# Transport-mode competition in intra-national trade: an empirical investigation for the Spanish case [1]

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**Abstract:**

*Trade* within and between countries can take place by alternative *transport modes*. Economic and logistical complexity is fostering multimodality as well as transport-mode competition. The international trade literature has given little attention to this issue. The aim of this paper is to analyze transport-mode competition in inter-provincial deliveries within Spain. To this end, we use a detailed dataset with fifty inter-provincial, industry-specific flows by four transport modes (*road*, *train*, *ship* and *aircraft*). We then feed this dataset into various specifications of a gravity model that incorporates cross-sectional dependence attributable to unobservable factors directly associated with the presence of transport-mode competition schemes. In considering alternative distance segments, we also test for competition effects between *road* and the other three modes.

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## 1. Introduction

Trade within and between countries can take place by alternative *transport modes*. Economic and logistical complexity is fostering multimodality as well as transport-mode competition (Rodrigue, 2003; Hesse and Rodrigue, 2004; Rodrigue and Notteboom, 2010).

According to the World Trade Organization (WTO), from 1990 to 2013 the world's international exports of goods increased about 8% annually. Most international trade had taken place by sea (89.8% in 2008), and to a lesser extent by land (road and, more rarely, train, with a total of about 9.96%). Ships are simply the most efficient mode for long distances, while road is the most convenient for door-to-ship/ship-to-door hauls and for distribution between and within countries. But when we look at trade *within* countries the pattern changes drastically. In Spanish interregional trade, for example, *road* is the transport mode with the greatest share, representing on average approximately 83% of trade value in 2005–2009, with ships representing around 19% and trains 3% for the same period.

Several factors can explain this polarized modal split in Spain. On the one hand, short-distance distribution of goods by truck represents a significant share of total trade within the country. On the other, Spain's geographical characteristics—natural impediments in some areas, small national territory—limit the maximum road distance to about 1,230 kilometers, at times making train transport or train-road combinations very costly. The Spanish Ministry of Public Works has estimated that for a road-train combination to be profitable the trip must exceed 600 kilometers, a distance threshold that we test in forthcoming sections.

As the next section will show, the variety and interconnection of transport modes are key to promoting economic and social welfare within countries (Bensassi et al., 2015; Duranton et al., 2013; Moïse and Le Bris, 2013; Nguyen and Tongzon, 2011; Korinek and Sourdin, 2011; Vasiliauskas and Barysiené, 2008; Martinez-Zarzoso et al., 2008; Lee and Rodrigue, 2006; Yap et al., 2006). Indeed, competition between these modes can bolster overall economic competitiveness and progress nationally, as the availability of transport modes other than road can be critical to making freight activity, and the whole modern economy, more sustainable.

The European Commission is working in this direction for the EU (Feo-Valero, 2011; European Commission, 2001, 2004, 2006).

Within this context, this paper analyzes the presence of transport-mode competition within a country, taking into consideration the international openness and key logistical infrastructures of each province. In contrast to other papers (Cantos-Sánchez et al., 2009; Álvarez-SanJaime et al., 2013a, 2013b), where modal shifts are modeled on demand functions, our methodology seeks to identify competing transport-mode structures (mainly between *road* and the other three modes) within actual flow data.For this purpose, we use a novel dataset, with aggregate and sector-specific flows between Spain's fifty-two provinces by four different transport modes (*road*, *train*, *ship* and *aircraft*). Our database includes 110,000 origin-destination observations (50*50*4*11[2]) for the single year of 2007, along with a comprehensive set of regressors and rich distance measures drawn from Spain's actual transportation network.

To deal with transport-mode competition, we plug our data into various specifications of the Spatial Autoregressive Gravity Model (SARGM), following LeSage and Pace (2009). These specifications incorporate spatial dependence for the endogenous variable attributable to omitted variables. In all of these specifications, we use three novel variables to capture competing effects between the main transport mode (*road*) and the three alternatives (*train, ship* and *aircraft*). Moreover, we define a set of specifications that accounts for four sources of cross-sectional effects. These effects can be associated with competition effects taking place not just between the trading provinces (*origin-destination* dyads), but also between each trading province and its neighboring regions, by each of the four alternative transport modes. This strategy allows us to identify *transport-mode competition schemes* hidden within aggregate trade flows. Furthermore, we define an extended specification of the SARGM in which transport distance is segmented. The aim of this extension is to test if the "road" transportation mode is able to co-exist (compete) with the other three alternative modes within each one of these segments of distance.

[2] The dimensions considered here correspond to: 50 provinces; 4 transport modes; 1 vector of aggregate flows + 10 vectors of sector specific flows.

This empirical approach permits us to delve deeply into a recent literature (Bensassi et al., 2015; Gallego et al., 2015; Alamá-Sabater et al., 2013; LeSage and Polasek, 2008) that links trade to transport through augmented gravity equations and includes either spatial or network autocorrelation terms in its trade-flow modeling. Whereas this literature covers both aggregate and sector-specific interregional flows, our empirical analysis provides a new *within-country spatial dimension* that, to the best of our knowledge, has not previously been considered.

The rest of the paper is structured as follows: Section 2 describes some important links between trade, transportation and logistics and briefly reviews the state of the art in the analysis of these complexities in Spain and elsewhere. Section 3 lays out our empirical strategy for dealing with transport-mode competition schemes. Section 4 describes the dataset. Section 5 comprises our descriptive and econometric analysis of the patterns obtained for each product type, and uses a hierarchical cluster analysis to elucidate differences and similarities. We finally estimate kernel regressions in search for the segments of distance at which the intensities of the flows using different modes tend to agglomerate.

## 2. Trade, logistics and transport-mode competition.

The literature on trade and transportation emphasizes the quality of logistics as a trade facilitator (Lee and Rodrigue, 2006; Vasiliauskas and Barysiené, 2008; Nguyen and Tongzon, 2011). High-quality logistics improve the competitiveness of a country by reducing the cost of transporting goods. In our view, it is straightforward to consider that countries (or regions within countries) with strong competition between transport modes are more likely to enjoy efficiency gains, not just when exporting to other countries (or regions) but also when distributing within their own territory.

