Intranational home bias in the presence of wholesalers, hub-spoke structures and multimodal transport deliveries[1]

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Abstract:

When modeling interregional flows it is standard to identify the origin and destination of a flow with the point of production and consumption. However, the presence of *hub-spoke* structures or *multimodal flows* may introduce bias, such as being an additional source for cross-sectional correlation between dyadic flows. The aim of this paper is to model inter-provincial flows within a country (Spain) considering this potential bias using a novel dataset with fifty inter-provincial flows and four transport modes. We then feed this dataset into various specifications of a gravity model that incorporates cross-sectional dependence attributable to hub-spoke structures.

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1. Introduction

Data on interregional commodity flows are, for most countries, scarce and incomplete. The literature on border effects abounds with analyses that measure the intensity of trade within a single country (or region) against the intensity of that country's trade with one or more other countries (or regions of the same country) (McCallum, 1995). However, most such studies use interregional transport flows or deliveries, as reported by exporting firms (Hillberry and Hummels, 2008), as the best proxy for internal trade. Of special concern to us here are papers (such as Wolf (2000), Millimet and Osang (2007) and Yilmazkuday (2012) for the United States; Helliwell (1996) for Canada; Helble (2007) and Nitsch (2002) for Germany; Combes et al. (2005) for France; and Garmendia et al. (2012) for Spain) that compute a single country's home bias or own-region effect, defined as how much more trade some region (province) conducts with itself than with any other region (province) of the same country. In principle, each commercial transaction entails the shipment of a good, but this shipment may involve single-mode or multimodal transport. It might be a simple door-to-door delivery or encompass a range of intermediation facilities (multimodal nodes, logistical platforms, warehouses, wholesale operations, etc.). As a result, a single trade transaction can be registered in any number of ways in trade and transport surveys, and these surveys, therefore, cannot ensure full product traceability. Thus, the increase in economic and logistical complexity—as documented in Rodrigue et al. (2009), Rodrigue (2003), Hesse and Rodrigue (2004), Rodrigue and Notteboom (2010), Woudsma (1999) and van Klink and van den Berg (1998)—can lead to erroneous interpretations of specific dyadic records for both international and intra-national trade flows. These potential biases have seldom been addressed in models of international and interregional trade flows.[2] The result is that points of origin and destination have usually been identified with points of production and consumption. Several authors—McCallum (1995), Henderson and Millimet (2008), Combes et al. (2005)—have admitted that this hypothesis is

[2] This applies strictly to the cited literature on trade and the gravity equation. Interesting and subtle strategies have been developed to model transport networks, transport-mode competition and cooperation in freight and passenger trips, but a detailed review of this alternative literature and its modeling strategies lies beyond the scope of this paper.

ad-hoc, as their datasets cannot fully compensate for biases introduced by hub-spoke structures, wholesales, re-exportation schemes, etc. To our knowledge, Hillberry and Hummels (2003), which analyzes the effect of wholesaling on the estimation of home bias within the US, is the chief exception. This paper shows that the home bias calculated by Wolf (2000) for the US is too high, as the data include shipments originating in both manufacturing and wholesale establishments. Hilberry and Hummels view manufacturers and wholesalers as forming a kind of hub-spoke arrangement, where manufacturers deliver products throughout the country to wholesalers, which then distribute said products over very short distances to retailers. A straightforward extension of this approach shows that the presence of logistical intermediaries and multimodal combinations also leads to re-exporting schemes, which can then introduce biases into analyses of intra- or international trade (or freight) flows.[3]

This paper serves two purposes.

First, it describes a new strategy for modeling observed trade flows within a country, employing various specifications of the gravity model that incorporate a cross-sectional autocorrelation term.[4] Our hypothesis is that the presence of hub-spoke structures and re-exporting schemes constitutes an additional source of cross-sectional correlation between dyadic commodity flows to the sources already described in the literature: LeSage and Pace (2008, 2009), Fischer and Griffith (2008), Chun (2008), Griffith and Fischer (2013), De la Mata and Llano (2013), LeSage and Llano (2013).

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[3] For example, with "production-chain fragmentation" and "value-added trade," transit flows and re-exporting may produce *double counting* problems and misinterpretations of the current account balance. See, for instance, Antràs y Chor (2012), Antràs et al. (2012), Ling Feng et al. (2012), Baldwin and Lopez-Gonzalez (2013). In the border-effect literature, moreover, we observe that the presence of two (or more) transport flows corresponding to the same *trade operation* can bias estimates of the border effect (Hillberry and Hummels, 2003). On the other hand, re-exportation within the destination region (e.g., through capillarity distribution from outskirt warehouses to urban centers) can lead to an overestimation of intra-national trade and therefore of *home bias* within the country. However, if the re-exportation scheme should be a concatenated set of inter-provincial deliveries of the same item (e.g., intermodal transport delivery with load/unload operations in the hub), it is inter-provincial freight flows that will suffer from double counting and lead to an underestimation of the intra-regional home bias. For a similar insight into multi-stage production and US home bias, see Kei-Mu (2010).

[4] There is a broad literature on spatial-interaction models. The gravity model is doubtless the most well-known approach, having received much attention in varied fields, and has thousands of applications for trade, freight, commuting, finance or migration flows. This paper takes up two strands of the literature: the use of gravity models to model trade flows between and within countries (see Head and Mayer, 2014, for a recent review) and the combination of gravity models with spatial econometric terms (LeSage and Pace, 2008, 2009; Fischer and Griffith, 2008). Additional approaches are not covered in this paper.

Our approach is in line with two previous attempts to combine trade flows, transport networks and logistics in the context of the gravity equation and spatial econometrics. LeSage and Polasek (2008) model commodity flows, using an extended gravity model that incorporates highway-network data into the spatial connectivity structure of the spatial autoregressive econometric model. Alamá-Sabater et al. (2013a) attempt to determine whether transport connectivity affects trade flows. Using first-order contiguity and incorporating logistics-network-structure dependence into a spatial autoregressive model, the paper considers flows between fifteen peninsular regions of Spain (NUTS 2) and sector-specific flows by road. The second aim of our paper is to conduct an empirical analysis that uses the aforementioned strategy to model inter-provincial observed trade flows within Spain while accounting for biases introduced by logistical infrastructures, warehouses, wholesale activities and hub-spoke structures. We use a novel dataset comprising domestic flows by four modes of transport (road, train, ship and aircraft) between Spain's fifty provinces. This dataset—which includes 10,000 origin-destination deliveries (50*50*4) for the single year of 2007 along with a comprehensive set of regressors and rich distance measures based on Spain's actual transportation network—is notable for both its size and quality. We precede our analysis with an illustrative exploration of the dataset, using a novel index to account for hub-spoke structures in each province's trade with other Spanish provinces. We analyze this index, using a Geographical Information System (GIS) to identify the actual transport network for each mode.

Our approach does not, however, attempt to explain the logistical complexity or the micro-foundations of transport-mode decisions but offers a way to control for them to avoid biases. In this regard, we part ways with other interesting attempts to employ alternative tools, such as De Jong et al. (2004), Tavasszy (2008), Álvarez-SanJaime et al. (2013a, 2013b), Cantos-Sánchez et al. (2009) and Monzón and Rodríguez-Dapena (2006).

We should also note that Spain—with its complex geography (two island provinces, two autonomous cities in Africa), diversified sectoral structure (agriculture, refineries / chemical clusters, automotive-equipment-machinery industrial clusters), relatively isolated location with respect to Europe (on a peninsula, with only two highway links to the rest of the continent and

almost no international train connections before the 1970s) and a centuries-old geographic advantage of access to the Mediterranean, America and Africa (a privileged enclave for interactions via the Atlantic Ocean)—provides a good experimental field in which to explore these topics.

The remainder of the paper is structured as follows: Section 2 defines the theoretical framework. Section 3 lays out our empirical strategy for dealing with logistical infrastructures and the presence of hub-spoke structures within and between transport modes. Section 4 briefly describes the dataset. Section 5 presents our descriptive and econometric analysis. A final section concludes.

2. A conceptual framework for hub-spoke structures

Let us begin by considering a country with I provinces ($I = 50$ for Spain). As is common in most European countries, although international exports and imports from each province are observable (T_{RoWi} and T_{jRoW}), inter-provincial trade flows within a country (T_{ji}) are not[5]. However, inter-provincial transport (freight) flows are registered separately for each transport mode (m), $\left\{F_{ji}^{R};F_{ji}^{T};F_{ji}^{S};F_{ji}^{A}\right\}$, namely: road ($R$), train ($T$), ship ($S$) and aircraft ($A$). In the absence of intermediation (re-exportation schemes), freight and trade flows are equivalent, and the aggregate of all deliveries is obtained by adding together the corresponding mode specific flows, $F_{ji} = F_{ji}^{R} + F_{ji}^{T} + F_{ji}^{S} + F_{ji}^{A}$.

However, economic complexity and modern logistics can skew this clean match between trade flows and transport flows. In some cases, this mismatch occurs when there are two or more transport flows ($F_{in}, F_{nm}, ...F_{cj}$) behind a single trade flow (one transaction, with just one producer and one final consumer, but multiple transporters or intermediaries involved

[5] Without loss of generality, i denotes the province of origin, and j denotes the province of destination. Thus, if i = j, we have intra-provincial flows, whereas if $i \neq j$, we have inter-provincial, intra-national flows.

in the logistics). This situation, which in this paper is labeled a hub-spoke or *a re-exporting scheme,* is illustrated in Figure 1.

<<<Figure 1 about here>>>

In principle, any province can serve as a *Hub* for intra-national or international flows. We assume that a *transit flow* implies that *two concatenated transport flows* correspond to exactly the same item and that the commodity undergoes no *transformation* at the Hub. For simplicity, we also assume no interconnections between *transit flows*—in other words, that a flow $i_1 \rightarrow H \rightarrow j_1$ is not connected to another flow $i_2 \rightarrow H \rightarrow j_2$, such that $j_1 = i_2$ becomes a new Hub (H), and so on.

As stated above, no additional conditions are set for the transport mode of the initial *inflow* to the Hub and the subsequent *outflow* from the Hub. Multiple combinations are possible. For example, we can account for (transit) flows entering or leaving a province (H) in at least one of the following two ways: (i) by the presence of *logistical infrastructures*, *warehouses* or *wholesale operations*[6] or (ii) by the presence of *multimodal platforms* (where the transport mode shifts).

Our approach assumes that trade and transport bilateral flows within a country are reported separately (by modes), with little connection between them. Thus, given our dataset, perfect traceability of flows through logistical intermediaries (warehouse, wholesalers, multimodal shifters, etc.) is not possible. Therefore, in the case of re-exportation schemes or multimodal flows, no information about the actual point of production/consumption or any previous or subsequent delivery using the same or an alternative mode is available (Boonstra,

[6] Moreover, inflows to and outflows from a warehouse could be different in nature: (a) the warehouse could be owned by a logistics company offering services to the producer or to retailers. In this case, although there is no transformation of the load when it is delivered to/from the warehouse, the outflows and inflows truly correspond to *trade flows*; (b) however, if the warehouse is owned by the producer or the retailer, product entry into or departure from that infrastructure does not necessarily imply a trade flow between *i* and *j* but, perhaps, an *intra-firm* displacement of products (*inventory management*), with the aim of getting said products closer to the final market. An additional problem is that the products could be produced abroad and merely moved within the country.

2011). In fact, when observing a specific delivery, registered by a specific transport mode survey (i.e., road), it is impossible to know whether such a flow is unique or a re-exportation. This is the situation of the Spanish statistical system and that of many other countries in Europe.

Perfect identification of such links between *concatenated flows* would, of course, require a very detailed dataset on the products and specific locations of each flow. Because such data are, to the best of our knowledge, unavailable in the EU, we have developed our empirical strategy so as to describe an average EU country while taking advantage of a rich dataset for Spain. This is the next best thing and far better than nothing at all.

