models. None of these efforts, however, has linked survey-based regional information to national and international IO tables. The lack of viable regional IO tables has encouraged scholars and practitioners to come up with clever solutions to ameliorate the usual problem of data scarcity (Lahr, 2018). Our present case is no exception. The literature identifies three main tools that deal with this problem: (i) import/export weights, (ii) gravity models and (iii) RAS techniques. This set of tools is by no means an exhaustive list of all alternative approaches that have been applied, nor are they mutually exclusive; indeed, they are often used in concert with each other.

1.3.1. Import/export weights

Fry et al. (2022) review multiscale MRIO models that have been produced over the last decade. They then introduce it into a GMRIO by extracting the corresponding national data, replacing it with an MRIO that they estimate with techniques applied by Lenzen et al. (2014), who essentially split national accounts into component subnational regional accounts. After that, the authors focus on estimating each subnational region's share of the nation's international trade flows using techniques in Wang, Geschke and Lenzen (2017) and applying import (μ) and export (ξ) weights to generate those shares.

Let a country c in a MRIO such as illustrated in table 1 be divided into $1, \cdots, r$ subnational regions. According to our notation, import and export weights for region r are defined as:

$$\mu_j^{or} = \frac{t_{\bullet j}^{or}}{t_{\bullet j}^{oc}} \quad \forall o \not\subset c \tag{1}$$

$$\xi_i^{rd} = \frac{t_{i\bullet}^{rd}}{t_{i\bullet}^{cd}} \quad \forall d \not\subset c \tag{2}$$

Numerators $t_{\bullet j}^{or}$ and $t_{i\bullet}^{rd}$ represent commodity j (i) imports (exports) related to region r from (to) country o (d) situated outside country c. Denominators $t_{\bullet j}^{oc}$ and $t_{i\bullet}^{cd}$ are the corresponding national totals for the regional shipments. While denominators can always be retrieved from the GMRIO to which the region is to be linked, numerators are rarely available with industry and country detail. Supporting information section S1-2 of Fry et al. (2022) provides a way for reducing information requirements. First, they estimate the share of commodity j (i) demanded (supplied) by each region. And second, the share of commodity j (i) shipped from (to) Australian ports is estimated using the inverse of the distance between regions (represented by their geographical centre) and ports—essentially applying a gravity model. Finally, the two ratios are combined to estimate the trade potential, which is subsequently normalised so their shares sum to unity. Applying these shares to total international trade by commodity then yields each region's international flows by commodity:

$$t_{ij}^{or} = \mu_j^{or} t_{ij}^{oc} \quad \forall i \tag{3}$$

$$t_{ij}^{rd} = \xi_i^{rd} t_{ij}^{cd} \quad \forall j \tag{4}$$

While the approach requires little information, it does not exploit some information that ***can*** generally be known—the distance among regions and to countries that trade with the nation.

1.3.2. Gravity models

Gravity models are among the most popular models within social physics (Quetelet, (1835). Reilly (1931) is generally credited with being the first to apply a gravity model, in his case, like ours, to estimate trade flows.[1] In his treatise, he applies Newton´s universal law of gravitation, which states that the force of attraction Φ between two bodies i and j is directly proportional to their masses (m_i and m_j) and inversely proportional to the square of the distance l that separates them. Formally:

$$\Phi_{ij} = k\frac{m_i m_j}{\left(l_{ij}\right)^2} \qquad (5)$$

where k is the so-called gravity constant.

Following Batten and Martellato (1985), Sargento, Nogueira Ramos and Hewings (2012) show how data limitations can affect gravity equations when estimating a country's interregional trade. Haddad (2014) even applied the gravity model to extreme cases of regional data scarcity to simultaneously calculate interregional and intraregional trade flows. But Yamada (2015) appears to be the first to apply gravity equation to produce a multiscale MRIO model. He breaks regional accounts of each Japanese prefecture into those for several metropolitan areas. In so doing, Yamada derives initial estimates for intra-Japan flows are by combining import/export weights with an adapted a generalised version of the gravity model shown in equation (5). Following our own notation, for an area r contained in a prefecture c trading with another area d outside the prefecture:

$$t_{ij}^{rd} = k^{rd}\frac{(t_{i\bullet}^{r\bullet})^{\alpha}\left(t_{\bullet j}^{\bullet d}\right)^{\beta}}{(l^{rd})^{\gamma}} \quad \begin{matrix} \forall i = j \\ \forall d \not\subset c \end{matrix} \qquad (6)$$

where $t_{i\bullet}^{r\bullet}$ stands for total supply of commodity $i = j$ shipped from r, $t_{\bullet j}^{\bullet d}$ stands for total demand of commodity $i = j$ by region d and l^{rd} is an employment-weighed distance[2] measure between regions. No off-diagonal t_{ij} are calculated. Taking the logarithm of both

[1] Batten and Boyce (1986) provide a comprehensive literature review on estimating trade flows.