Several studies have analyzed the link between international trade and logistics, but few have simultaneously considered the link between logistics, on the one hand, and internal and external trade flows, on the other. In Korinek and Sourdin (2011), for example, 'only logistics services that are directly related to international trade and the transport of goods from one economy to another are covered…'. Others just focus on logistics and the distribution of products within a country. Thus Alamá-Sabater et al. (2013), who analyze whether transport connectivity affects trade flows within a country. To find out, they develop a logistics-network index and plug it into a spatial autoregressive model for fifteen inner regions (Nuts 2) of Spain and sector-specific flows by road. The results confirm the role of logistics-platform location in satisfying existing demand for transport structures in Spain and the presence of spatial-dependence effects. In an interesting departure, Bensassi et al. (2015) stress the quality of logistics, rather than just geographical factors and transport infrastructure, as a key factor in international and intra-national competitiveness. In addition to transportation cost (proxy by distance), then, the quality of logistics infrastructure and the distribution of intermodal facilities within countries may significantly enhance international competitiveness and expand company market shares. Using a similar dataset for inter-provincial trade, they find that logistics is indeed important for the analysis of trade flows in goods and highlight the importance of regional logistics measures.

In a recent article, Gallego et al. (2015) describe a methodology that aims to control for potential cross-section autocorrelation induced by the presence of hub-spoke structures both within each mode (re-exporting schemes) and between modes (multimodal deliveries). The approach is based on an extended gravity equation that incorporates these network autocorrelation effects.

Our focus, meanwhile, is the alternative problem: the possibility that competition between modes also affects the sector-specific flows modeled by the gravity equation[3].

[3] The literature in this area contains a number of stimulating papers that take alternative approaches to analyzing the presence of competition and cooperation schemes between different transport modes within Spain (Monzón and Rodríguez-Dapena, 2006; Cantos-Sánchez et al., 2009; Feo-Valero et al., 2011; Álvarez-SanJaime et al., 2013a, 2013b).

## 3. The empirical strategy

### 3.1. A conceptual framework for competition between transport modes

Let us start by considering a country with *I* provinces (*I* = 50 for Spain). Without loss of generality, all types of bilateral national trade flows from province *i* to province *j* could be defined as $F_{ij}$ . If $i = j$ we have intra-provincial trade flows, while if $i \neq j$ we have inter-provincial trade flows. Each bilateral aggregated flow can be broken down into a set of sector-specific flows for every set of tradable industries (*k*), whose products can be delivered by four alternative transport modes (*m*): road (*R*), train (*T*), ship (*S*) and aircraft (*A*). Therefore, the most general case of aggregate trade flow, $F_{ij}$ , can be broken down as:

$$F_{ij}^{k} = F_{ij}^{kR} + F_{ij}^{kT} + F_{ij}^{kS} + F_{ij}^{kA} \qquad (1)$$

where $F_{ij}^{kR}$ is the bilateral trade flow, in current euros, of industry *k* from province *i* to province *j* within Spain. This idea can also be summarized as in Figure 1.

Firms in province *i* have access to a range of transport-mode mixes with which to deliver products from a given industry *k* to some other province *j*, whether within the country or abroad. All these transport modes differ in cost, security and speed. Because of the geographical location of firms and final markets and the current state of the transport network, similar products can be shipped in parallel by alternative transport modes. The likelihood of mode competition differs by industry *k* and dyad *i-j*. When it comes to island provinces, for example, *ship* and *aircraft* may compete for certain products but not for others. For a given pair of inner Spanish provinces *i-j*, competition between *road* and *train* (and, more rarely, *aircraft*) depends on the transport network and the nature of the industry. In other words, competition between certain transport modes is more likely for certain distance segments than for others.

**<<<Figure 1 about here>>>**

### 3.2. A gravity model for capturing transport-mode competition

The gravity equation has been used to model international and interregional trade flows, and can be justified by a broad range of trade theories (Head and Mayer, 2014). We also find some recent attempts to connect the micro-founded structural gravity equation with the literature on spatial autocorrelation effects (Behrens et al. 2012; Koch and LeSage, 2015). Departing from this strand of the literature, a set of alternative gravity models are defined in this section with the aim of modeling inter-provincial flows within Spain.

In our case, a baseline model would be:

$$F_{ij}^{R} = \alpha i_N + X_i\beta_1 + X_j\beta_2 + d_{ij}\beta_3 + Intra_{ij}\beta_4 + Adj_{ij}\beta_5 + F_{ij}^{T}\beta_6 + F_{ij}^{S}\beta_7 + F_{ij}^{A}\beta_8 + \varepsilon_{ij} \quad (2)$$

where the variable $F_{ij}^{R}$ represents current value of shipments by *road* between province *i* and *j*.. To model sector-specific flows, this dependent variable can take the form $F_{ij}^{kR}$, where *k* is the product exported by road with origin *i* and destination *j*. $i_N$ is a constant; $X_i$ contains a set of regressors representing the production capacity of province *i;* and $X_j$ the absorption capacity of province *j*; $d_{ij}$ is the bilateral distance between the exporting and the importing province. A dummy variable, $Intra_{ii}$, is included to control for potential differences in the nature of flows within a province and between provinces. The variable takes the value 1 if the flow's origin and destination are the same "province" and 0 otherwise. $\varepsilon_{ij}$ is an $n^2 \times 1$ vector of normally distributed constant variance disturbances. We add an additional dyadic dummy, $Adj_{ij}$, to control for trading-partner adjacency. We have also added a set of three different continuous variables, $F_{ij}^{T}$, $F_{ij}^{S}$, $F_{ij}^{A}$, for bilateral trade flows by alternative transport modes, such as *train*, *ship* and *aircraft*.