3. The gravity model and spatial econometrics: theory and applications

In this section, we define specifications to model inter-provincial flows within Spain (2007) in the presence of (potential) hub-spoke structures—i.e., of logistical intermediaries (warehouses, wholesalers) or multimodal nodes. Before doing so, we briefly review the economic theory behind the gravity model, its connection with the spatial econometrics literature and the presence of hub-spoke structures.

3.1. Some theoretical foundations

The gravity model has been commonly used to model international and interregional trade flows. As recently reviewed by Head and Mayer (2014), the gravity equation can be justified by a broad range of trade theories, such as those based on differences in factor-endowments (Deardorff 1998), monopolistic competition (Helpman and Krugman, 1985), home-preferences (Anderson, 1979; Anderson and van Wincoop, 2003) or increasing returns to scale (Helpman and Krugman 1985; Evenett and Keller, 2002).

In connection with this literature, we find some recent attempts to connect the micro-founded structural gravity equation with the literature on spatial autocorrelation effects. For example, Behrens et al. (2012) derives a gravity equation from the quantity-based version of the CES model by exploiting the property that price indices in that model are themselves implicit functions of trade flows. The resulting equilibrium system allows them to derive an econometric specification in which bilateral trade flows between two regions depend on trade flows

involving all other trading partners in a manner similar to that used in the spatial econometrics literature to address simultaneous spatial autoregressive structures. They show how controlling for cross-sectional correlations, using spatial econometric techniques, allows for control of the multilateral resistance terms described by Anderson and van Wincoop (2003). With a similar goal, Koch and LeSage (2015) show how linearizing the system of nonlinear relationships defined by Behrens et al. (2012) around a free trade world leads to an interdependence structure that can be used as a Bayesian prior to produce statistical estimates of inward and outward multilateral resistance indices.

Furthermore, there are no previous attempts to use a micro-founded gravity equation with spatial autocorrelation effects to control for hub-spoke structures. Indeed, several papers analyze the effect of hub-spoke structures on trade, using the gravity equation (Deltas et al., 2012; Kowalczyk and Wonnacott, 1992; Kowalczyk 2000). However, most of these focus on international flows and re-exportation schemes derived from the presence of bilateral/multilateral free trade agreements or rules of origin, while none use spatial econometrics. The studies that consider hub-spoke structures associated with the transport network (Behrens et al., 2007) emphasize the agglomeration forces of economic activity rather than the specific patterns of trade induced by such agglomerations. Finally, Kei-Mu Yi (2010) develops an interesting theoretical model that explains home-bias in the US. In doing so, Kei-Mu Yi considers an alternative phenomenon to the consolidation-re-exportation scheme considered here (logistics), that is, the scheme associated with multi-stage production (fragmentation) within a country. Although the economic foundations of these phenomena differ, in both cases, observed flows in a country can be inflated — by the performance of intermediaries in logistics, in the former case, and by deliveries of parts and components versus final products, in the latter case.

3.2. The basic gravity equation

The simplest gravity equation for modeling aggregate commodity flows between a set of *n* provinces within a country is described in **Eq. (1)**:

$$\ln\left(F_{ji}/Y_iY_j\right)=\alpha i_N+\ln X_i\beta_1+\ln X_j\beta_2+\ln d_{ji}\beta_3+Intra\beta_4+Adj\beta_5+\varepsilon_{ji} \quad (1)$$

where $\ln\left(F_{ji}/Y_iY_j\right)$ is the logarithm of the bilateral flow in current euros, with the origin in province *i* and the destination in province *j,* divided by the corresponding GDPs of the origin and destination provinces. Note that the term F_{ji} indicates the use of aggregate flows, both in terms of products and transport modes (*road* + *train* + *ship* + *aircraft*). Flows F_{ji} are organized into an n × n Destination-Origin (*j*-*i*) flow matrix, which contains intra-provincial flows in the on-diagonal elements and inter-provincial flows in the off-diagonal elements. This matrix will be transformed in the corresponding vector, following the destination-origin layout detailed in the Annex. A dummy variable, $Intra$, is included to control for the potentially different nature of flows within a province and between provinces. This dummy variable takes the value one if the flow's origin and destination are the same province and zero otherwise. The anti-log of this dummy is the *own-region effect* or *home bias* discussed in the introduction; we add a dyadic dummy, Adj, to control for trading-partner adjacency; In the above equation, αi_N is a constant; X_i is a matrix of regressors representing the productive capacity of the exporting province *i*; X_j is an equivalent matrix of regressors representing the absorptive capacity of the importing province *j*; and d_{ji} is the bilateral distance between the exporting and importing provinces (taken as a proxy for transport cost by mode and commodity type). Note that all variables are expressed in logs.

3.3. The gravity equation in the presence of cross-sectional dependence

According to various authors (Griffith and Jones, 1980; Black, 1992; Bolduc et al. 1992;

LeSage and Pace, 2008), bilateral flows in a system may be autocorrelated, biasing the classical Ordinary Least Squares (OLS) estimation procedures for spatial interaction models. LeSage and Pace (2008) suggest that the variable-omission problem is a potential cause[7] of such bias.

As explained in the previous section, in many cases, two or more bilateral transport flows might be anything but independent; the end of the one could be the beginning of the next, and they might transport exactly the same item and thus correspond to a single transaction. Transport infrastructures (the network itself but also ports, airports and logistical facilities) are usually not included as explanatory variables in trade-flow models. Moreover, models of aggregate flows and sector-specific deliveries often overlook the actual transport mode used for delivery and any transport-mode combinations. All of these omitted variables can easily generate additional network autocorrelation effects and skew spatial-interaction models.

In this section, we formally test an extended gravity-model specification to account for such cross-sectional autocorrelation effects in models of inter-provincial flows within Spain. The extended model subsumes as special cases models that exclude such dependence.

3.4. Addressing hub-spoke structures within individual transport modes

As previously described, a *hub-spoke structure* exists when an apparent transport flow *j-i* is connected with a subsequent flow (with *j* serving as a Hub: $j = H$). For the sake of simplicity, we assume that there are no concatenations of two transit flows. We also assume that *transit flows* can be associated with any combination of transport modes (*R*, *T*, *S*, *A*). Thus, any *j* in a system of *N* (n × n) bilateral flows *j-i* can behave as a Hub *(H)*.[8] If, then, we wish to explain an (apparent) inter-provincial flow by road from *i* (Seville) to *j* (Madrid), we should consider the possibility that Madrid will become *H*—that is, that it will re-export the same load or some

[7] There exist several explanations for these effects in most socioeconomic spatial interactions (migration, trade, commuting, etc.). For example, neighboring origins (exporting provinces) and destinations (importing provinces) can occasion estimation errors of similar magnitude if underlying latent or unobserved forces are at work, so that missing covariates exert a similar impact on neighboring observations. Such missing covariates can be associated with various factors, such as common agglomeration economies, common transport infrastructures, factor endowments, un-observed linkages between sectors or firms, etc.

[8] Note that the same assumption can be made for any origin *(i)* in the system and lead to the same conclusion.

part of it to a third province (say, Barcelona) that is the final destination *j*. For this reason, the absorptive capacity of any destination should be reinforced with variables to account for the possibility that it will serve as a Hub. We must consider, among other factors, the number of potential re-exporting flows from *H* to other destinations in the country (in this case, Barcelona as final destination *j*). As will be seen in **Eq. (2)**, we can put this idea to use in a standard gravity equation with a spatial autocorrelation term (SAR) but with a special version of the weight matrix, labeled W_H (*H* for Hub):

$$\ln\left(F_{ji}^{m}/Y_iY_j\right)=\alpha i_N+\ln X_i\beta_1+\ln X_j\beta_2+\ln d^{m}{}_{ji}\beta_3+Intra\beta_4+Adj\beta_5+\rho W_H\ln\left(F_{ji}^{m}/Y_iY_j\right)+\varepsilon_{ji} \qquad (2)$$

where $\ln\left(F_{ji}^{m}/Y_iY_j\right)$ is the logarithm of the bilateral flow via a specific transport mode (e.g., *m* = *road*), with origin *i* and destination *j,* divided by the corresponding GDPs of the origin and destination provinces. The elements αi_N, X_i, X_j, Adj and $Intra$ are the same as in **Eq. (1)**. Note that $d^{m}{}_{ji}$ is a transport-mode specific distance measure, which will be explained in the next section.

The main novelty here is that the regressors in some specifications include variables that capture the logistical capacity of trading partners and other important controls for international transit flows. The following variables are defined for the exporting province *i,* although there is an equivalent set for the importing province *j*:

Ln(wholesales pc$_i$): the ratio of the number of wholesalers in province *i* (La Caixa, Anuario Económico, 2007) to the population of *i*. It is expressed as a log and includes the number of *intermediaries* (wholesalers, warehouses, etc.) per capita in each province.

Island$_i$: a dummy variable representing the three island provinces of Spain (Islas Baleares, Las Palmas and Santa Cruz de Tenerife) as exporting regions.

Border int. core EU$_i$: a dummy variable representing Spanish provinces that border France or Andorra in the north. This variable—taking a value of one for border provinces and

zero otherwise—is intended to control for expected higher flows to and from these *gateway* provinces for trade with the EU core. A positive and significant coefficient for the variable should be interpreted as a *symptom* that these border provinces are behaving as Hubs for international flows; in other words, their exports exceed expected inter-provincial flows (relative to their size, remoteness, etc.) because they are receiving from the EU core international imports of product *k*, which will subsequently be re-exported domestically (generating an *apparent inter-provincial flow*). Note that by including *Border int. core* EU_j:, we also control for the potential of border provinces to behave as Hubs and receive domestic imports for subsequent re-exportation to the EU core.

Border int. other$_i$: a dummy variable intended to control for the same effect as the previous variable but applied to Spanish provinces that border countries to the southeast (Portugal and countries in Africa). Although the aim is equivalent, the importance of the EU core and these other markets and the sizes of Spain's border provinces make it worthwhile to consider these effects separately.

Ln(imp. int. all_i/Y_i*)*: a further variable added to compensate for the bias introduced by ambushed international flows within domestic flows. In addition, to control for Spanish provinces bordering foreign markets, this variable is the logarithm of total products (measured in euros) imported by *i* (origin province of the domestic flow), regardless of transport mode. The idea is to acknowledge that even a non-border province can behave as a Hub (not, in this case, as a *gateway*), thanks to a large maritime port (e.g., Barcelona, Bilbao, Valencia). Thus, a positive and significant coefficient for this variable indicates that inter-provincial product exports from *i* are positively associated with the province's absorptive capacity with respect to *international imports*. Note that by including *Ln(exp. int.* all_j/Y_j*)* for importing provinces *j*, we also control for the contrary case, where the high capacity of a province *j* to import inter-provincial Spanish flows is associated with a high intensity of international exports, regardless of transport mode. These variables reinforce the previous dummy variables for the frontiers, as certain non-border provinces can enjoy other locational advantages for international deliveries, such as a strong maritime port or a high concentration of multinational firms (i.e., GM, Renault,

Citroen, VW, or any other foreign car maker located in Spain). In both cases, the variables are expressed relative to the GDP of the exporting (importing) Spanish provinces.

where $\rho W_H \ln\left(F_{ji}^m / Y_i Y_j\right)$ is a spatial lag term similar to that used in such papers as Griffith and Fischer (2013), De la Mata and Llano (2013), LeSage and Llano (2013), LeSage and Pace (2008, 2009), Chun (2008), Chun and Griffith (2011) and Fischer and Griffith (2008). The main difference lies in the weight matrix W_H, which—unlike the purely spatial $W = W_i + W_j$ found in the aforementioned papers—is defined on the basis of potential re-exporting schemes from the destination province (*Hub*) of a primal flow to the final destination of a concatenated delivery (spoke), for a given transport mode *m*. The purpose of W_H is to control for potential autocorrelation between flows entering a given province and outflows exiting the province for other parts of the system. That is, to capture all flows departing from a potential Hub (destination of an initial flow) to the final destination *j* in the system, we consider all potential (final) destinations except the origin of the first flow *i* (perfect loop), thereby excluding re-exporting (with no further transformation) of initial flows from region *i* to the hub (*H)* back from *H* to *i*. We obtain the W_H matrix as follows:

Because the structure of all our observations has a *destination-origin* layout, the column vector obtained by vectorization of the destination-origin matrix is, in the terminology of LeSage and Pace (2009), *destination-based*. The first *n* (50) observations correspond to inter-provincial flows exported by province *i = 1*, the next *n* (50) to exports departing from *i = 2*, and so on. We thus generate W_H as a matrix with *n* block matrices, each referring in turn to every exporting province *i*. In this way, W_H captures every (subsequent) flow *departing* from the destination province *j* of a given dyad *i*→*j*.