[2] See footnote 8 in Yamada (2015, p. 17) for greater detail.

sides in equation (6), parameters α, β, γ are estimated by regression using the 2005 survey-based Japanese MRIO model elaborated by the ministry of economy, trade and industry (METI, 2010) as sample. More recent research, e.g., Zheng et al. (2019), continues to follow a similar path.

Gravity models are one way to estimate trade flows when information on freight shipments by transportation modes are minimally available (if at all) and distance is an important consideration (i.e., a nation is sufficiently large, e.g., say, at least larger than Lichtenstein). They can use aggregate (and thus more accessible) import/export data and data on the value/weight ratio of a commodity. Most importantly, they use distance (or travel time) between regions to explain trade flows, just as freight providers do when allocating shipping costs to their customers. Unfortunately, precise gravity model parameters (α, β, γ) cannot be established readily a priori (Lahr, Ferreira, & Többen, 2020). But use of posteriori calculations from other survey-based models can be a legitimate alternative for obtaining reasonable estimates of these parameters. Still, there is no way of assuring that interregional trade flows estimated in this way will be close to actual ones, unless some of the trade flows are truly known. Furthermore, this way of proceeding is undoubtedly weaker from an epistemologically perspective than are aprioristic alternatives (Fernández Liria, 2004).

1.3.3. RAS techniques

Both import/export weights and gravity models are often combined with RAS balancing (Bacharach, 1970; Stone & Brown, 1962).[3] More recent developments inform how model builders can handle negative numbers (Günlük-Şenesen & Bates, 1988; Junius & Oosterhaven, 2003), make use of known interior constraints (Gilchrist & St. Louis, 1999; Valderas Jaramillo & Rueda-Cantuche, 2021) and problems of conflicting information (Lenzen, Gallego, & Wood, 2009). Temursho, Oosterhaven and Cardenete (2020) apply these developments when balancing an MRIO model.

Three goals justify the use of RAS when building a MRIO model. First, RAS is a straightforward way to assure interregional accounts respect “known” data (e.g., regional

[3] Lahr and De Mesnard (2004) offer a clear overview on the matter.

gross output). Second, it ensures coherence between the production and the consumption aspects of interregional accounts. Third, the introduction of additional information constrains RAS, forcing solutions that emerge from the algorithm to be more accurate (if they, in fact, do emerge).

As Jackson & Murray (2004) show, a matrix obtained after RAS balancing is just one of many that could results from the constraints inherent to the balancing problem to be solved—albeit the one that as close as possible to the prior matrix to which RAS is applied. RAS techniques cannot compensate for inaccurate MRIO unbalanced estimation Wiebe & Lenzen (2016). Fournier Gabela (2020) supports this empirically in his tests of various gravity-RAS methods. RAS ensures coherency but not accuracy when it comes to estimate MRIO models.

1.4. The aim of the present paper: opportunities for improvement?

In the research we present here, we suggest improvement opportunities that considers both import/export weights and gravity approaches described in preceding sections for estimating a region's international trade flows. The idea is to make use of widely available data to exploit as much as possible any trade-off between information requirements and accuracy to produce MRIO accounts that are as precise as possible. These accounts are subjected to RAS balancing only to ensure their coherence.

2. **Our methodological proposal**

We start by considering a generalised gravity model equation in a similar fashion to equation (6).

$$\tilde{t}_{ij}^{od} = k \frac{(t_{i\bullet}^{o\bullet})^{\alpha} \left(t_{\bullet j}^{\bullet d}\right)^{\beta}}{(l^{od})^{\gamma}} \quad \forall i, j \tag{7}$$

Tilde (~) indicates hypothetical, as opposed to estimated, behaviour. Unlike (6), only off-diagonal trade flows are here considered. That is, we start by assuming intraregional intermediate trade flows are known for all regions.

For region r contained in country c and import flows with foreign origin o between industries i and j can be expected to behave as:

$$\tilde{t}_{ij}^{or} = k\frac{(t_{i\bullet}^{o\bullet})^{\alpha}\left(t_{\bullet j}^{\bullet r}\right)^{\beta}}{(l^{or})^{\gamma}} \quad \begin{matrix} \forall i,j \\ \forall o \not\subset c \end{matrix} \tag{8}$$

where $t_{i\bullet}^{o\bullet}$ denotes total exports of commodity i from o; $t_{\bullet j}^{\bullet r}$ denotes total imports needed to fulfil region r's demand for commodity j; and l^{or} is the distance (or total travel cost) between o and r.