With respect to regressors (X*i* and X*j*), the main novelty is the inclusion of variables to capture the logistical capacity of trading partners (logistics platforms, warehouses, wholesale activities) and of other important controls for (potential) international transit flows. For simplicity, we will define these variables only for the exporting province *i* (there is an equivalent set for the importing province *j*):

*Ln(wholesales pc$_i$)*: the ratio between the number of wholesale activities in province *i* (La Caixa, Anuario Económico, 2007) and the population of *i*. It is expressed as a log and used as an alternative to the "platform infrastructure" in Alamá-Sabater et al. (2013) and Bensassi et al. (2015).

*Island$_i$*: a dummy variable identifying 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 identifying Spanish provinces that border on France and Andorra. This variable—taking the value 1 for border provinces and 0 otherwise—is meant to control for expected higher flows into and out of these "gateway" provinces to 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 be subsequently re-exported domestically (generating an *apparent inter-provincial flow*). Note that by including an equivalent dummy for importing provinces *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 meant to control for the same effect as the previous variable but for Spanish provinces that border on countries to the southeast: that is, Portugal and countries in Africa. The importance of the EU core and these other markets, along with the size of Spain's border provinces, make it worthwhile to consider the effects separately.

*Ln(imp. int. all/gdp$_i$):* a further variable added to take into account the bias introduced by ambushed international flows within domestic flows. This variable represents aggregated imports by *i* (exporter of the domestic flow analyzed), in euros, regardless of transport mode, divided by the GDP of province *i*. The idea is to acknowledge that even a non-border province can behave as a "hub" (not, in this case, as a "gateway") if it has a large maritime port (e.g., Barcelona, Bilbao, Valencia). Thus, a positive and significant coefficient for this variable indicates that interprovincial product exports from *i* are positively associated with the province's absorption capacity for "international imports". Note that by including the counterpart for importing provinces *j*, $Ln(exp.\ int.\ all/gdp_j)$, we also control for the contrary case, where the large capacity for importing interprovincial Spanish flows of a province *j* is associated with its high intensity of international exports, regardless of transport mode, divided by the GDP of province *j*.

Moreover, in specifications that use sector-specific flows as endogenous variables, we redefine the previous variables $Ln(imp.\ int.\ all/gdp_i)$ and $Ln(exp.\ int.\ all/gdp_j)$ much more precisely as $Ln(imp.\ int.all^k_i/gdp_i)$ and $Ln(exp.\ int.\ all^k_j/gdp_j)$, international exports and imports being *k-specific*.

In some of our specifications, we also include two additional exogenous variables: the GDPs of the exporting and the importing province. The baseline model excludes these variables. We have included them to avoid multicolinearity between the GDP and the other explanatory variables—monadic variables (wholesales or international trade), dyadic variables (distance)—and to test the robustness of the basic specification.

For simplicity, **Eq. (2)** uses only road flows for an endogenous variable (modeling the flows for the alternative transport modes is straightforward). *Road* is by far the main mode in Spain (accounting for more than 80% of all the interregional trade flows), and is thus the mode most likely to compete with any of the other three. Moreover, and importantly for the modeling of product-specific flows, the number of zero flows is lower for *road* than for any other mode. For these reasons, **Eq. (2)** includes three elements, $F^T_{ij}; F^S_{ij}; F^A_{ij}$, each of which corresponds to an equivalent flow between *i* and *j* by an alternative transport mode. With these new elements, we hope to determine whether the trade flows of these modes are, on average, compatible with flows by *road* at either the aggregate level or the industry level (*k*). It is interesting to remark that the coefficients of these three elements will capture the extent to which they could coexist with deliveries by *road* between the same two Spanish provinces *i-j*. A positive coefficient for these three elements indicates an increased probability of deliveries by *road*. By contrast, a negative coefficient could signal transport-mode competition. Thus the use of a certain mode between *i* and *j* would reduce the probability of non-zero deliveries by *road* for the same *i-j* pair. Indeed, a negative coefficient could result from a perfect incompatibility of one mode for a given delivery type (e.g., delivery of coal by *aircraft* between contiguous provinces, or of perishables—fresh food, daily press—by *ship* from an inner province to an island).

### 3.3. A Spatial Autoregressive Gravity Model

Standard gravity models have assumed that the decisions of economic agents in a certain province *i* to deliver products by *road* to a certain province *j* are not affected by equivalent decisions in neighboring regions. The decisions are independent, and thus there is no spatial dependence in choice outcomes. Several authors (Griffith and Jones, 1980; Black, 1992; Bolduc et al., 1992; Griffith, 2007; LeSage and Pace, 2008) have questioned this assumption, pointing out potential spatial and network dependencies that can in fact affect different types of bilateral flows. These authors argue that the omission of neighboring variable values gives rise to spatial autocorrelation. For most socioeconomic spatial interactions (migration, trade, commuting, etc.), there are several explanations for the effects. For example, neighboring origins (exporting provinces) and destinations (importing provinces) could exhibit estimation errors of similar magnitude if underlying latent or unobserved forces were at work, such that missing covariates exerted a similar influence on neighboring observations. Agents in contiguous provinces could experience similar transport costs and profit opportunities when evaluating alternative nearby destinations. This similar positive/negative influence among neighbors could also be explained in terms of common factor endowments, complementary/competitive sectoral structures, etc.

Logistical complexity and transport infrastructures can also be sources of cross-sectional autocorrelation in the flows observed in a sample. Several cases can be considered with respect to the transport-competition schemes considered here.

The standard variables in the gravity equation (just for *i* and *j*) cannot by themselves explain the intensity of the flows by a specific transport mode (road) between two specific provinces *i* and *j*. We need in addition to consider the presence of a non-zero flow in a vector with flows by alternative (competing) transport modes between those same provinces *i* and *j*, or the corresponding neighbors of *i* and/or *j*. Several mechanisms are possible here. For instance:

a) The delivery of products from a province *i* to a province *j* by a specific transport mode (e.g., *train*) may explain a zero flow between these two locations by another mode (e.g., *road*).

b) The same delivery from *i* to *j* could raise the price of that mode for that specific trip (dyad *i*-*j*). Thus neighboring provinces of *i* (or of *j*) could gain by using an alternative transport mode (e.g., *road*) for their deliveries to *j* (or from *i*).

c) The delivery of products by industry *k* from a province *i* to a province *j* by, say, *train* could increase the probability that *i* or *j* will become a "hub", since economies of scale might induce neighboring provinces of *i* or *j* to ship their products to *i* for train delivery to *j*, rather than ship them directly by an alternative mode (e.g., *road*).