We use two alternative criteria to fill in W_H:

Option A: The first and more restrictive way to define this hub-spoke structure is provided by W_{Ha} in **Eq. (3)**. The matrix W_{Ha} contains *n* rectangular matrices of type A_n, which contain ones for the 'nodes' connecting *H* (destination of a previous flow) to its contiguous

regions n_H and zeros otherwise. We thus link every flow $i \rightarrow H$ with every flow $H \rightarrow n_H$[9]. Note that the perfect-loop elements ($i \rightarrow H \rightarrow i$) are also zero.

$$W_{Ha} = \begin{pmatrix} A_1 \\ A_2 \\ \vdots \\ A_n \end{pmatrix} \tag{3}$$

Option B: Next, we define an alternative, less-restrictive version of the weight matrix, based on **Eq. (4)**, where W_{Hb} contains a set of n rectangular matrices B_n. Here, we link every flow $i \rightarrow H$ with every node $H \rightarrow j$ (except i) but assign a different weight to each potential re-exportation flow. The weight structure is based on the inverse of the distance from the Hub (H) to the final destination *(j)*. Thus, the closer is H to j, the larger is the weight for the potential re-exportation flow $H \rightarrow j$.

$$W_{Hb} = \begin{pmatrix} B_1 \\ B_2 \\ \vdots \\ B_n \end{pmatrix} \tag{4}$$

The two alternative matrices, which are row-standardized, are illustrated with maps in Figure 2.

<<<Figure 2 about here>>>

3.5. Extended specifications for multi-modal transport flows

To extend the scope of our analysis, we now define a set of new specifications that can control for multi-modal hub-spoke structures, both in the aggregate (**Eq. 5**) and in detail (**Eq. 6**).

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[9] Note that, by means of W_{Ha}, flow $i \rightarrow j$ is associated with (subsequent) flow $j \rightarrow n_j$. This "network autocorrelation scheme," which is explained by "re-exportation" activity within a "hub-spoke" structure, differs from the typical "destination-base" spatial autocorrelation scheme (LeSage and Pace, 2008, 2009), where matrix W_j associates flow $i \rightarrow j$ with the flow from the same origin i to the neighbor of destination j (here labeled n_j).

$$\ln\left(F_{ji}^{m}/Y_iY_j\right)=\alpha i_N+\ln X_i\beta_1+\ln X_j\beta_2+\ln d^{m}{}_{ji}\beta_3+Intra\beta_4+Adj\beta_5$$
$$+\left(\mathrm{Re}\,st\mathrm{modes_inflows}_i/Y_i\right)\beta_6+\left(\mathrm{Re}\,st\mathrm{modes_outflows}_j/Y_j\right)\beta_7+\rho W_H\ln\left(F_{ji}^{m}/Y_iY_j\right)+\varepsilon_{ji} \quad (5)$$

Eq. 5 includes all the elements considered in the SAR specification described in **Eq. 2** along with two new variables:

$\left(\mathrm{Re}\,st\mathrm{modes_inflows}_i/Y_i\right)$: this new variable is intended to control for all inflows to the exporting province from elsewhere in the country (domestic flows) but transported by modes other than that of the endogenous variable, *m*. Inflows are expressed relative to the GDP of exporting (*i*) Spanish provinces. Suppose, for example, we were modeling a delivery by road (*m*) from Sevilla (*i*) to Madrid (*j*). Our new variable would include all products received in Sevilla from other Spanish provinces by modes other than *road* (*train* + *ship* + *aircraft*), expressed in relation to Sevilla's GDP. Note that if *m* = train, then $\left(\mathrm{Re}\,st\mathrm{modes_inflows}_i/Y_i\right)$ includes inter-provincial inflows arriving at *i* by *road* + *ship* + *aircraft*.

Equivalently, $\left(\mathrm{Re}\,st\mathrm{modes_outflows}_j/Y_j\right)$ controls for all outflows from the importing province (potential *H*) to any other province in the country (domestic flows) by a transport mode other than that of the endogenous variable, *m*.

For additional insight into specific multimodal re-exportation schemes, we define a final set of specifications. For the sake of brevity, **Eq. (6)** describes deliveries by road. Equivalent specifications can be defined for every alternative transport mode.

$$
\begin{aligned}
&\ln\left(F_{ji}^{road}\Big/Y_iY_j\right)=\alpha i_N+\ln X_i\beta_1+\ln X_j\beta_2+\ln d^{road}{}_{ji}\beta_3+Intra\beta_4+Adj\beta_5\\
&+\left(\text{Inflows}_i^{train}\Big/Y_i\right)\beta_6+\left(\text{Inflows}_i^{ship}\Big/Y_i\right)\beta_7+\left(\text{Inflows}_i^{aircraft}\Big/Y_i\right)\beta_8\\
&+\left(\text{Outflows}_j^{train}\Big/Y_j\right)\beta_9+\left(\text{Outflows}_j^{ship}\Big/Y_j\right)\beta_{10}+\left(\text{Outflows}_j^{aircraft}\Big/Y_j\right)\beta_{11}\\
&+\rho W_H\ln\left(F_{ji}^{road}\Big/Y_iY_j\right)+\varepsilon_{ji}
\end{aligned}
\tag{6}
$$

Here again, most of the elements are familiar from **Eq. (2)**. However, in **Eq. (6)** (with *m* = road), all potential cross-mode effects are captured one for one by the following six variables:

$\left(\text{Inflows}_i^{train}\Big/Y_i\right)$: captures inter-provincial inflows by train to the exporting province (*i*) relative to its GDP, while $\left(\text{Inflows}_i^{ship}\Big/Y_i\right)$ and $\left(\text{Inflows}_i^{aircraft}\Big/Y_i\right)$ capture inflows to *i* by ship and aircraft, respectively. Thus, we control for the use of any modes alternative to the one designated by the endogenous variable (*m* = road).

Similarly, the variables $\left(\text{Outflows}_j^{train}\Big/Y_j\right)$, $\left(\text{Outflows}_j^{ship}\Big/Y_j\right)$ and $\left(\text{Outflows}_j^{aircraft}\Big/Y_j\right)$ capture outflows from *j* by each of the modes alternative to *road*, all expressed relative to the GDP of the potential Hub province (*j*).

Before we proceed to our empirical analysis, let us remark that the cross-mode effects captured by these new specifications are usually hidden behind aggregate flows (all transport modes analyzed together). By splitting and controlling for these hidden multi-modal relationships, we reveal a hidden effect of the "omitted network structure" on the frame of aggregate flows. This effect may exceed the explanatory capacity of standard gravity models that assume an isolated *i-j* pair and do not consider re-exporting schemes within or between modes.

In these two final specifications, potential hub-spoke structures within a specific mode *m* will be captured by the spatial lag term, $\rho W_H \ln\left(F_{ji}^{road} \Big/ Y_i Y_j\right)$, while the cross-mode effects of multimodal re-exportation schemes will be captured by the previously described inflow and outflow variables.

3.6. Discussion: potential endogeneity problems

Once the previous two weight matrices have been defined, it is worth briefly discussing their exogenous nature, in line with recent suggestions of some authors (Kelejian and Piras, 2014; Pinkse and Slade, 2010; Fingleton and Ertur, 2012)[10]. In this regard, Fingleton and Ertur (2012) suggest that, ideally, the weight matrix should be theory-based, citing Behrens et al. (2012) as an example of how to derive an interaction matrix from a structural theoretical model. They also comment on the need for future research into the exogenous nature of this type of spatial weights matrix. Indeed, Kelejian and Piras (2014) have recently discussed this issue, considering weight matrices such as those used in Behrens et al. (2012) as endogenous. Weight matrices defined by pure geographical features, such as contiguity or the inverse of distance, can be accepted as exogenous, while others, such as dyadic indexes built upon socioeconomic indicators, may be endogenous (note that Behrens et al. 2012 use the relative sizes of regions, as reflected by population shares).

---

[10] Several sources of "endogeneity problems" are potentially present in our empirical exercise: i) the specification of the gravity equation, if the "endogenous" variable appears on both sides of the equation (i.e., T_{ij} versus Y_i and Y_j); ii) W, if it is defined in terms of the flows or other variables correlated with the endogenous variable; iii) a potential contemporaneous round-causation effect between the endogenous and exogenous variables. In this section, we focus specifically on the second potential source of endogeneity problems. Regarding the other two: Our specification of the gravity model (Eq. 2) shifts the $Y_i Y_j$ terms to the denominator of the left-hand side of the equation in an attempt, suggested by Head and Mayer (2000) and Poncet (2004), to overcome possible endogeneity problems; with regard to the round causation effect (iii), we acknowledge that the number of warehouses and wholesalers can increase in the provinces characterized by large intensities of inflows/outflows (rather than explain the intensity of the flows). Thus, one may argue that the appearance of logistic infrastructures and intermediaries is endogenous to the flows (X_i and X_j are explained by F_{ij} and not the other way around). Thus, by lagging (i.e., t-5) the X_i X_j variables, such round causation can be avoided. Although we have considered that option, it was impracticable due to data limitations. Moreover, as logistic infrastructures are very complex (it takes years to build them), we believe that such circular causation is more theoretical than practical. The use of IV lies beyond the scope of this paper and, moreover, is unsuited to the available information at this fine spatial level.

Based on this discussion, and avoiding the tension between theory-based weight matrices and their pure exogenous nature, we note that the two novel weight matrices defined in this paper to control for hub-spoke structures remain in a middle ground. Although this paper does not provide an ad-hoc theoretical model to derive the two weight matrices defined above, the matrices fit with the contrasting hypothesis that re-exporting schemes are more likely to appear in provinces contiguous with (W_{Ha}) or located near (W_{Hb}) the Hub. Moreover, by considering the cross mode effects described in the previous section, we also consider the higher probability of finding multimodal combinations on Islands and in coastal provinces. Regarding their exogenous nature, it is important to note that our weight matrices are not computed on the basis of the flows themselves or by using socio-economic indices suspected of being correlated with the endogenous or exogenous variables. In W_{Ha}, we include only 'zeros' and 'ones'; the 'ones' correspond to the 'nodes' between the destination province (potential Hub) of each flow and its contiguous provinces. In W_{Hb}, we include elements computed based on a pure geographical variable that is the inverse of the distance. The only difference between this weight matrix and the standard weight matrix used in other papers is that we use the inverse of the distance from any province in the system (except the perfect loop) to the Hub (destination of a given flow)[11].