The same equation (8) can describe country c import trade with the rest of the World:

$$\tilde{t}_{ij}^{oc} = k\frac{(t_{i\bullet}^{o\bullet})^{\alpha}\left(t_{\bullet j}^{\bullet c}\right)^{\beta}}{(l^{or})^{\gamma}} \quad \begin{matrix} \forall i,j \\ \forall o \not\subset c \end{matrix} \tag{9}$$

This leads to our set of simplifications, the novelty of our work. We calculate import shares by dividing (8) by (9):

$$\mu_{\mathrm{ij}}^{\mathrm{or}} = \kappa\frac{t_{\bullet j}^{\bullet r}/t_{\bullet j}^{\bullet c}}{\lambda^{rc}} \quad \forall t_{ij} \subset T^{o\neq c,r} \tag{10}$$

where $\lambda^{rc} = l^{or}/l^{oc}$ is a fixed measure of relative distance between region r, country c and origin o whereas parameter κ is considered as a normalisation factor that ensures:

$$\sum_{\mathrm{r}} \mu_{\mathrm{ij}}^{\mathrm{or}} = 1 \quad \forall o \not\subset c \tag{11}$$

By making use of (10), we can find that region r's international imports are, thus, simply shares of the nation's international imports:

$$t_{ij}^{or} = \mu_{\mathrm{ij}}^{\mathrm{or}} t_{ij}^{oc} \quad \forall t_{ij} \subset T^{o\neq c,r} \tag{12}$$

Analogously, for region r in country c and a foreign destination d, export flows between industries i and j can be expected to be:

$$\tilde{t}_{ij}^{rd} = k\frac{(t_{i\bullet}^{r\bullet})^{\alpha}\left(t_{\bullet j}^{\bullet d}\right)^{\beta}}{(l^{rd})^{\gamma}} \quad \begin{matrix} \forall i,j \\ \forall d \not\subset c \end{matrix} \tag{13}$$

where $t_{i\bullet}^{r\bullet}$ denotes r's total international exports of commodity i, $t_{\bullet j}^{\bullet d}$ denotes total international imports by d of commodity j, and l^{rd} denotes the distance between r and d.

The same equation can be written to describe country c exports to the rest of the World:

$$\tilde{t}_{ij}^{cd} = k \frac{(t_{i\bullet}^{c\bullet})^{\alpha}\left(t_{\bullet j}^{\bullet d}\right)^{\beta}}{(l^{cd})^{\gamma}} \quad \begin{matrix} \forall i, j \\ \forall d \not\subset c \end{matrix} \tag{14}$$

So now, export shares can now be calculated by dividing (13) by (14):

$$\xi_{ij}^{rd} = \kappa \frac{t_{i\bullet}^{r\bullet}/t_{i\bullet}^{c\bullet}}{\lambda^{rc}} \quad \forall t_{ij} \subset T^{r,d\neq c} \tag{15}$$

where $\lambda^{rc} = l^{rd}/l^{cd}$ is the fixed relative distance between r, c, and destination d, whereas parameter κ is a normalisation factor that ensures:

$$\sum_{r} \xi_{ij}^{rd} = 1 \quad \forall d \not\subset c \tag{16}$$

A region's international imports are, thus, a share of the nation international imports making use of (15):

$$t_{ij}^{rd} = \xi_{ij}^{rd} t_{ij}^{cd} \quad \forall t_{ij} \subset T^{r,d\neq c} \tag{17}$$

Note that in our gravity model, we assigned $\alpha = \beta = 1$ and $\gamma = -1$ by relying on the large literature on the home bias of trade (e.g., Hillberry & Hummels, 2003; Martínez San Román, Bengoa Calvo, & Sánchez-Robles Rute, 2012). Naturally, other values can be applied.

3. **Empirical application: introducing Galicia (NW Spain) to the Word**

We now illustrate our proposal's usefulness via a modest empirical application. The goal of the application is to split Spain (ES) into a bi-regional MRIO composed of Galicia (GZ) and the rest of Spain (RES). To do so, we apply Section 2 developments to calculate Galicia´s trade with the rest of the World (ROW). We then balance the results using RAS to guarantee the multiscale MRIO model´s coherence. After estimating and linking these two accounts to a GMRIO, we calculate interregional spillovers and feedbacks for each of Galicia's 73 industries.

3.1. Data

3.1.1. FIGARO Global MRIO

FIGARO[4] is our choice of GMRIO model in which to embed the Galician IO table. It has acceptable industry detail for the European Union (EU) countries,[5] which is where most of Galician trade concentrates (López Iglesias, 2016). FIGARO also is fairly up-to-date compared with other GMRIOs available and has fully comparable accounts from 2010 to 2017. Remond-Tiedrez and Rueda Cantuche (2019) report on FIGARO quite comprehensively.

3.1.2. Our case study: Galicia (NW Spain)

We retrieved data for Galicia from *Marco Input-Output de Galicia*[6] (MIOGAL), which was elaborated by the Galician Statistical Institute (IGE, 2019). From 2010-2017 IGE produced two survey-based supply and use tables (SUT) and their corresponding symmetric tables (ST) in 2011 and 2016. Galician SUTs have commodity-wise territorial breakouts for imports and exports separated into the rest of Spain, the rest of EU and the rest of the World. Bifurcations between domestically produced and imported commodities for Use tables are also published enabling the derivation of domestic, imports and total ST flows. To achieve equivalent coverage across years, the 2011 Galician SUT was used along with information contained in the Galician Annual Regional Accounts[7] for as a basis for estimating accounts 2010, 2012 and 2013. The 2016 Galician SUT was similarly applied to derive accounts for 2014, 2015 and 2017. Published data are insufficiently detailed to make use of classical RAS or SUT-RAS (Temursho & Timmer, 2011) update techniques. So, instead, we applied PATH-RAS

[4] FIGARO database is available for public access: https://ec.europa.eu/eurostat/web/esa-supply-use-input-tables/data/database

[5] The United Kingdom (UK) is included since it formally remained in the EU until January 31st, 2020.