In light of all this, and in keeping with LeSage and Pace (2009), we arrive at the spatial version of the previous gravity model, **Eq. (3),** which accounts for such cross-sectional autocorrelation effects.

$$F_{ij}^{R} = \alpha i_N + X_i\beta_1 + X_j\beta_2 + d_{ij}\beta_3 + Intra_{ij}\beta_4 + Adj_{ij}\beta_5 + F_{ij}^{T}\beta_6 + F_{ij}^{S}\beta_7 + F_{ij}^{A}\beta_8 + \rho_1 WF_{ij}^{R} + \varepsilon_{ij} \qquad (3)$$

Here, an interdependent regression allows decisions in one province (regarding exports to *j* by mode *m*) to depend on decisions in a nearby province. This model includes all the explanatory variables in the previous models, subsuming non-spatial regression models as special cases.

The definition of neighboring provinces derives from the spatial weight matrix *W*. In a typical cross-sectional model with *n* provinces, where each pair of provinces represents an observation, spatial regression models rely on an $n \times n$ non-negative weight matrix that describes the connectivity structure between the *n* provinces. For example, $W_{ij} > 0$ if province *i* is contiguous to province *j*. By convention, $W_{ii} = 0$ to prevent an observation's being defined as a neighbor to itself, and the matrix *W* is typically row-standardized. In the case of bilateral flows, where we are working with N = $n^2$ observations, LeSage and Pace (2008) and Fischer and Griffith (2008) suggest using $W = W_j + W_i$, where $W_j = I_n \otimes W_s$ represents an N × N spatial weight matrix that captures connectivity between the importing province and its neighbor, and $W_i = W_s \otimes I_n$ is another N × N spatial weight matrix that captures connectivity between the exporting province and its neighbor.[4] We row-standardize the matrix $W$ to form a spatial lag of the N × 1 dependent variable.

LeSage and Pace (2008) note that the spatial lag variable captures both 'destination'- and 'origin'-based spatial dependence relations using an average of flows from neighbors to each origin (exporting) and destination (importing) province. Specifically, this means that flows from any origin to a particular destination may exhibit dependence on flows to the same destination from the origin's neighbors. LeSage and Pace (2008) call this origin-based dependence. The spatial lag matrix ($W$) also captures destination-based dependence, the term used in LeSage and Pace (2008) to reflect dependence between flows from a particular origin province to neighbors of the destination province.

We now define an alternative specification **Eq. (4)** that departs from the SARGM model described in **Eq. (3)**:

$$\begin{aligned} F_{ij}^{R} &= \alpha i_N + X_i\beta_1 + X_j\beta_2 + d_{ij}\beta_3 + Intra_{ij}\beta_4 + Adj_{ij}\beta_5 + F_{ij}^{T}\beta_6 + F_{ij}^{S}\beta_7 + F_{ij}^{A}\beta_8 \\ &+ \rho_1 WF_{ij}^{R} + \rho_2 WF_{ij}^{T} + \rho_3 WF_{ij}^{S} + \rho_4 WF_{ij}^{A} + \varepsilon_{ij} \end{aligned} \tag{4}$$

This model includes all the explanatory variables, adding three new elements to the spatial lag term for the endogenous variable, $\rho_1 WF_{ij}^{R}$. The new elements attempt to capture transport-mode competition effects not between the dyadic terms themselves (*i-j*) but between each of these elements and the corresponding neighbors:

$\rho_2 WF_{ij}^{T}$ : This element captures the equivalent relationships described by the first spatial lag but takes into account the cross-effect between flows of the endogenous variable by one

[4] We use the symbol ⊗ to denote a Kronecker product.

mode (e.g., *road*) and flows between the neighbors of *i-j* by an alternative mode (in this case, *train*). This new element complements the competing transport-mode term described by $F_{ij}^{T}$ , which considers only competing structures between the *i-j* dyadic elements (i.e., *road* and *train*). The new element $WF_{ij}^{T}$ is a weighted average of flows by *train*, using the *W* matrix described before. The new element is plugged into the model as a new variable, generating $\rho_2$ .

$\rho_3 WF_{ij}^{S}$ : Similarly, this element captures the competing transport-mode relationship between the dyadic flows of the dependent variable (i.e., *road*) and another alternative transport mode (e.g., *ship*) between the neighbors of *i* and *j*.

$\rho_4 WF_{ij}^{A}$ : Equivalently, this element captures the competing transport-mode relationship between the dyadic flows of the dependent variable (i.e., *road*) and the last alternative transport mode (i.e., *aircraft*) between the neighbors of *i* and *j*.

In this paper, the effect captured by the three elements $F_{ij}^{T}; F_{ij}^{S}; F_{ij}^{A}$ is called *explicit transport-mode competition*, having in mind that these elements are referred to the *i-j* provinces involved in the flow by road between *i* and *j* to be explain ( $F_{ij}^{R}$ ). By contrast, the effect captured by the three elements $\rho_2 WF_{ij}^{T}$ , $\rho_3 WF_{ij}^{S}$ and $\rho_4 WF_{ij}^{A}$ is called *implicit transport-mode competition*, since it captures the relationship between *i-j* flows by *road* ( $F_{ij}^{R}$ ) and flows to and from neighboring provinces to *i* and *j* by alternative modes[5]. The pure spatial autoregressive element, $\rho_1 WF_{ij}^{R}$ , cannot be described as capturing transport-mode competition effects as such, but as a term controlling for cross-sectional effects within the mode considered in the endogenous variable (*road*, in our case).