4. Data

The dataset used to feed the endogenous variable (flows) contains the most accurate available data on Spanish flows of goods by transport mode (road, train, ship, aircraft) and fifty specific export-price vectors, one per province of origin, transport mode and product type. It was collected and filtered in accordance with the methodology described in Llano et al. (2010) and published as part of the C-intereg project (www.c-intereg.es). By combining

[11] As in LeSage and Pace (2008), our W_H are built using 'zeros', 'ones', or fractions of 'ones' (inverse of distance to the Hub). The only difference is that, instead of specifying a 'one' to pinpoint the node that corresponds to the flow F_{nji} (i.e., flows from i to the spatial neighbor of j), we specify a 'one' to indicate the node that corresponds to the flows F_{Hj}, that is, the flows delivered from the destination of a prior delivery (potential hub H) to another province d, which might be the final destination of a re-exportation scheme.

transport and price databases, it provides initial estimates of inter-provincial trade flows in current euros. At each stage up to the final aggregation, the methodology relies on the lowest available level of disaggregation. **Table 1** summarizes the original data for each transport mode, while **Table 2** describes the variables used as regressors.

<< Table 1 about here>>

<< Table 2 about here>>

Following the recommendation of an anonymous referee, we have used alternative distance measures, one per transport mode, whenever transport cost breakdowns by mode are not available. In this way, we attempt to control for differences between modes and the competition or synergies between them. Each of these alternative distance measures will be used to model transport-mode-specific flows, as described in **Eq. (2)**, **Eq. (5)** and **Eq. (6)**. They are:

$d^{m=road}_{ji}$, which represents the most likely bilateral distance (in *km*) for deliveries by road. We obtain this measure as follows:

(i) For all bilateral deliveries within the peninsula (47 inner provinces), we follow Zofío et al. (2011), where GIS software determines the shortest trip distance between any two places on the basis of the actual network of roads and highways (including such parameters as slope, quality and maximum legal speed). We thus obtain raw bilateral distances for a detailed picture of the Iberian Peninsula, split into more than 800 areas. These raw distances are aggregated, with averages weighted by the various populations of these areas, to produce a province-to-province matrix of inter-provincial distances.

(ii) For the three island provinces, we obtain bilateral distances between them and the inner provinces by adding the official distance traveled by ship between the islands and the main maritime ports (Cádiz for the Canary Islands, Barcelona for the Balearic Islands) to the road distance from these two main ports to each inner province. This road distance exactly

corresponds to the distance described above. This treatment is justified because deliveries between inner regions and the islands are in fact made by *Roll On-Roll Off* and similar strategies, with trucks loaded onto ships.

We have checked the results against alternative distances, such as actual distances reported by trucks upon their deliveries, and found them to be robust. However, we have decided to use GIS distances, as they avoid problems related to computations of intra-provincial distances traveled by trucks within each province (critical for estimating *home bias*). GIS distances are simply not affected by the huge number of short trips entailed by capillary distribution from wholesalers to retailers (see Diaz-Lanchas et al., 2013).

$d^{m=train}_{ji}$, which represents the bilateral distance (in *km*) traveled by trains, as reported by RENFE (the former Spanish rail monopoly). RENFE expresses data on bilateral flows between any two provinces in tons*km and tons. By dividing the first measure by the second, we obtain a fairly precise average distance traveled by trains in a given year (2007) for the main inter-provincial pairs. When a specific bilateral distance is not available, we substitute road distance.

$d^{m=ship}_{ji}$, which represents bilateral distance (in km) by ship. The distance between ports (coastal and islands provinces) is reported by the official Spanish port authority, Puertos del Estado. Again, to fill gaps in the data and in the unlikely event that an island reports flows by ship with inner regions (multimodal), we substitute road distance.[12]

$d^{m=aircraft}_{ji}$, which represents the most likely bilateral distance (in km) for air transport. This is the straight-line distance computed by GIS between airport locations in Spain. For provinces with no airports, we substitute road distance.

[12] Note that in all cases, this will correspond to a zero flow in the regression. However, our SAR specification disallows the removal of observations from the sample (a square DO matrix is needed). We also considered (and rejected) the alternative of using zero (or infinity) for the distance variable for the island-inner region pairs.

Finally, as stated above, the specifications described by **Eq. (1)** and **Eq. (2)** are fed by aggregate flows (by product and transport mode). In this case, the variable d_{ji} corresponds to the most representative distance for the largest share of deliveries observed in Spain: *road* for deliveries within the Iberian Peninsula, *ship* for trade with the islands. Thus, the average distance for aggregate flows is equivalent to distance by road for inner flows and distance by ship for islands.

5. Results

5.1. Descriptive Analysis

To briefly describe our novel dataset, we define an index, called the *Intra-Mode Re-exporting Index* (IMRI), that can be used to identify high levels of re-exportation within a region. The index is defined in **Eq. (7)**. The purpose of the index is to measure the preponderance in certain provinces of inter-provincial exports and imports of the same products by the same transport mode (m).

$$IMRI_i^m = \frac{1}{K}\sum_{k=1}^{K}\left(\frac{F_{i.}^{km}+F_{.i}^{km}}{\max\left(F_{j.}^{km}+F_{.j}^{km}\right)}\left(1-\frac{\left|F_{i.}^{km}-F_{.i}^{km}\right|}{F_{i.}^{km}+F_{.i}^{km}}\right)\right) \tag{7}$$

The IMRI takes inspiration from the well-known Grubel and Lloyd index, the standard tool used to measure intra-industry trade between countries. Here, instead of international trade flows (regardless of transport mode), we use inter-provincial freight flows broken down by transport mode, where the variable $F_{i.}$ represents total freight flows originating in province i and terminating elsewhere in the country, with freight flows within i excluded. Conversely, the variable $F_{.i}$ represents total inter-provincial freight flows arriving at province i from elsewhere in the country. The second term of the index strictly concerns each transport mode m in sector k, while the first term weights the importance of exports and imports relative to the maximum level of exports plus imports observed in the data for sector k and transport mode m. If total import freight flows for province i in sector k ($F_{.i}^{km}$) are equal to province i's total export

freight flows ($F_{i.}^{km}$), the ratio of the second term of the IMRI is zero, and the whole term equals one. On the other hand, if a province receives or sends freight flows only within the same sector and by the same transport mode—i.e., buys or sells goods only from sector *k*—the second term of the IMRI is zero.

Finally, to summarize the information, we take the average mean for the fifteen sectors to obtain one unique index by transport mode. If the index for a specific province and transport mode approaches one, the province is, in relation to the rest of Spain, a re-exporting province (potential "Hub"), with a high intensity of trade flows by that transport mode. By contrast, if the index is closer to zero, the province could be a site of consumption or production without re-exporting flows.

The following maps illustrate the index, with each transport mode highlighted. **Figure 3-Panel A**, showing the main road network in Spain (highways and national routes), reflects the IMRI for *road* by province. At a glance, we see that the index identifies three main Hubs (Madrid, Barcelona and Valencia) when *road* is considered alone. These regions present the widest road-crossing intensity, with a positive correlation between re-exporting flows by road and the *actual road network*, especially for regions crossed by main highways. Other provinces with high intensities of trade (Zaragoza, Sevilla, Valladolid and the three provinces of the País Vasco) are not especially significant in terms of re-exportation.

<<<Figure 3 about here>>>

Figure 3-Panel B reflects the IMRI for *train* and the main Spanish rail network. Again, there is a strong correlation between the rail network and re-exportation trade flows by train. Here, the potential Hubs are Madrid, Barcelona, Valencia and Vizcaya to the north, with important provinces to the northeast and the south. Indeed, there is a positive correlation between provinces that re-export by rail and provinces that re-export by road.

For *ship* (**Figure 3-Panel C**), as expected, only provinces with ports (the islands, Cádiz in the south and, at a lower intensity, Valencia and Barcelona on the Mediterranean coast)

appear to be potential Hubs, as they receive high-intensity inflows from the rest of Spain for export outflows to the islands (Islas Baleares and Islas Canarias) or to other provinces with ports.[13]

Finally, **Figure 3-Panel D** presents the IMRI for *aircraft* along with the location of the main Spanish commercial airports. Again, Madrid, Valencia and Barcelona appear to be potential Hubs, with Madrid's Barajas airport, one of the largest in Europe, playing a particularly important role and maintaining high-frequency freight flows with the Islas Canarias (Las Palmas and Santa Cruz de Tenerife). The Islas Baleares and the Islas Canarias are also important hub provinces for airplanes, as most of their re-exporting flows occur between the small islands forming each province (e.g., the single province of Islas Baleares, which includes such islands as Mallorca, Menorca, Ibiza and Cabrera) and use planes as the most efficient transport mode. For peninsular provinces with airplane freight flows but no airport, we advance the same explanation as for ship flows, although freight-flow volumes tend to be insignificant in these provinces.

5.2. Econometric Analysis

In this section, we present estimates of the expressions in Section 3. For each model, it is important to consider the endogenous variable (aggregate or mode-specific). Results for aggregate flows (all transport modes together) are reported in **Table 3,** and results for mode-specific flows are reported in **Table 4**.[14] The results in **Table 5** correspond to the specifications described by **Eq. (6)** and **Eq. (7),** which account for multimodal hub-spoke relationships.

[13] Anecdotally, it is worth highlighting that certain inner provinces show slight (but not null) intensity of inflows/outflows by ship. This is because trade-flow statistics with Islas Canarias are, as explained in the Annex, official statistics from the AEAT, which collects the data that establish the main transport mode used in the freight flow. That is, a freight flow originating in an inner province and proceeding by road to a port before taking a ship is nevertheless recorded as a delivery by ship from the inner province.

[14] Rather than unduly lengthen this paper, we will reserve the necessarily painstaking analysis of sector-specific flows for future research. Modeling sector-specific flows by transport mode at the NUTS-3 level generates an extremely high number of zero flows. This creates a need for alternative procedures, such as pseudo-Poisson estimators, that have not yet been developed for SAR models in the context of the gravity equation (dyadic observations).

The results for M1 and M2 correspond to **Eq. (1)**: i.e., the specification based on a simple OLS estimation procedure with a cross-sectional dataset and two alternative sets of regressors. The remaining models (M3–M16) are based on **Eq. (2), Eq. (5) and Eq. (6)** and include the autoregressive term, which in this case is meant to capture network effects derived from hub-spoke relationships within each previously described mode.

<<<Table 3 about here>>>

The five first models (M1–M5) in **Table 3** use the log of the aggregate flows divided by the corresponding GDPs, $\ln\left(F_{ji}/Y_iY_j\right)$, as the exogenous variable.

The results for the basic specifications, shown in **Table 3**, are in line with standard results in the gravity-model literature on interregional and international trade flows. In M1, we find significant and negative coefficients for distance and positive and significant results for the intra dummy. This confirms that intra-provincial flows are much higher than inter-provincial flows. The antilog of this result suggests that, on average, a Spanish province trades approximately 44 times more with itself—exp(3.788)—than with any other Spanish province of comparable size and equivalent distance.

This result is in general agreement with previous literature on internal home bias within countries, although the factor here is larger than in other papers, which use alternative datasets and specifications for the Spanish case (Garmendia et al., 2012; Requena and Llano, 2009). We should thus take care to note that these results are very sensitive to the dataset and specifications used.[15] In M1, $Island_i$ is highly negative and significant, indicating that the Spanish island provinces tend to export less to other provinces in the country than one might expect from their economic and geographical characteristics (logistics, relative distance). However, the parameter

[15] The main differences with alternative estimates are as follows: Garmendia et al. (2012), although using inter-provincial flows within Spain, focus on deliveries by road within the Iberian Peninsula, to the exclusion of the islands. Moreover, most previous specifications use multilateral resistance terms (fixed effects for origins and destinations), which can be redundant in the posterior estimates we base on a gravity SAR model.

for $Island_j$ is positive but non-significant, which could be a sign that Spanish islands import from other provinces at a rate similar to that of the non-island provinces.