[6] MIOGAL database is available for public access: https://www.ige.gal/web/mostrar_actividade_estatistica.jsp?idioma=gl&codigo=0307007003

[7] More specifically, data used for estimating the remaining SUT matrices can be consulted here: https://www.ige.gal/igebdt/selector.jsp?COD=9610&paxina=001&c=0307007001

(Pereira López, Carrascal Incera, & Fernández Fernández, 2013; Pereira López & Rueda Cantuche, 2013), which requires less information.

3.1.3. Key features

Table 2 shows key features of the data sets that we applied to the problem. As for $\mathbf{T}^{od}$ matrices, Galicia, European Union (EU) countries plus the United States (US) and the remaining countries from the rest of the World present different sectoral detail. Final demand matrices $\mathbf{F}^{od}$ has $q = 5$ columns: (i) household consumption, (ii) collective consumption, (iii) government spending, (iv) gross fixed capital formation and (v) inventory variations. Matrices $\mathbf{W}^{\bullet o}$ have $p = 3$ different rows: (a) compensation of employees, (b) gross operating surplus and (c) other net taxes on production.

Table 2. Datasets used to build the model. Key features.

	MIOGAL	*FIGARO*
Regions	1	45 + Rest of the World
Industries	73	64 for EU + US and 30 for the Rest of the World
GVA components	3	3
Final demand components	5	5
Year coverage	2011 & 2016	2010-2017

Source: Own elaboration.

We retained different industry classifications for Galicia than those in FIGARO, keeping the greatest possible disaggregation possible, as suggested in Lahr and Stevens (2002) among many others. Aggregation to comport with regions with less sectoral detail is done by straightforward summation. Disaggregation is operated in two steps. Let us illustrate them with an example. Matrix $\boldsymbol{Z}^{\mathbf{0}}_{(\mathbf{2}\times\mathbf{2})}$ is to be disaggregated into $\boldsymbol{Z}^{\mathbf{1}}_{(\mathbf{3}\times\mathbf{2})}$ where the resulting second and third row are obtained by splitting the values of its original second row. First, we created a concordance matrix $\boldsymbol{\rho}$ (Lenzen, Kanemoto, Moran, & Geschke, 2012; Lindner, Legault, & Guan, 2012). In our example, we split the second row of $\mathbf{Z}^0$ equally:

$$\rho = \begin{pmatrix} 1 & 0 \\ 0 & 0.5 \\ 0 & 0.5 \end{pmatrix} \quad (18)$$

Matrix $\boldsymbol{Z}^{\mathbf{0}}_{(\mathbf{2}\times\mathbf{2})}$ pre-multiplied by matrix $\boldsymbol{\rho}$. Following our example:

$$Z^1_{(3\times2)} = \rho_{(3\times2)} Z^0_{(2\times2)} \tag{19}$$

Once could also proceed using an analogous process for column disaggregation.

3.2. Obtaining a multiscale MRIO model

3.2.1. Interregional trade flows

We started by partially estimating a Spanish (ES) bi-regional MRIO with Galicia ($g = 1$) and the rest of Spain ($g = 2$). Table 3 depicts the structure of this block. For $\mathbf{T}^{21}$ and $\mathbf{F}^{21}$ estimates are obtained proportionally scaling adequately aggregated $\mathbf{T}^{\bullet 1}$ and $\mathbf{F}^{\bullet 1}$ matrices using the imports from the rest of Spain vector ($\mathbf{t}^{21}_{\bullet j}$) provided by supply tables.

Table 3. Structure of the Spanish MRIO block.

	GZ	*RES*	*GZ*	*RES*
GZ	$\boldsymbol{T}^{\mathbf{11}}$	$\boldsymbol{T}^{\mathbf{12}}$	$\boldsymbol{F}^{\mathbf{11}}$	$\boldsymbol{F}^{\mathbf{12}}$
RES	$\boldsymbol{T}^{\mathbf{21}}$	$\boldsymbol{T}^{\mathbf{22}}$	$\boldsymbol{F}^{\mathbf{21}}$	$\boldsymbol{F}^{\mathbf{22}}$

Source: Own elaboration.

Matrices $\boldsymbol{T}^{\mathbf{12}}$, $\boldsymbol{T}^{\mathbf{22}}$ and $\boldsymbol{F}^{\mathbf{12}}$, $\boldsymbol{F}^{\mathbf{22}}$ remain unknown. However, we have complete information about row and column sums for this block. Hence, we could estimate matrices by applying RAS to an appropriate benchmark obtained from FIGARO´s $\boldsymbol{T}^{es,es}$ and $\boldsymbol{F}^{es,es}$. In the absence of such complete information, other regionalization procedures present in literature can be used. See as an example supporting information in Cazcarro, Duarte and Sánchez Chóliz (2013).