As Lesage and Pace (2009) describe, all these models are solved using the Maximum Likelihood methods (www.spatial-econometrics.com). Note that the weight matrix used in all cases is always the same, and row-standardized. The four elements $\rho_1 WF_{ij}^{R}$ , $\rho_2 WF_{ij}^{T}$ , $\rho_3 WF_{ij}^{S}$ and $\rho_4 WF_{ij}^{A}$ are computed with the logs of the actual flows by each of the transport modes..

[5] Alternative terms like *direct/indirect transport mode competition* were discarded to avoid confusion with other terms (e.g., *direct* and *indirect effect*) currently used in the literature of spatial econometrics (LeSage and Pace, 2009).

### 3.3.1. For what distance segments does transport-mode competition hold?

To shed new light on the distance segments over which *road* coexists with the three alternative transport modes in Spain, we take an approach similar to that in other papers with segmented distance vectors (Eaton and Kortun, 2002; Díaz-Lanchas et al., 2013; Gallego and Llano, 2014).

First, we compute the max (2,440 km) and min (33 km) distance in the sample. As others have done (Eaton and Kortun, 2002; Gallego and Llano, 2014), we divide this range by four. The result is an *ad hoc* number. However, as noted in the introduction, cooperation in Spain between *train* and *road*, the main transport modes on the Iberia Peninsula, occurs from 600 km onwards[6]. Interestingly enough, as shown in **Figure 2**, the four segments under consideration do account for the two main observed instances of transport-mode competition: namely, between *road* and *train* for trade between inner regions, and between *ship* and *aircraft* for longer distances (mainly from the peninsula to the islands). In dividing our range into four segments, we construct four semi–dummy variables of segmented distance, as follows: S1 ($0 < d_{ij} <= 600$ km); S2 ($600 < d_{ij} <= 1{,}200$ km); S3 ($1{,}200 < d_{ij} <= 1{,}800$ km); S4 ($1{,}800 < d_{ij} <= 2{,}400$ km). Any of these dummies will take the value 1 when an observation corresponds to a flow whose actual distance falls within the dummy's range (i.e. S1 ($0 < d_{ij} <= 600$ Km.), and 0 otherwise.

We then multiply these four dummy variables by the three elements included in the models that capture *i-j* flows by alternatives to the transport mode of the dependent variable (*road*). For instance, if the endogenous variable corresponds to the binary variable constructed upon inter-provincial trade flows by *road* ($F_{ij}^{R}$), the new elements capturing the direct transport-mode competition will be:

- *Train* flows by segmented distance: $F_{ij}^{T}$ *S1; $F_{ij}^{T}$ *S2; $F_{ij}^{T}$ *S3; $F_{ij}^{T}$ *S4
- *Ship* flows by segmented distance: $F_{ij}^{S}$ *S1; $F_{ij}^{S}$ *S2; $F_{ij}^{S}$ *S3; $F_{ij}^{S}$ *S4
- *Aircraft* flows by segmented distance: $F_{ij}^{A}$ *S1; $F_{ij}^{A}$ *S2; $F_{ij}^{A}$ *S3; $F_{ij}^{A}$ *S4

Note that for each of these elements we obtain a set of semi-dummy variables, for flows by *competing transport modes* between *i* and *j* over the corresponding distance segment alone,

[6] Note that the larger the number of segments (or the smaller the segments), the more cases we would have where *road* was the only mode available. In cases where the segmented distance vectors for alternative modes do not include non-zero flows, the model cannot be estimated.

and zero otherwise. With these variables, we can determine the presence of mode-competition schemes over four different distance segments. In sum, this new strategy generates **Eq. (5)**:

$$
\begin{aligned}
F_{ij}^{R} &= \alpha i_N + X_i\beta_1 + X_j\beta_2 + d_{ij}\beta_3 + Intra_{ij}\beta_4 + Adj_{ij}\beta_5 \\
&+ F_{ij}^{T} * S1\beta_6 + F_{ij}^{T} * S2\beta_7 + F_{ij}^{T} * S3\beta_8 + F_{ij}^{T} * S4\beta_9 \\
&+ F_{ij}^{S} * S1\beta_{10} + F_{ij}^{S} * S2\beta_{11} + F_{ij}^{S} * S3\beta_{12} + F_{ij}^{S} * S4\beta_{13} \\
&+ F_{ij}^{A} * S1\beta_{14} + F_{ij}^{A} * S2\beta_{15} + F_{ij}^{A} * S3\beta_{16} + F_{ij}^{A} * S4\beta_{17} \\
&+ \rho_1 WF_{ij}^{R} + \rho_2 WF_{ij}^{T} + \rho_3 WF_{ij}^{S} + \rho_4 WF_{ij}^{A} + \varepsilon_{ij}
\end{aligned} \quad (5)
$$

## 4. Data

The flow data used in this paper are based on the most accurate data on Spanish transport flows of goods by transport mode (*road*, *train*, *ship*, *aircraft*), in addition to fifty specific export price vectors, one per province of origin, transport mode and product type. This rich dataset was collected and filtered in accord with the methodology described in Llano et al. (2010) and published as part of the C-intereg project (www.c-intereg.es). This data is the extended version (provinces instead of regions; four mode-specific flows instead of aggregate flows) of the database used in other papers (Alamá-Sabater et al., 2013; Bensassi et al., 2015) for domestic Spanish trade. The largest common product disaggregation for all transport modes is for fifteen product types (R-15),[7] in keeping with the official NACE classification. From this range of products, Section 6.2 provides results for ten industries. (Estimates for the remaining industries were rendered impossible by the excessive number of non-zero flows for certain transport modes.) We also use a rich set of regressors, described in **Table 1**.

**<< Table 1 about here>>**

[7] R1-Agriculture and Fishing; R2-Mining; R3-Food and Beverages; R4-Textiles; R5-Shoes; R6-Lumber; R7-Paper and Publishing; R8-Chemicals; R9-Plastics; R10-Non-Metallic Minerals; R11-Metalurgy and Metal Products; R12-Machinery and Mechanical Equipment; R13-Electronics and Electrical Materials; R14-Transport Materials; R15-Other.