The M2 regression presents the augmented gravity model, with new variables relating to the logistical capacity and international connectivity of each province. In this specification, distance and the *Intra* dummy are significant and have the expected signs. Home bias reaches a factor of 23, halving the previous factor. This indicates that when the logistical characteristics of the exporting and importing provinces are taken into account, trade is 23 times greater within each province than between the two provinces. This result could be a first sign of home-bias magnification at the province level when logistical infrastructure is ignored.

As in M1, the coefficient for $Island_i$ is negative and highly significant, while that for $Island_j$ itself is now negative but still non-significant. More interestingly, *international import flows relative to GDP*$_i$ (*Ln(imp. int. all*$_i$*/Y*$_i$)) appear to be positively and significantly correlated with capacity to export goods within the country. This result suggests that the more a province imports internationally, the more domestic deliveries it receives. This could be due to the presence of hub-spoke structures in the regions with the greatest international inflows (Cataluña, País Vasco, Madrid) but could also be due to other economic phenomena, such as strong input-output linkages or a *high level of internationally imported intermediate products per unit of inter-provincial export*. However, the coefficient for international exports—*Ln(exp. int. all*$_j$*/Y*$_j$)—appears to be negative, indicating a negative association between high imports of national products and high exports to international markets.

Additionally, no international border dummy has a significant impact on trade except *Border int. other* $_i$, which turns out to be negative. Accordingly, the capacity to export within Spain of provinces that share a border with Africa is below average. This suggests a degree of international isolation in Spanish border provinces, which indeed show a negative correlation between their international importing/exporting capacity and their inter-provincial export/import deliveries. This finding makes sense in light of these border provinces' past political tensions with international neighbors and their tendency to be overshadowed by other, larger Spanish provinces nearby (e.g., Girona vs. Barcelona, Guipuzcoa vs. Vizcaya, Cáceres vs. Sevilla). The

previous result for border regions and the link between internal and external trade are crucial to researchers using the C-intereg dataset—Llano et al. (2010), Garmendia et al. (2012), Llano-Verduras et al. (2011), Ghemawat et al. (2010)—or the official freight flows considered in this paper, as the data show no clear sign that international transit flows are included with inter-provincial flows.

As for the role of logistics in a trading province, the logistical-infrastructure variables in M2 (aggregate flows)—*Ln(wholesales pc_j) and Ln(wholesales pc_j)*—have a positive and significant impact on trade for both exporting and importing provinces.

The next two columns of **Table 3** report the results for aggregate flows (from both the sectoral and the transport-mode viewpoint) and the specification defined by **Eq. (2)**, which is designed specifically to address hub-spoke structures. The only difference between the two models is the weight matrix used to capture the re-exporting scheme of importing province *j* when it can be assumed to be serving as a Hub within the country. M3 uses W_{Ha}, and M4 uses W_{Hb}.

In the two cases, we obtain a positive and significant ρ, indicating that, with two alternative measures for the re-exportation scheme, there is, on average, a positive and significant relationship between inflows received (by all modes) in province *j* and exports dispatched to other provinces (by all modes) from *j*. With aggregate flows, this *could* signal a hub-spoke structure, but it could also be an effect of intra-industry trade or an indication of intense inflows and outflows of strong urban provinces. Clearly, a more detailed analysis with sector-specific flows is needed.

Furthermore, our two weight variables are defined with respect to two alternative hypothetical re-exporting schemes. Accordingly, it is worth noting that the largest positive values obtained for ρ are consistent with these levels of restrictiveness, as we obtain $\rho = 0.09$ for M3 and $\rho = 0.398$ for M4.

5.2.1. Mode-specific and cross-mode effects

For a deeper examination, we now explore flow relationships for each transport mode individually. Results for effects within each mode are reported in **Table 4.** See **M5** for *road*, **M6** for *train*, **M7** for *ship* and **M8** for *aircraft*. In all cases, the specifications follow **Eq. (2)**, and the hub-spoke network autocorrelation effect is controlled for by W_{Hb}, which in our view is the most suitable scheme for the problem at hand. Again, for the sake of brevity, we deal exclusively with hub-spoke relationships within single modes (the most natural approach with a SAR model) rather than with multimodal connections (**Table 5**).

<<<Table 4 about here>>>

In all cases, we obtain a positive and significant ρ, although with a certain variability by mode. The higher coefficients are obtained for *aircraft* (ρ=0.791) and *ship* (ρ=0.678), while the lower coefficients are obtained for *train* (ρ=0.242) and *road* (ρ=0.394). The variability of *home bias* is also considerable. Not surprisingly, the lowest (although still positive and significant) coefficient is obtained for *aircraft* (1.77), followed by *ship* (9.13), *road* (12.64) and *train* (25.58).

In interpreting these results, we would do well to focus on extreme values. On the one hand, we can account for the low but still significant home bias for *aircraft* flows by considering the intense intra-provincial *aircraft* flows between certain islands among the Canary Islands (seven islands split between the two provinces of Tenerife and Las Palmas) and the Balearic Islands (two main islands and a number of small ones). The high home bias for *ship* flows is also puzzling. On the one hand, as *ship* is the preferred mode for long-distance deliveries, we should see low *home bias* because, in terms of volume, long inter-provincial flows should exceed short intra-provincial flows. On the other hand, *ship* is also the normal mode for the transport of products between the islands of a single province as well as for heavy materials (fuel, oil, etc.) in certain coastal regions of the Iberian Peninsula. This suggests that

the *home bias* obtained for each mode should not necessarily be attributed to an external barrier to trade or fragmentation of the domestic market.

The results for our other mode-specific variables are fairly consistent with those for aggregate flows. More interestingly, the elasticity of each mode's distance variable varies from a very negative coefficient for *road* (–2.969) through a moderately negative coefficient for *ship* (–0.403) to a high positive coefficient for *aircraft* (0.604). We may interpret this result in light of the common (if insufficiently tested) practice of relating transport-mode specialization to trip distance. Thus, ground transportation, where possible, is assumed to be the most competitive mode for short trips (first *road*, then *train*), with *aircraft* and *ship* preferred for deliveries to distant markets. Here, given Spain's geography, it is reasonable to find low negative or even positive elasticities of distance for the former two modes, which are the ones needed for delivering products from the peninsula to the Canary Islands (the highly populated and most distant provinces). Conversely, we find that *road,* which is the main mode for intra-peninsular deliveries (accounting for more than 85%), shows sharp *distance decay,* in line with previous findings (Diaz-Lanchas et al., 2013; Garmendia et al., 2012).

Moreover, the coefficient for $Island_i$ is negative and significant for *road* (M5) and *train* (M6) but positive and significant for *ship* (M7) and *aircraft* (M8). Similarly, the coefficient for $Island_j$ is negative for *road*, *train* (significant) and *aircraft* (non-significant) but positive (and significant) for *ship*. This leads to the following conclusion: for the Spanish islands, transport-mode specialization is clear for *ship* for both exports and imports; however, for *aircraft*, it is positive and significant only for exports. The opposite signs for the Island dummies obtained for inter-provincial inflows and outflows by aircraft may prompt discussion of inter-modal economies of scale in the archipelagos, attributable perhaps to their imbalance with the peninsula in the trade of goods or to their strong capacity to attract national tourists by aircraft (De la Mata and Llano, 2012).

Also worth examining are the results for variables controlling for logistical infrastructure and international connectivity (presence of international borders, international trade flows). The coefficients obtained for *Ln(wholesales* pc_i*)* and *Ln(wholesales* pc_j*)* are in all

cases positive and significant. The dummy variables controlling for border provinces—*Border int. core* EU_i and *Border int. core* EU_j—always generate negative or non-significant coefficients. The coefficients for *Border int. other*$_j$ are also predominantly negative and not always significant. As for *Ln(imp. int.* all_i/Y_i), no mode generates a coefficient that is both positive and significant. *Ship* alone generates a significant but negative coefficient. *Ln(exp. int.* all_j/Y_j*)* generates negative and significant coefficients in all cases but *ship* (M8).

<<<Table 5 about here>>>

Finally, we arrive at the results in **Table 5**. These include not only the hub-spoke effects observed within each transport mode (captured by ρ) but the cross-mode effects controlled for in the inter-provincial inflows and outflows of **Eq. (5)** and **Eq. (6)**. The four first columns (**M9–M12**) correspond to the specifications described by **Eq. (5)**, where multimodal relationships are represented by two variables, *Ln(Restmod_inflow*$_i/Y_i$*)* and *Ln(Restmod_outflow*$_j/Y_j$*)*, and within-mode effects are captured by the corresponding ρ and W_{Hb}. In all cases, R^2 rises, and the coefficients obtained in the previous specifications remain slightly invariant. For *road*, *train* and (less clearly) *ship*, *Ln(Restmod_inflow*$_i/Y_i$*)* generates a positive and significant coefficient. On average, then, provinces with high numbers of inter-provincial deliveries by one mode (say, *road*) relative to their GDPs also receive intense inflows (from other provinces) via the other modes. By contrast, no such positive and significant effect is clear for *Ln(Restmod_outflow*$_j/Y_j$*)*, where only *train* (0.13) and *road* (0.062) appear to be significant. The *train* result, for example, indicates that, on average, provinces that receive considerable inter-provincial inflows by train are also likely to have considerable inter-provincial outflows by other modes.

In the next four specifications, each cross-effect is considered individually. In **M13**, we observe positive and significant effects on road flows, with inflows by *train* (0.19), *ship* (0.109) and *aircraft* (0.33). Conversely, only *ship* outflows appear to be significant. This is consistent with the aggregate results in **M9**.

More interestingly, we can now confirm that *road* plays a more important role as a complementary mode for inflows than it does for outflows. This illustrates the expected relationship whereby provinces, acting as Hubs—thanks to large ports, airports and train connections—receive flows by road from all over the country to re-export some portion of the received products to other provinces within the country, whether by road or one of the three alternative modes.

No mode other than *road* exhibits any such level of cross-mode cooperation. In **M15**, for example, we observe a negative and significant coefficient for inflows by road *(Ln(Infl_r_i/Yi))* and by train *Ln(Infl_t_i/Yi)* but no significant relationship for any other mode. We also emphasize that, in all models incorporating multimodal effects (**M9–M16**), the within-mode effects captured by the SAR component (ρ) remain, like the variables controlling for logistical infrastructures, almost invariant, with positive and significant coefficients. As for variation in other coefficients, the inclusion of cross-mode effects confirms the positive and significant elasticity of trade with respect to distance not just for *aircraft* (**M12, M16**) but also for *ship* (**M11, M15**). For home bias, if we control for cross-mode effects, then the factors decrease for all modes except *ship*, which generates a huge value (**M12, M15**). Regarding the home bias for *Road*, Spain's primary transport mode and the mode most commonly used to compute *home bias* in previous papers on Spain, we obtain a factor of 26 for the simplest specification.[16] This drops to a factor of 12.64 with the introduction of within-mode hub-spoke structures (M5) and then drops again to 8.44 and 7.99 with the introduction of between-mode effects for multimodality (**M9** and **M13**, respectively).

6. Conclusions

The aim of this paper is to propose a new strategy for the modeling of bilateral trade flows, using the gravity equation, but also to account for the cross-sectional autocorrelation effects of unobservable re-exporting schemes occasioned by *logistical infrastructures* (warehouses and wholesale activities) and *hub-spoke structures*. The paper develops various

[16] This factor of 26 (exp(3.268) is obtained when running model M1, using *road* flows.

gravity models that incorporate cross-sectional autocorrelation effects and feeds into them a novel dataset containing aggregate flows between the fifty provinces of Spain by four alternative transport modes (road, train, ship and aircraft). This approach yields rich and promising results:

In most of our specifications, significant and positive autocorrelation effects are obtained when modeling aggregate flows. Although this could be associated with the detection of hub-spoke structures due to re-exportation schemes of specific items, it could also be plausibly explained by other factors (e.g., vertical intra-industry trade due to multi-stage production). Thus, additional investigation, using finer datasets at the product level, is needed. We can, however, draw at least four important conclusions:

(i) As our results suggest, our dataset is (mostly) free of international transit flows, as we find no "inflation" of inter-provincial flows among border provinces, attributable to their status as *gateways* or *corridors* to important foreign markets.