3.2.2. Galicia's international trade flows

When implementing equations (7)-(17), we make use of disaggregated data for EU and non-EU imports and exports. Let $g = 3, \cdots, 29$ be the subset of EU countries (excluding Spain) and $g = 30, \cdots, 47$ the remaining countries in the model. For the numerators $t^{\bullet r}_{\bullet j}/t^{\bullet c}_{\bullet j}$ and $t^{r\bullet}_{i\bullet}/t^{c\bullet}_{i\bullet}$ in equations (10) and (15) we consider sums $t^{\sum_{g=3}^{29} o,r}_{\bullet j}/t^{\sum_{g=3}^{29} o,c}_{\bullet j}$ and $t^{r,\sum_{g=3}^{29} d}_{i\bullet}/t^{c,\sum_{g=3}^{29} d}_{i\bullet}$; $t^{\sum_{g=30}^{47} o,r}_{\bullet j}/t^{\sum_{g=30}^{47} o,c}_{\bullet j}$ and $t^{r,\sum_{g=30}^{47} d}_{i\bullet}/t^{c,\sum_{g=30}^{47} d}_{i\bullet}$ for EU and non-EU import/export weights respectively.

We use minimum highway-travel distances between capital cities of Europe's continental countries. For non-European countries and islands, we use minimum water-transport distances between the ports of each country with the largest cargo flows.[8] Specifically, we use the ports of A Coruña and Algeciras for Galicia and Spain, respectively.

3.2.3. Final merging and balancing

We then assembled the different estimated blocks following the scheme depicted in Table 3. Value added for RES is calculated as a simple difference between $\boldsymbol{W^{es}}$ and $\boldsymbol{W^{1}}$. We retrieved the matrices $\boldsymbol{T}$, $\boldsymbol{F}$ and $\boldsymbol{W}$ for all origins and destinations that were ***not*** Galicia and the rest of Spain directly from published FIGARO tables as we did not disaggregate them. Table 4 illustrates the final structure of our multiscale MRIO model.

Table 4. Description of the multiscale MRIO model

	GZ	*RES*	$\cdots$	*g*	*GZ*	*RES*	$\cdots$	*g*	*Sum*
GZ	$\boldsymbol{T^{11}}$	$\boldsymbol{T^{12}}$	$\cdots$	$\boldsymbol{T^{1g}}$	$\boldsymbol{F^{11}}$	$\boldsymbol{F^{12}}$	$\cdots$	$\boldsymbol{F^{1g}}$	$\boldsymbol{x^{1\bullet}}$
RES	$\boldsymbol{T^{21}}$	$\boldsymbol{T^{22}}$	$\cdots$	$\boldsymbol{T^{2g}}$	$\boldsymbol{F^{21}}$	$\boldsymbol{F^{22}}$	$\cdots$	$\boldsymbol{F^{2g}}$	$\boldsymbol{x^{2\bullet}}$
$\vdots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$	$\vdots$
g	$\boldsymbol{T^{g1}}$	$\boldsymbol{T^{g2}}$	$\cdots$	$\boldsymbol{T^{gg}}$	$\boldsymbol{F^{g1}}$	$\boldsymbol{F^{g2}}$	$\cdots$	$\boldsymbol{F^{gg}}$	$\boldsymbol{x^{g\bullet}}$
GVA	$\boldsymbol{W^{\bullet 1}}$	$\boldsymbol{W^{\bullet r2}}$	$\cdots$	$\boldsymbol{W^{\bullet g}}$	$-$	$-$	$\cdots$	$-$	$\boldsymbol{w^{\bullet\bullet}}$
Sum	$\boldsymbol{x^{\bullet 1}}$	$\boldsymbol{x^{\bullet 2}}$	$\cdots$	$\boldsymbol{x^{\bullet g}}$	$\boldsymbol{f^{\bullet 1}}$	$\boldsymbol{f^{\bullet 2}}$	$\cdots$	$\boldsymbol{f^{\bullet g}}$	

Source: Own elaboration.

We applied a final balancing step to achieve a region/country-wise coherent model. Two reasons justify this final adjustment for all rows and columns. First, incomplete information results in mismatches between Galicia´s row/column sum and figures published by IGE. Since their rest of Spain counterparts are calculated by difference, RES row/column sums do not tally to desired values either. Secondly, FIGARO accounts retain

[8] Except for the US and México, where we considered the largest ports in their East coast.