## 5. Descriptive analysis

Before analyzing the results of our econometric analysis, we will first describe the dataset. The starting point for the analysis (**Figure 2**) is total inter-provincial flows for each province in 2007.

**<<<Figure 2 about here>>>**

As shown above, the main inter-provincial flows stem from Spain's richest provinces: Madrid, Barcelona, Valencia, Sevilla and Zaragoza. The northeast shows high trade volume; the west and south, low.

**<<<Figure 3 about here>>>**

**Figure 3** shows the association/disassociation between the ranking of the main provinces by flow direction (outflows vs. inflows) and transport mode. The three panels are connected. The first one shows the correspondence for outflows (inter-provincial deliveries or exports). If the volume and the ranking of the four modes were exactly the same, the lines would be parallel. This is evidently not the case. The main provinces exporting by *road* (Barcelona, Madrid and Valencia, whose lines appear in green) are also among the main exporters by *train*, but not by *ship* or *aircraft*. Similarly, the second panel shows the ranking of provincial imports (within the country) for each mode. Again, the three main provinces importing by *road* (Barcelona, Madrid and Valencia, in green) are also the main importers by *train*, and very relevant as importers by *aircraft*, but, of course, only Barcelona and Valencia import by *ship*, Madrid being an inland province.

At the bottom of the graph, we have a percentile map for outflows by *road*. The content of this map is equivalent to the elements represented in the first panel-axis (Y_RI). For clarity, we have connected them with a red doted arrow. The three provinces highlighted in the map (Barcelona, Madrid, Valencia) are the main ones in terms of outflows by *road*. For these main provinces, inflows and outflows by each of the four transport modes appear in green in the upward panels.

At this point, it is reasonable to test the presence of the explicit and implicit transport mode schemes described in the previous section, which are added, for the first time, in our empirical strategy. The interested reader will find a complete analysis in the Annex.

## 6. Results

Here we present estimates for the specifications defined in Section 3. The analysis is divided into two parts. First, we present a set of models that consider flows aggregated from the sector perspective, with both normal and segmented distance. Next, we analyze sector-specific flows. For each model it is important to consider the inclusion of endogenous variables, as well as aggregate or sector-specific factors considered to be regressors.

### 6.1. Aggregate flows by mode

**Table 2** shows the results for four alternative specifications of the previously described SARGM—Eq. (2) through Eq. (4)—with aggregate flows. All use the same endogenous variable: that is, the euro value of the interprovincial deliveries by road in 2007.. The point of departure is **Model 0**, a naïve gravity equation without implicit transport mode competition effects. Then, as described in Eq. (3), (**Model 1**) corresponds to the SARGM that includes all the terms capturing explicit transport-mode competition, $F_{ij}^{T};F_{ij}^{S};F_{ij}^{A}$, plus the traditional spatial lag term for the endogenous variable. The results are, in general, in line with expected results:

**<<<Table 2 about here>>>**

The coefficient for distance is negative and significant in both specifications. The coefficient for the intra dummy is also positive and significant. This confirms that intra-provincial flows are higher than inter-provincial flows, as other papers in the border-effect and home-bias literature (Requena and Llano, 2009; Ghemawat et al., 2010; Garmendia et al., 2012; Gallego and Llano, 2014) have found.

The coefficients for $Island_j$ and $Island_i$ are highly negative and significant, indicating that the intensity of inflows/outflows for the Spanish island provinces is much lower than for the other provinces, once economic and geographical characteristics (logistics infrastructures and distance) have been controlled for. Note that some logistic strategies (Roll-on-Roll-off and *road-ship-aircraft* mode combinations) allow these provinces to have non-zero flows with the inner regions.

Regarding the results for cases where we have added variables to capture the logistical capacity and international openness of each province:

i) The coefficient for the two variables capturing the logistical-infrastructure of each province—*Ln(wholesales* $pc_j$*)* and *Ln(wholesales* $pc_j$*)*—are both positive and significant in Model 0. Thus, the more wholesale establishments per capita in a province, the higher the intensity of inflows and outflows by *road* for that province. Alternatively, when the GDP of the trading partners is included (**Model 1** and subsequent models) these variables become non-significant. As expected, GDP tends to absorb the effects of other monadic variables such as *wholesales pc*. For this reason, GDP will be removed from when modeling sector-specific flows in the last section.

ii) None of the international border dummies included has a significant and positive impact on intra-national deliveries by *road*. In fact, for **Model 0**, *Border int.* $other_i$ and *Border int.* $other_j$ register negative and significant coefficients. Accordingly, the capacity to deliver products to other provinces within Spain by *road* is lower than the average for provinces that share a border with Portugal or African countries.

iii) In **Model 1**, the coefficient for *international import flows relative to* $GDP_i$ (*Ln(imp. int.* $all_i/Y_i$*)*) is positive and significant. This result suggests that the more a province imports internationally, the more domestic deliveries by *road* it has. 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 interprovincial export*. As for the alternative variable for international exports, *Ln(exp. int. all$_j$/Y$_j$)*, the coefficient appears to be negative and significant, indicating a negative association between high imports of national products by *road* and high exports to international markets. This result is found in every specification.

For (explicit) transport-mode competition effects, *train* $\log(F_{ij}^{T}) = 0.034$ and *aircraft* $\log(F_{ij}^{A}) = 0.209$ generate positive and significant coefficients. The coefficient for *ship* is non-significant. The cross-sectional autocorrelation term $\rho_1 WF_{ij}^{R}$ is positive and significant (0.377).