(ii) Our mode-specific flow calculations generate interesting results with regard to the elasticity of distance (positive for *ship* and *aircraft*) and the specialization of certain provinces (islands) in non-ground transport modes.

(iii) Although we find variation in *home bias* when modeling mode-specific flows, we have shown that it decreases if we control for logistical infrastructure and the network autocorrelation effects associated with (potential) hub-spoke structures.

(iv) Whether we examine aggregate or mode-specific flows, Spanish provinces that are strong inter-provincial importers are also strong intra-provincial exporters. This important result is consistent with our two definitions of hub-spoke structures. The extended specifications incorporating cross-mode effects also produce very interesting results with regard to the likely presence of multimodal re-exporting schemes in Spain.

Further research is needed to refine the modeling strategy and the empirical assessments, for Spain and other countries, of sector-specific flows and to develop procedures that can handle large numbers of zeroes. The use of alternative approaches based on spatial filtering to control for the re-exporting flows associated with the hub-spoke structure (Fischer

and Griffith, 2008) should also be considered. For the present, however, we submit these results as a contribution to a complex topic that has received little attention in the field of spatial analysis and in the literature on international and interregional trade.

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Tables

Table 1: Transport statistics used to estimate Spanish interregional trade

MODE	DESCRIPTION AND MAIN FEATURES
ROAD	*Permanent Survey on Goods Transport by Road (Encuesta Permanente de Mercancías por Carretera-EPTMC)* Source: Ministerio de Fomento (Spanish Ministry of Public Works)
TRAIN	*RENFE Statistics on Complete Wagon and Container Flows.* Source: Statistics Department of RENFE
SHIP	*Statistics from Spanish Ports (Puertos del Estado).* Source: Llano et al. (2009)
AIRCRAFT	*O/D matrices of domestic flows of goods by airport of origin and destination 1995. AENA.* Source: AENA & Ministerio de Fomento.

Table 2: Variables

Name (variables for importing regions in parentheses)	**Description**	**Source**
$F_{ji}^{R}; F_{ji}^{T}; F_{ji}^{S}; F_{ji}^{A}$	Inter-provincial flows in Spain by transport mode (R, T, S and A)	Several sources reported in Table 1. Prepared for the C-intereg project.
Pop_i (Pop_j)	Population of province *i* (Population of province *j*)	INE. Regional Accounts.
GDP_i (GDP_j)	Gross Domestic Product of province *i* (Gross Domestic Product of province *j*)	INE. Regional Accounts.
d_{ij}	▪ For distance within the Iberian Peninsula: actual distance traveled by trucks on their deliveries (EPTMC). ▪ For distance between provinces within the Iberian Peninsula and islands: actual distance to main ports + actual distance from ports to islands by ship.	▪ EPTMC. Ministerio de Fomento. ▪ Puertos del Estado.
$Intra_{ij}$	Dummy variable that takes value 1 if $i = j$ and 0 otherwise.	Authors
$Adjac_{ij}$	Dummy variable that takes value 1 if *i* and *j* share a common border within Spain and 0 otherwise.	Authors
Wholesalers pc_i (*Wholesalers* pc_j)	Ratio between number of wholesale companies in province *i* (*j*) and population of same province. Variable expressed in logs and used as alternative to the "platform infrastructure".	La Caixa, Anuario Económico, 2007.
$Island_i$ ($Island_j$)	Dummy variable that takes value 1 if exporting region *i* (importing province *j*) is an island province: Islas Baleares; Las Palmas and Santa Cruz de Tenerife.	Authors
Imp. int. all$_i/Y_i$ (*Exp. int. all*$_i/Y_j$)	International imports of all products in province *i* regardless of transport mode, in relative terms to province GDP (Idem for exports in province *j*)	Official international trade data. AEAT
Border int. core EU$_i$ (*Border int. core EU*$_j$)	Dummy variable that takes value 1 for Spanish provinces bordering on France or Andorra and 0 otherwise. (Idem for province *j*)	Authors
Border int. other$_i$ (*Border int. other*$_j$)	Dummy variable that takes value 1 for Spanish provinces bordering on Portugal or Africa and 0 otherwise. (Idem for province *j*)	Authors
Restmodes_inflows$_i/Y_i$ (*Restmodes_outflows*$_i/Y_j$)	Inflows to the exporting province from the rest of the country, by modes other than that of the endogenous variable. Inflows expressed in relative terms to GDP of the exporting province *(i)* (equivalent definition for *Restmodes_outflows*$_i/Y_j$).	
$\left(\text{Inflows}_i^{train} \Big/ Y_i \right)$	Interprovincial inflows by train to the exporting province (i), relative to the exporting province's GDP.	

Table 3. Estimates for sectoral aggregated flows. All modes.

	M1	**M2**	**M3**	**M4**
Flow type	All modes	All modes	All modes	All modes
	$Ln(F_{ij}/YiYj)$	$Ln(F_{ij}/YiYj)$	$Ln(F_{ij}/YiYj)$	$Ln(F_{ij}/YiYj)$
W type			W_{Ha}	W_{Hb}
Rbar-squared	0,1297	0,1897	0,1899	0,2017
$sigma^2$	29,9132	27,1393	26,9839	26,2179
log-likelihood			-6799,9784	-6772,8262
Ln(wholesalers pc_i)		0.293***	0.293***	0.294***
		(4.292)	(4.316)	(4.392)
$Island_i$	-2.742***	-2.016***	-2.019***	-1.944***
	(-5.42)	(-3.985)	(-4.001)	(-3.908)
Border int. core EU_i		0.38	0.378	0.384
		(1.066)	(1.062)	(1.096)
Border int. $other_i$		-0.83***	-0.826***	-0.823***
		(-2.846)	(-2.839)	(-2.871)
Ln(imp. int. all_i/Y_i)		8.3***	8.271***	8.31***
		(8.775)	(8.764)	(8.932)
Ln(wholesalers pc_j)		0.15**	0.149**	0.16**
		(2.084)	(2.073)	(2.258)
$Island_j$	0.82	-0.291	-0.287	0.243
	(1.621)	(-0.521)	(-0.515)	(0.439)
Border int. core EU_j		-0.528	-0.526	-0.364
		(-1.492)	(-1.49)	(-1.046)
Border int. $other_j$		-0.352	-0.343	-0.159
		(-1.209)	(-1.18)	(-0.554)
Ln(exp. int. all_j/Y_j)		-2.071**	-2.102**	-3.595***
		(-2.497)	(-2.525)	(-4.289)
Ln(distance)	-1.704***	-2.044***	-2.044***	-2.099***
	(-7.218)	(-8.79)	(-8.802)	(-9.182)
Intra	3.788***	3.127***	3.126***	3.287***
	(4.15)	(3.565)	(3.573)	(3.812)
Adjac	2.867***	2.668***	4.626***	2.663***
	(6.089)	(5.918)	(11.688)	(6.01)
Constant	7.323***	-24.057***	-23.924***	-12.331***
	(4.928)	(-7.052)	(-6.989)	(-3.36)
rho			0.09***	0.398***
			(9.163)	(7.854)
exp (intra)	44,17	22,81	22,78	26,76

Table 4. Estimates for transport-mode-specific flows

	M5	**M6**	**M7**	**M8**
Flow type	Road	Train	Ship	Aircraft
	$Ln(F^{R}_{ij}/Y_iY_j)$	$Ln(F^{T}_{ij}/Y_iY_j)$	$Ln(F^{S}_{ij}/Y_iY_j)$	$Ln(F^{A}_{ij}/Y_iY_j)$
W type	W_{Hb}	W_{Hb}	W_{Hb}	W_{Hb}
Rbar-squared	0,3293	0,2592	0,432	0,6018
sigma^2	30,6416	30,1559	19,2091	5,9474
log-likelihood	-6967,5415	-6942,1488	-6401,0029	-4945,0298
Ln(wholesalers pc$_i$)	0.824***	1.362***	0.835***	0.499***
	(11.336)	(18.89)	(14.621)	(15.666)
Island$_i$	-5.605***	-2.874***	9.107***	6.313***
	(-10.424)	(-5.483)	(22.664)	(26.491)
Border int. core EU$_i$	0.5	0.101	-1.022***	-0.397**
	(1.318)	(0.268)	(-3.405)	(-2.373)
Border int. other$_i$	-1.541***	-1.885***	0.39	-0.614***
	(-4.971)	(-6.145)	(1.592)	(-4.495)
Ln(imp. int. all$_i$/Y$_i$)	1.152	1.353	-1.143	-1.612***
	(1.116)	(1.357)	(-1.439)	(-3.646)
Ln(wholesalers pc$_j$)	0.381***	0.637***	0.194***	0.147***
	(4.757)	(7.211)	(3.206)	(3.928)
Island$_j$	-3.722***	-2.452***	2.486***	-0.593
	(-5.73)	(-4.044)	(5.531)	(-1.075)
Border int. core EU$_j$	-0.032	-0.523	0.355	-0.168
	(-0.086)	(-1.403)	(1.193)	(-1.013)
Border int. other$_j$	-0.78**	0.017	0.05	-0.212
	(-2.458)	(0.055)	(0.203)	(-1.543)
Ln(exp. int. all$_j$/Y$_j$)	-7.841***	-4.723***	-0.624	-1.534***
	(-8.585)	(-5.397)	(-0.899)	(-3.776)
Ln(distance)	-2.969***	-0.504**	-0.403***	0.604***
	(-11.944)	(-2.199)	(-2.75)	(5.642)
Intra	2.537***	3.242***	2.212***	0.57
	(2.715)	(3.533)	(2.699)	(1.409)
Adjac	2.01***	2.574***	0.465	0.401*
	(4.186)	(5.568)	(1.293)	(1.901)
Constant	40.307***	10.324***	4.749*	2.629
	(10.048)	(2.913)	(1.787)	(1.684)
rho	0.394***	0.242***	0.678***	0.791***
	(7.723)	(7.426)	(127.076)	(15.976)
exp (intra)	12,64	25,58	9,13	1,77

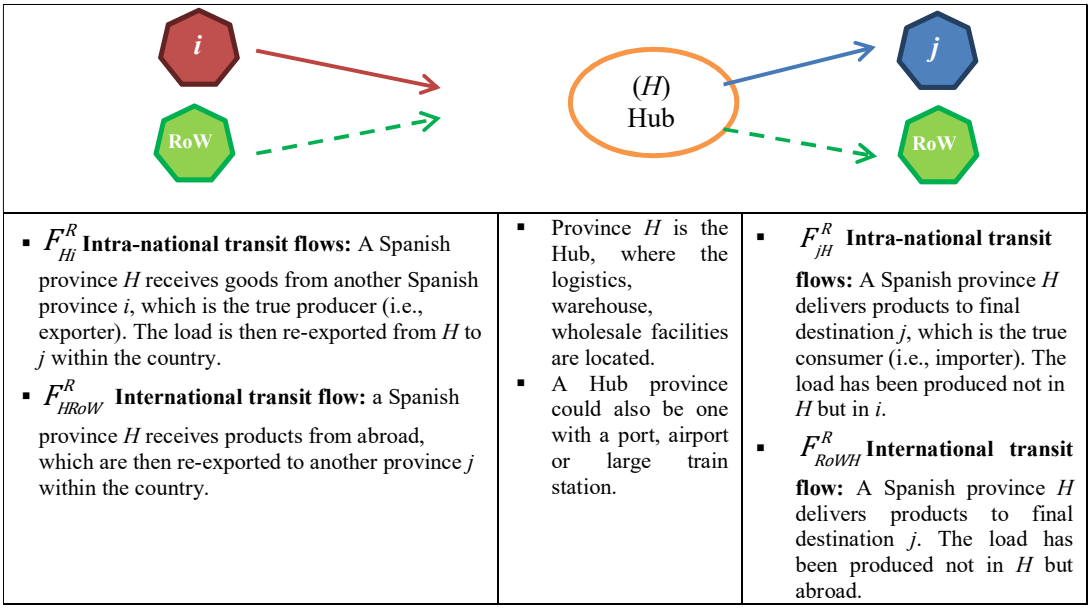
Table 5. Estimates for transport-mode-specific flows with cross-mode effects