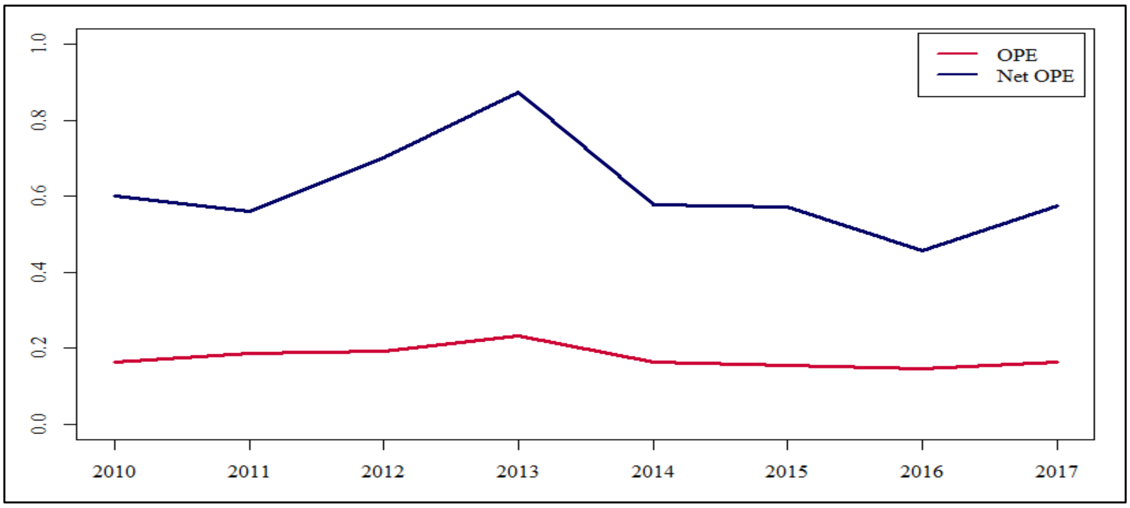
inherent minor mismatches in row and column sums due to legally mandatory statistical disclosure issues. Thus, some minor adjustments are needed in this part of the model too. So, we apply a simple GRAS adjustment as final step. After the iterative procedure concluded, we found that we had a coherent and balanced multiscale MRIO model with Galicia disaggregated from the rest of Spain, including the region's international trade flows as well as Galicia's trade with reast of Spain.

3.3. Putting our model to some use: interregional feedbacks and spillovers

3.3.1. Feedback effects

Feedback effects are the impacts that a demand stimulus has on a region´s own output through trade linkages with other regions. Following Miller and Blair (2009, pp. 80–86) we calculate the *overall percentage error* (OPE) to measure the relative contribution of interregional feedback effects over an entire economy. We also consider indirect impacts separately, (as suggested by Oosterhaven, 1981), to obtain the *net overall percentage error* ($Net\ OPE$). Figure 1 shows results obtained for Galicia that arise from a positive 1% final demand shock. For the rest of the regions final demand was set to zero.

Figure 1. Total feedback effects measured by OPE and net OPE (2010-2017).



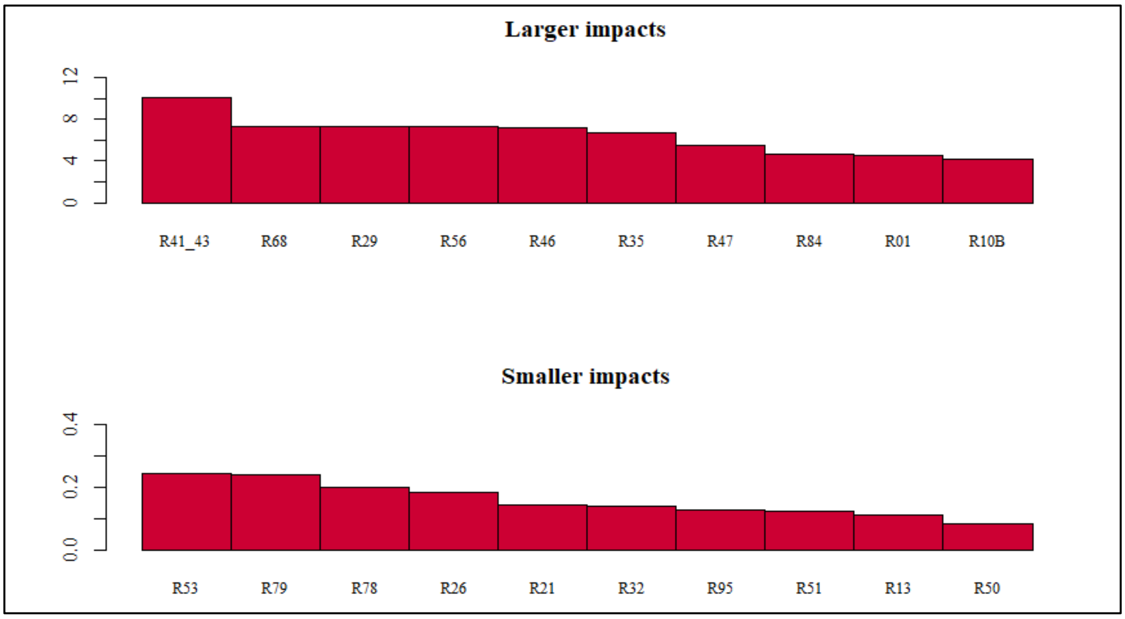
Source: Own elaboration.