Next, in keeping with the specification in Eq. (4), the results for **Model 2** also include the rest of the spatial lag terms, $\rho_2 WF_{ij}^{T}$, $\rho_3 WF_{ij}^{S}$ and $\rho_4 WF_{ij}^{A}$, to capture cross-mode implicit competition effects. The results are consistent with previous results for all the common variables, now presenting a negative and significant coefficient for distance. With respect to the *explicit transport-mode competition elements*, $F_{ij}^{T}; F_{ij}^{S}; F_{ij}^{A}$, the coefficient for *train* remains positive and significant with little variation (from 0.034 to 0.047), and a positive and significant coefficient for *aircraft* (from 0.209 to 0.113). The positive coefficient indicates that the two ground transportation modes can coexist for the same pairs of trading provinces, at least in aggregate-flow models. Moreover, as **Figure 3** shows, the ranking of the main flows by *road* is correlated with the main flows for *train*. The negative coefficient for *ship* indicates that, on average, there is a negative specialization pattern in these two modes. Extreme cases aside, there is, of course, room for a certain degree of sharing (partial specialization in one mode) between these two modes over the longest distance.

In relation to the results for *cross-mode implicit competition effects* we just find significant (and positive) effects for *aircraft* ($\rho_4$= 0.337). As in the previous specification, the result for the pure spatial lag element ( $\rho_1 WF_{ij}^R$ ) is also positive and significant, with a very similar factor (0.367).

Similarly, the results for **Models 3** and **4** are equivalent to those for the previous two models, but the explicit competition terms are now split between the four distance segments described above.

For **Model 3** robust results are obtained for all the previously included variables. The spatial lag element for the endogenous variable (*road*), is positive and significant, with a factor of $\rho_1$ =0.351 a, slightly less than the previous two.

The results for **Model 3** when we break down the explicit transport-mode competition elements by distance segment are interesting and to a certain degree heterogeneous:

i) For *train*, we obtain clearly positive and significant coefficients for $log(F^T_{ij})$*S2 (0.107).. Our interpretation of this is geographical. Since the longest distance segment corresponds in almost all cases to flows from inner regions to the islands (especially Islas Canarias), there is little chance of finding for that segment a positive correlation between deliveries by *road* and by *train*; full specialization in *aircraft* or *ship* is almost imposed by the geography. For the second segment of distance (600-1200 km), *train* really is an option and can be an efficient alternative to *road*.

ii) For *ship*, the coefficients are significant and negative for the second segment ( S2) but positive for the largest one (S4). Probably, the significant coefficient for the second segment is associated with flows from the Mediterranean coast to Balearic Islands, while the ones for S4 are explained by flows between the main provinces (Barcelona, Madrid, Valencia, Sevilla) to the Canary Islands, and the use of Roll-on-Roll-off strategies.

iii) For *aircraft*, finally, we obtain a positive and significant coefficients for the first and third segments, . The first one could just be explained by short flights within the Islands (there are several Islands in each archipelago); the second indicates that *road* and *aircraft* are positively correlated (co-exist) for distances of 1,200 km to 1,800 km. The rest of the coefficients are non-significant, which indicates that aircraft is not an alternative to road for intermediate and very long distances (the ones connecting the Peninsula with the Canary Islands)

Finally, **Model 4** also includes cross-mode implicit transport-mode competition elements. Our results take into account all the variables considered before, including the spatial lag term for *road* ($\rho_1$=0.363). As for the other three neighbor effects, which in this case capture *cross-mode implicit mode competition*, we obtain only a small, negative and significant relationship between *road* and *ship* ($\rho_2$ = –0.156). As in **Model 2**, this indicates that the intensity of flows by road between any *i-j* pair is negatively associated with the intensity of *ship* flows from *i* to the neighbors of *j* and from the neighbors of *i* to *j*.

Results for the breakdown of *explicit transport-mode competition elements* are robust with previous results: i) For *train*, we obtain clear positive and significant coefficients for $log(F^T_{ij})$*S2. ii) For *ship*, only segment S4 generates a positive and significant coefficient. iii) For *aircraft*, we obtain positive and significant coefficients for the third segment.

### 6.2. Industry-specific flows

Departing from the previous analysis of aggregate flows, **Table 4** shows the results for ten industry-specific flows[8], using the preferred specification of the spatial gravity equation, which corresponds to Eq. (5). The coefficients for certain variables perfectly match those obtained for aggregate flows, showing little variability by product either in sign or in level of significance. Such is the case for the distance, intra and island dummy variables. The adjacency dummy is also positive and significant in all cases.

The variables capturing logistical capacity and international connectivity, *Ln(wholesales* $pc_j$*)* and *Ln(wholesales* $pc_j$*)*, are both positive and significant. The international border dummies reveal that the intensity of trade by road between two provinces is negative and significant in two cases: when the exporting province is adjacent to the EU core (*Border int. core EU* $_i$: R2;

[8] There are fifteen sector-specific flows in the original dataset: R1-Agriculture and Fishing; R2- Mining, Oil and Refinery; R3-Food and Beverages; R4-Textiles; R5-Shoes; R6-Lumber; R7-Paper and Publishing; R8-Chemicals; R9-Plastics; R10-Non-Metallic Minerals; R11-Metalurgy and Metal Products; R12-Machinery and Mechanical Equipment; R13-Electronics and Electrical Materials; R14-Transport Materials; R15-Other. However, because of the number of zero flows, estimates for certain sectors fail. Results for these sectors are therefore not reported.

R6; R8; R10; R11) and when the importing province is adjacent to the EU core (*Border int. core EU* $_j$: R1; R3; R10; R13; R14). The relationship is also negative and significant for *Border int. other* $_I$ (R6; R7; R8; R10) and *Border int. other* $_j$ (R6; R7; R8). In no case are the coefficients for these variables positive and significant. This is a good sign that there are no international deliveries hidden within our inter-provincial flows.

In contrast to the positive coefficient obtained with aggregate-flow models for *international import flows relative to GDP*$_i$ ($Ln(imp.\ int.\ all_i/Y_i)$), here only R6 generates similar results. In fact, in six cases we get a negative and significant coefficient. For $Ln(exp.\ int.\ all_j/Y_j)$ the coefficient is positive and significant for a single sector (R3); it is a negative and significant for other six products.