	M9	M10	M11	M12	M13	M14	M15	M16
Flow type	Road	Train	Ship	Aircraft	Road	Train	Ship	Aircraft
	$Ln(F^{R}_{ij}/Y_iY_j)$	$Ln(F^{T}_{ij}/Y_iY_j)$	$Ln(F^{S}_{ij}/Y_iY_j)$	$Ln(F^{A}_{ij}/Y_iY_j)$	$Ln(F^{R}_{ij}/Y_iY_j)$	$Ln(F^{T}_{ij}/Y_iY_j)$	$Ln(F^{S}_{ij}/Y_iY_j)$	$Ln(F^{A}_{ij}/Y_iY_j)$
W type	W_{Hb}	W_{Hb}	W_{Hb}	W_{Hb}	W_{Hb}	W_{Hb}	W_{Hb}	W_{Hb}
Rbar-squared	0,3471	0,2738	0,4368	0,6011	0,3522	0,2773	0,5139	0,625
$sigma^2$	29,9988	29,6452	19,0487	5,9512	29,8093	29,4358	17,187	5,7377
log-likelihood	-6940,5282	-6920,2576	-6388,5761	-4945,5623	-6931,2438	-6911,6721	-6261,7244	-4901,6206
Ln(wholesalers pc_i)	0.444***	1.165***	0.74***	0.501***	0.421***	1.206***	0.422***	0.433***
	(4.964)	(14.402)	(10.97)	(13.041)	(4.692)	(14.394)	(6.29)	(11.244)
$Island_i$	-7.306***	-3.976***	7.912***	6.334***	-7.712***	-3.368***	-5.684***	2.718***
	(-12.51)	(-6.579)	(18.664)	(26.683)	(-10.438)	(-2.807)	(-5.869)	(5.362)
Border int. core EU_i	0.387	0.312	-1.279***	-0.384**	0.434	0.194	-0.955***	-0.489***
	(1.031)	(0.834)	(-4.257)	(-2.289)	(1.126)	(0.518)	(-3.265)	(-2.92)
Border int. $other_i$	-1.509***	-1.77***	0.237	-0.609***	-1.531***	-1.758***	-0.691***	-0.94***
	(-4.92)	(-5.804)	(0.969)	(-4.455)	(-5.004)	(-5.576)	(-2.869)	(-6.739)
log (imp. int. alli/Yi)	0.86	1.403	-1.084	-1.483***	1.223	0.898	7.404***	0.913
	(0.842)	(1.418)	(-1.353)	(-3.282)	(1.14)	(0.749)	(7.797)	(1.667)
log (wholesalers pc_j)	0.26**	0.553***	0.165**	0.144***	0.248**	0.564***	0.182**	0.133***
	(2.545)	(6.156)	(2.138)	(3.114)	(2.437)	(6.191)	(2.376)	(2.882)
$Island_j$	-3.522***	-2.13***	1.988***	-0.52	-4.843***	-0.857	2.604***	-0.63
	(-5.487)	(-3.649)	(3.863)	(-0.94)	(-6.696)	(-0.709)	(2.712)	(-0.903)
Border int. core EU_j	-0.086	-0.507	0.279	-0.158	0.083	-0.532	0.303	-0.123
	(-0.231)	(-1.37)	(0.935)	(-0.95)	(0.22)	(-1.437)	(1.065)	(-0.741)
Border int. $other_j$	-0.653**	0.204	-0.042	-0.207	-0.699**	0.357	-0.011	-0.167
	(-2.056)	(0.654)	(-0.165)	(-1.473)	(-2.206)	(1.093)	(-0.043)	(-1.137)
Ln(exp. int. allj/Yj)	-8.1***	-4.704***	-0.246	-1.445***	-7.286***	-4.955***	-0.979	-1.431***
	(-8.911)	(-5.399)	(-0.348)	(-3.44)	(-7.557)	(-4.74)	(-1.213)	(-3.093)
Ln(distance)	-3.172***	-1.02***	1.012***	0.613***	-3.186***	-0.978***	0.56***	0.432***
	(-12.83)	(-4.192)	(5.18)	(5.568)	(-12.859)	(-3.951)	(2.932)	(3.894)
Intra	2.133**	2.26**	5.663***	0.631	2.079**	2.345**	4.794***	0.276
	(2.303)	(2.465)	(7.701)	(1.533)	(2.248)	(2.552)	(6.808)	(0.678)
Adjac	1.927***	2.109***	2.023***	0.397*	1.926***	2.133***	1.747***	0.246
	(4.056)	(4.476)	(5.354)	(1.879)	(4.062)	(4.53)	(4.837)	(1.179)
Ln(Restmod_infl/Yi)	0.181***	0.161***	0.058*	-0.004				
	(7.159)	(5.264)	(1.949)	(-0.292)				
Ln(Restmod_outfl/Yj)	0.062*	0.13**	0.023	-0.001				
	(1.864)	(2.439)	(0.746)	(-0.049)				
Ln(Infl_r_i/Y_i)						0.075	-3.414***	-1.299***
						(0.231)	(-13.668)	(-8.954)
Ln(Infl_t_i/Y_i)					0.19***		-0.074**	0.028
					(4.017)		(-2.07)	(1.355)
Ln(Infl_s_i/Y_i)					0.109***	0.254***		-0.062***
					(2.678)	(6.075)		(-3.529)
Ln(Infl_a_i/Y_i)					0.33***	-0.09	0.415***	
					(4.118)	(-1.146)	(7.256)	
Ln(Outfl_r_j/Y_j)						0.456	0.088	0.031
						(1.469)	(0.364)	(0.214)
Ln(Outfl_t_j/Y_j)					-0.05		0.051	-0.015
					(-1.098)		(1.491)	(-0.737)
Ln(Outfl_s_j/Y_j)					0.297***	-0.006		0.051
					(3.189)	(-0.066)		(1.308)
Ln(Outfl_a_j/Y_j)					0.142	0.25***	-0.097	
					(1.524)	(2.715)	(-1.455)	
Constant	39.487***	6.794*	-6.77**	2.17	35.875***	5.66	25.429***	14.765***
	(9.983)	(1.727)	(-2.329)	(1.337)	(8.748)	(0.951)	(5.617)	(5.351)
rho	0.382***	0.221***	0.652***	0.787***	0.349***	0.232***	0.674***	0.805***
	(7.457)	(72.913)	(124.732)	(16.029)	(7.065)	(74.705)	(127.22)	(16.395)
exp (intra)	8,44	9,58	288,01	1,87	7,99	10,43	120,78	1,31

Figures

Figure 1:

Figure 1: "Hub-spoke" structure with national and international "transit flows"

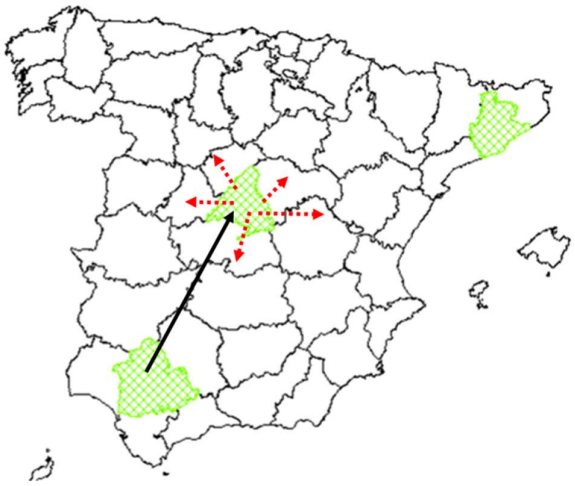


▪ F^{R}_{Hi} **Intra-national transit flows:** A Spanish province *H* receives goods from another Spanish province *i*, which is the true producer (i.e., exporter). The load is then re-exported from *H* to *j* within the country. ▪ F^{R}_{HRoW} **International transit flow:** a Spanish province *H* receives products from abroad, which are then re-exported to another province *j* within the country.	▪ Province *H* is the Hub, where the logistics, warehouse, wholesale facilities are located. ▪ A Hub province could also be one with a port, airport or large train station.	▪ F^{R}_{jH} **Intra-national transit flows:** A Spanish province *H* delivers products to final destination *j*, which is the true consumer (i.e., importer). The load has been produced not in *H* but in *i*. ▪ F^{R}_{RoWH} **International transit flow:** A Spanish province *H* delivers products to final destination *j*. The load has been produced not in *H* but abroad.

Figure 2. Two alternative definitions of the hub-spoke relationship

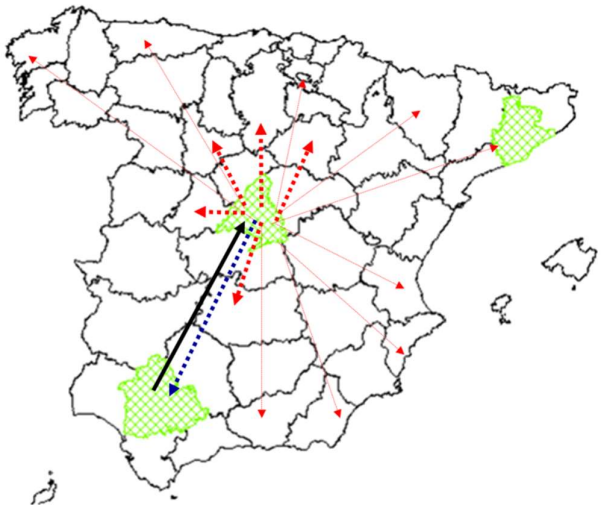
Example: $F_{ji}^{R} = F_{21}^{R}$

Let us consider a system of 5 provinces and the interprovincial delivery by road from province 1 to 2 (*1→2).*



W_{Hb}

Here, the "potential re-exporting flows from the hub" will be all deliveries going from 2 (potential Hub) to its contiguous provinces exclusively: e.g., 2→4 (since 2→1 is excluded). This is the most restrictive definition of "re-exportation" in this paper.