From a dynamic perspective, interregional feedback rose from 2010 to 2013 and basically declined from 2013 to 2017. Feedback effects are inversely related to a region's degree of self-sufficiency, so these results comport with improvements observed by González Laxe, Armesto Pina and Sánchez-Fernánde (2018) in Galicia's trade balance since the financial crisis. Results confirm, as literature suggests, that interregional feedback effects for open economies like Galicia's are relatively small. But, as Round (2001) has pointed out, other issues related to globalization and regionalization need to be addressed using MRIO models. The following sections intend to briefly illustrate this point.

3.3.2. A little step beyond feedback effects: linkages and spillovers

Scholars and policy makers are often insterested in knowing the set of domestic industries that most influence the performance of their economy. This can be explored by examining total backward or forward interindustry linkages (see Miller and Lahr, 2001 for an interesting review). We only consider a demand model in this paper, so apply the standard sectoral *hypothetical extraction*[9] method to all industries of the single-region model of Galicia. Conceptually this means suppressing all interindustrial flows of an industry and, subsequently, observing the extent to which the economy's total gross output varies. See Miller and Blair (2009, pp. 563–565) and Miller and Lahr (2001) for mathematics behind the approach. Figure 2 summarises our findings.[10]

Figure 2. Industries with larger and smaller average % impacts in the output of Galicia (2010-2017).



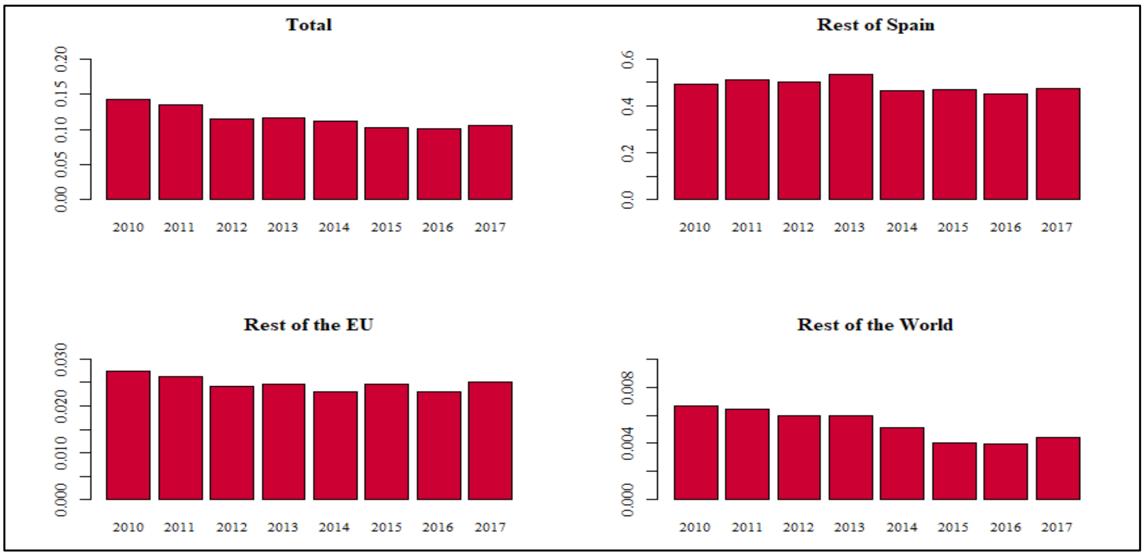
Source: Own elaboration.

[9] Which was originally formulated by Paelinck, De Caevel, and Degueldre (1965) and Strassert (1968).

[10] All MIOGAL codes refer to Classification of Products by Activity by Eurostat. See: https://ec.europa.eu/eurostat/web/cpa/cpa-2008

Galicia's regional economic structure is generally dominated by low-technology industries[11] (with the exception of R29) and less knowledge-intensive services[12] (with the exception of R84). Conversly, knowledge-intensive market services (R50, R51, R78), high-techonology industries (R26, R21), textiles (R13) and other services (R53, R79, R95) tend to contribute less to Galicia's economy.

Figure 3. Regional extraction impact through backwards linkages. Breakdown for the rest of Spain, rest of the EU and rest of the World. Galicia, 2010-2017.



Source: Own elaboration.

Returning to the MRIO model, we can derive more insight into the importance of Galicia to Spain and to the EU. We do so by first measuring the influence of all Galician industries in the global economy using the *regional extraction* method popularized by Dietzenbacher, van der Linden and Steenge (1993) but first applied by Miller (Miller, 1966, 1969). Methodologically speaking, the approach is identical to hypothetically extracting a sector but, in this case, we suppress all interindustrial flows of one region of the MRIO. We then observe how total gross output of the remaining regions change. This is one possible way for measuring the global or partner-specific relavance of a region. Figure 3 summarises our results.