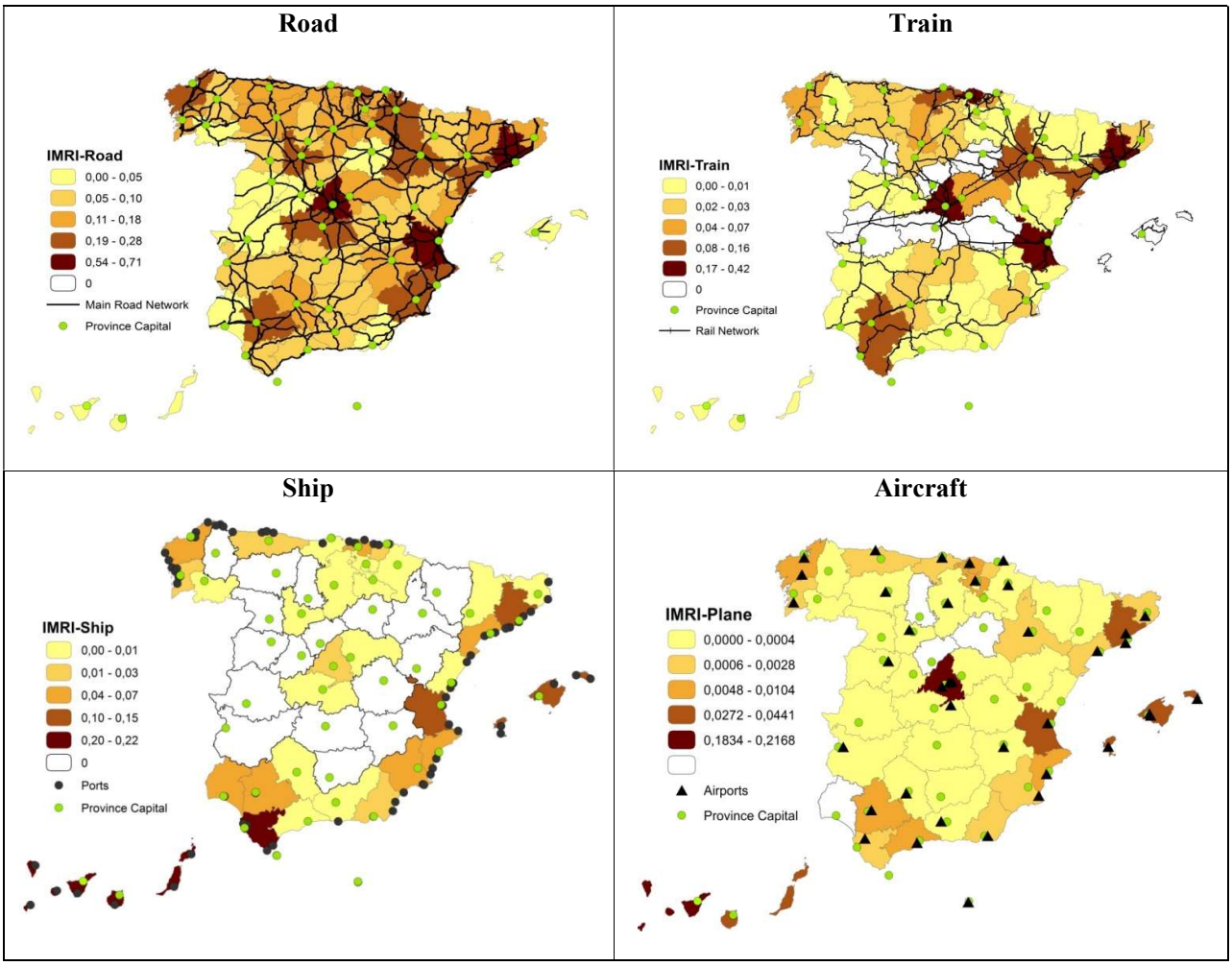


W_{Hc}

In this case, the "potential hub-spoke relationships" corresponds to all potential nodes connecting the province 2 (potential hub) to any region except 1 in the system. Each node is weighted by the relative distance to the Hub (H = 2). Thus, the nearest provinces receive a larger weight. If 3 is the nearest region to 2, followed by 4 and then 5, we have:

$$\left\{ 1/D_{23} > 1/D_{24} > 1/D_{25} \right\}$$

Figure 3. IMRI computed for freight flows by mode (2007).



Annex: Case 1

For the sake of clarity, in this annex an example is described in detail. As in LeSage and Pace (2008), we depart from a Destination-Origin matrix (D-O), where destinations *j* appear in rows and origins in columns *i*. Intra-provincial flows are in on-diagonal elements and inter-provincial flows in the off-diagonal ones. Let us consider a system of 5 provinces, and the interprovincial delivery (1→2) from province *i*=1 to a province *H*=2 by road, which may operate as a potential *Hub* re-exporting the same load to other final destinations by road ($F_{21}^{R} = 687€$). Besides, the contiguity matrix is reported. Below, this D-O matrix is expressed as a linear vector F_{ji}^{R} . In both cases, the observation $F_{21}^{R} = 687€$ is highlighted in black. In addition, we have also remarked in red in the contiguity matrix the two provinces (1 and 4) that are adjacent to province 2, that is, the destination province (*H=2*) of the flow under consideration.

Figure 4. Scheme representing the Destination-Origin matrix and the contiguity matrix

Flows (D-O matrix)

	Origins	1	2	3	4	5
Dest	1	12	699	98	87	6
	2	**687**	23	93	3	561
	3	98	93	23	14	4
	4	5634	67	14	53	456
	5	6	566	56	567	45

Contiguity

	1	2	3	4	5
1	0	1	0	0	1
2	1	0	0	1	0
3	0	0	0	1	0
4	0	1	1	0	1
5	1	0	0	1	0

					Alternative W		
Observ	F_{ji}	**Orig**	**Dest**	**Flow**	W_d	W_{Ha}	W_{Hb}
1	F_{11}	1	1	12	1	0	0
2	F_{21}	**1**	**2**	**687**	0	0	0
3	F_{31}	1	3	98	0	0	0
4	F_{41}	1	4	5634	0	0	0
5	F_{51}	1	5	6	0	0	0
6	F_{12}	2	1	699	0	0	0
7	F_{22}	*2*	*2*	*23*	0	0	$1/d_{22}$
8	F_{32}	*2*	*3*	*93*	0	0	$1/d_{32}$
9	F_{42}	*2*	*4*	*67*	0	1	$1/d_{42}$
10	F_{52}	*2*	*5*	*566*	0	0	$1/d_{52}$
11	F_{13}	3	1	98	0	0	0
12	F_{23}	3	2	93	0	0	0
13	F_{33}	3	3	23	0	0	0
14	F_{43}	3	4	14	0	0	0
15	F_{53}	3	5	56	0	0	0
16	F_{14}	4	1	87	1	0	0
17	F_{24}	4	2	3	0	0	0
18	F_{34}	4	3	14	0	0	0
19	F_{44}	4	4	53	0	0	0
20	F_{54}	4	5	567	0	0	0
21	F_{15}	5	1	6	0	0	0
22	F_{25}	5	2	561	0	0	0
23	F_{35}	5	3	4	0	0	0
24	F_{45}	5	4	456	0	0	0
25	F_{55}	5	5	45	0	0	0

On the left hand side of the vector, we report the 25 observations as they appear after transforming the D-O matrix into a *destination-based vector*. In the right hand side, we report three colored columns with the two weigh matrices used to address the hub-spoke structures (W_{Ha}, W_{Hb}) along with the standard *destination-based* W_d matrix used in other papers (LeSage and Pace, 2008; LeSage and Llano, 2013; De la Mata and Llano, 2013; Alamá-Sabater et al, 2013).

By means of colors, it is easy to describe which "nodes" that are "associated" for each W to the reference flow F_{21}^{R} :

- ***W_d:*** This is the standard destination-based weight matrix used in previous papers. With it, just the 'nodes' $\left(F_{11}^{R}; F_{41}^{R}\right)$, highlighted in grey, will have a 'one'. Those are the nodes that identify the deliveries from the same origin (*i=1*) to the neighbors of 2 (1 & 4). This matrix is not considered in our paper. We include it here to highlight that it is defined in a similar way than ours.

- ***W_{Ha}:*** this matrix corresponds to the most restrictive definition of "potential hub-spoke" relationships used in this paper, since it just considers potential re-exportation schemes from the potential hub *H=2* to its neighbors $\left(F_{42}^{R}\right)$, with the exception of the perfect loop $\left(F_{12}^{R}\right)$, shadowed in yellow. Note that in this case the *associated* flow to F_{21}^{R} , highlighted in magenta, is different to the ones in ***W_d***.

- ***W_{Hb}:*** the flows associated to F_{21}^{R} using this weight matrix are the ones departing from the potential hub *H=2* $\left(F_{22}^{R}; F_{32}^{R}; F_{42}^{R}; F_{52}^{R}\right)$, with the exception of the perfect loop $\left(F_{12}^{R}\right)$. Note that each of these 'nodes', highlighted in purple, has a factor equal to the inverse of the distance to the potential hub *H=2*. None of these "nodes" were considered as "destination-neighbors" in W_d, and just one in ***W_{Ha}*** with a factor of 1.

Finally, as a complement to the previous example, the following **Figure 5** (**panels A, B**) shows the structure of the two alternative W_H matrices, and the way in which they identify the precise flows that are relevant for each kind or definition of "potential hub-spoke" relationship. Cells highlighted in yellow correspond to the perfect-loop flows, set to zero by assumption.

Figure 5. Scheme representing the two alternative weight matrices

Panel A

W_{Ha}: Flows from *H* to its contiguous provinces

Observ		1	2	3	4	5	6	7	8	9	10	…	21	22	23	24	25
		dest															
		1	2	3	4	5	1	2	3	4	5	…	1	2	3	4	5
orig	1	0	1	0	0	1	0	0	0	0	0	…	0	0	0	0	0
	2	0	0	0	0	0	0	0	0	1	0	…	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0	0	…	0	0	0	0	0
	4	0	0	0	0	0	0	0	0	0	0	…	0	0	0	0	0
	5	0	0	0	0	0	0	0	0	0	0	…	0	0	0	1	0
	1	0	0	0	0	1	0	0	0	0	0	…	0	0	0	0	0
	2	0	0	0	0	0	1	0	0	1	0	…	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0	0	…	0	0	0	0	0
	4	0	0	0	0	0	0	0	0	0	0	…	0	0	0	0	0
	5	0	0	0	0	0	0	0	0	0	0	…	1	0	0	1	0
	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋱	⋮	⋮	⋮	⋮	⋮
	1	0	1	0	0	0	0	0	0	0	0	…	0	0	0	0	0
	2	0	0	0	0	0	1	0	0	1	0	…	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0	0	…	0	0	0	0	0
	4	0	0	0	0	0	0	0	0	0	0	…	0	0	0	0	0
	5	0	0	0	0	0	0	0	0	0	0	…	1	0	0	1	0

Panel B

W_{Hb}: all flows from *H* weighted by the inverse of distance from *H to j*

Observ		1	2	3	4	5	6	7	8	9	10	…	21	22	23	24	25
		dest															
		1	2	3	4	5	1	2	3	4	5	…	1	2	3	4	5
orig	1	0	$1/D_{21}$	$1/D_{31}$	$1/D_{41}$	$1/D_{51}$	0	0	0	0	0	…	0	0	0	0	0
	2	0	0	0	0	0	0	$1/D_{22}$	$1/D_{32}$	$1/D_{42}$	$1/D_{52}$	…	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0	0	…	0	0	0	0	0
	4	0	0	0	0	0	0	0	0	0	0	…	0	0	0	0	0
	5	0	0	0	0	0	0	0	0	0	0	…	0	$1/D_{25}$	$1/D_{35}$	$1/D_{45}$	$1/D_{55}$
	1	$1/D_{11}$	0	$1/D_{31}$	$1/D_{41}$	$1/D_{51}$	0	0	0	0	0	…	0	0	0	0	0
	2	0	0	0	0	0	$1/D_{12}$	0	$1/D_{32}$	$1/D_{42}$	$1/D_{52}$	…	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0	0	…	0	0	0	0	0
	4	0	0	0	0	0	0	0	0	0	0	…	0	0	0	0	0
	5	0	0	0	0	0	0	0	0	0	0	…	$1/D_{15}$	0	$1/D_{35}$	$1/D_{45}$	$1/D_{55}$
	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋱	⋮	⋮	⋮	⋮	⋮
	1	$1/D_{11}$	$1/D_{21}$	$1/D_{31}$	$1/D_{41}$	0	0	0	0	0	0	…	0	0	0	0	0
	2	0	0	0	0	0	$1/D_{12}$	$1/D_{22}$	$1/D_{32}$	$1/D_{42}$	0	…	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0	0	…	0	0	0	0	0
	4	0	0	0	0	0	0	0	0	0	0	…	0	0	0	0	0
	5	0	0	0	0	0	0	0	0	0	0	…	$1/D_{15}$	$1/D_{25}$	$1/D_{35}$	$1/D_{45}$	0