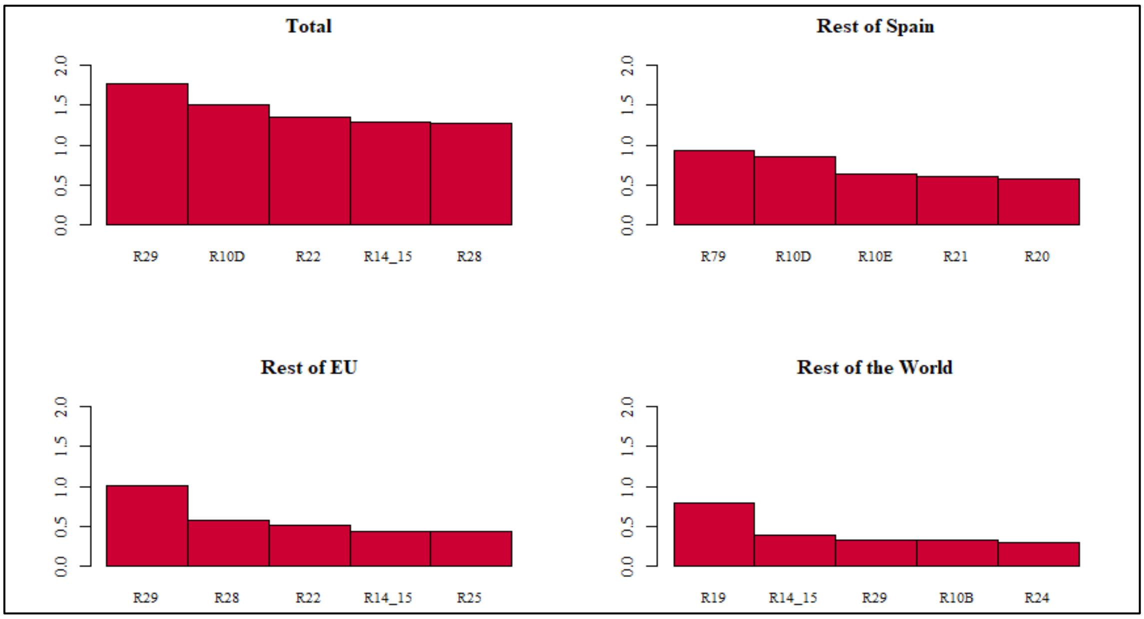
[11] We take Eurostat´s technological classification of manufacturing industries: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:High-tech_classification_of_manufacturing_industries

[12] We take Eurostat´s Knowledge-intensive services classification: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Knowledge-intensive_services_(KIS)

Galicia has a limited global impact but with some high partner-specific values for the rest of Spain and the rest of Europe. It is worth highlighting that the region´s impact diminished over the study period. This trend is particularly accute in the case of extra-EU relationships, appearing to confirm the literature on post-2008 global trade-bloc formation that we referred to earlier (Xiao et al., 2020; Zhang et al., 2022).

At an industry-specific level, interregional spillover effects identify the economywide output elasticity a unit of regional final demand. Formally, this is equivalent to the column sum of the Leontief inverse matrix excluding the entries of the region to be analysed (see Miller and Blair, 2009, pp. 261–264 for a more detailed explanation). Figure 4 summarises our results for Galicia.

Figure 4. Industries with greater interregional spillover effects. Total values and detail for rest of Spain, European Union, and the World. Average 2010-2017.



Source: Own elaboration.

Different from the picture given in Figure 2, we observe larger spillover effects are experienced by industries that generate low domestic output impacts. They include both medium and high technology industries (R19, R20, R21, R22, R24, R25, R28 and R29). Demand policies intended to foster output, if directed to these sectors, would yield results less than proportional to the shocks induced as shown by Pérez, Dones, and Llano (2009). Not only are regional economic structures important (Percoco, 2017) but interregional linkages matter as well. This is because they can encourage or harm the redistributive effects of regional development policies. Furthermore, we observe differentiated patterns for the rest of Spain, rest of the EU and rest of the World as also found in other research (e.g., de la Torre Cuevas, 2020). The choice of information to be used in a policy instance depends on the intended audience of the findings, i.e., the hierarchical level of the governmental body (regional, national, supranational) that designs, funds and/or executes the regional economic development policies to be implemented as a result of such findings.

4. **Conclusions**

In the present paper we suggest an alternative way to nest regions into a global multiregional input-output (MRIO) model. This makes it easier to assess current global challenges from regional perspectives. Our approach estimates import/export weights via a gravity formulation, thus taking distance into account. Information and computational requirements are minimal.

Despite the approach's modest demands, the empirical application of our MRIO with a focus on Galicia (NW Spain) yields coherent results that also appear quite reasonable. When it comes to estimating the output produced by a region, interregional linkages (measured by interregional feedback effects) do not make a big difference. We also showed how other techniques that exploit MRIO information can provide pertinent insight about a region's influence on the rest of the World. It is to be noted that when we get to know how a region or a region´s industry affect other region´s output, calculations regarding employment, energy use, pollution, etc. effects become possible too. This can allow for more informed discussion within the different scales of government involved in regional policy and also with the general public.

A main limitation of our work is our inability to verify specific interregional trade flows. So, empirical assessments will remain intriguing as well as a necessary future path for research. We hope to be able to develop regression-based parameters and use balancing procedures with more constraints as we apply more data to the problem. The use of more constrained balancing procedures when subset figures need to be respected can also be considered as a possible extension of our work.

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