The cross-sectional autocorrelation term $\rho_1 WF_{ij}^R$ is positive and significant for all industries, with a factor that varies from 0.279 (R13) to 0.556 (R1). The other three spatial lag terms, $\rho_2 WF_{ij}^T$ , $\rho_3 WF_{ij}^S$ and $\rho_4 WF_{ij}^A$ , introduced to capture cross-mode implicit competition effects, present great variability. In the case of $\rho_2 WF_{ij}^T$ , six sectors get a positive and significant $\rho_2$ (R1; R2; R7; R8; R10; R11). For neighbor effects by *ship*, $\rho_3 WF_{ij}^S$ , just one sector get a negative and (slightly) significant $\rho_3$ (R11). For neighbor effects by *aircraft*, $\rho_4 WF_{ij}^A$ , two sectors get a positive and significant $\rho_4$ (R13; R14).

The breakdown of explicit transport-mode competition elements by distance segment also shows certain level of heterogeneity: i) For *train*, positive and significant coefficients in the first two stages are present for all products with the single exception of R1 and R2 for $log(F^T_{ij})$*S2. For the other transport modes, positive and significant coefficients are obtained for: ship (*S1:* R1, R2; *S2:* R2, R6; *S4:* R1, R2); aircraft (*S1:* all sectors; *S3:* R3, R11; *S4:* R1, R3, R6, R7, R8, R10, R11).

**<<<Table 4 about here>>>**

To conclude, we run a cluster analysis in order to find similarities/dissimilarities in the behavior of each sector-specific flow. Specifically, we apply a hierarchical cluster algorithm with “average linkage” using Stata for the coefficients obtained via Eq. (4) and reported in **Table 3**. The variables are those that directly measure logistics infrastructures and product transportability and all those that capture implicit and explicit transport-mode competition and cross-sectional autocorrelation effects for the *road* variable *($\rho_1$ (road))*.

**<<<Figure 4 about here>>>**

**Figure 4, Panel A**, shows the dendogram resulting from the cluster analysis. Alternative algorithms produce almost identical clusters. The analysis identifies two big groups of products: one that integrates R6, R7, R10 and R11; another that includes R1, R3, R14, R2, R8 and R13. R7 (Paper and Publishing) and R10 (Non-Metallic Minerals) form another group separate from the other sectors. Note that the former is strongly associated with construction materials, and, as it is shown in **Figure 4, Panel B**, it registers the lowest value-to-volume ratios, while the others in the group (R6, R7, R10 and R11), are also in the range of sectors with the lowest value-to-volume ratios. It is also interesting to see how the cluster analysis associates R8 (Chemicals) and R13 (Electronics and Electrical Materials), two industries that, showing different value-to-volume ratios, register lower shares in road transportation than the average.

**<<<Figure 5 about here>>>**

In order to dig deeper in the relationships described before, **Figure 5** plots, for each transport mode, the kernel regression of the intensity of the flows (Panel A) and the value-to-volume ratio (Panel B) along with the distance traveled. Regarding Panel A, several points are worth mentioning: i) the largest intensity of trade flows by road with respect to the other three (Second Y axis); ii) the largest agglomeration of road flows in the shortest distance (0-200 km); iii) The concentration of the flows by ship in the longest distance (the one corresponding to the interconnection of the Islands to the Peninsula) and the shortest trips (mainly between the islands within the same archipelago); iv) the distribution of train is almost flat till 1,200 km; v) reversely, the distribution for aircraft shows a clear concentration for the largest distances, with a bump also for 1,200 km. By contrast, Panel B, shows a complementary view on the concentration of unit values (€/Tons) by mode: i) it is clear how aircraft attracts the most expensive products, whose unit value decreases with the distance; ii) conversely, for the rest of the modes, the unit values rise with the distance. Remarkable is also the jump observed for train and road in the range between 1,000-1,400 km. Furthermore, it is interesting to see how the unit price for the train even bits the one for the road in the longest distance, since the one for the road reach a pick in 1,400 km. As expected, ship is used for the delivery of the less expensive products (bulk transportation).

**<<<Figure 6 about here>>>**

For convenience, **Figure 6** shows a scatterplot for the bilateral flows of each sector and mode along with the distance traveled, ranked in increasing order. The four segments are also highlighted with a vertical line, to show how flow intensities for each mode and sector are concentrated (or dispersed) over the whole of the potential spatial range. Clearly, flows by *road* account for the largest intensity and appear to be very concentrated in the shortest distances (the first two segments). The concentration of *train* in these first two segments is also very evident. By contrast, deliveries by *ship* are observed (with smaller intensities) in the four stretches, while *aircraft* appears mainly in the third and fourth segments. Interestingly, the thresholds of 600 km and 1,200 km happen to coincide with windows of distance where few flows are observed for any mode.

## 7. Conclusions

Many papers comparing international and interregional flows use transport flows as the best proxy for internal bilateral trade. Very few, however, have seriously addressed the growing complexity of logistics and its effect on trade-flow modeling.

This paper focuses on modal competition in the context of interprovincial flows within a country. It develops various gravity models incorporating cross-sectional autocorrelation effects, and conducts tests upon a rich dataset of aggregate and sector-specific flows between the fifty provinces of Spain by four transport modes (*road*, *train*, *ship* and *aircraft*). The results show some degree of transport-mode specialization for trade in specific products or with particular provinces. They also show significant and negative trading capacity for the islands in all types of deliveries. Surprisingly, provinces sharing borders with foreign countries also show below-average trading capacities. The results obtained with the segmented distance between road and railway suggest the clearest policy implications. Our findings show that both modes coexist and are positively associated for the segment of distance between 600 km and 1,200 km. Thus, if both modes are present for this segment of distance, there is room for additional migration from road to train, if the aim is reducing congestion in roads and to promote the environmental sustainability of the Spanish current transport-mode mix. In addition, we found negative and significant results between road and ship for the first three segments (S1, S2, S3). In our view this result is mainly explained by the specialization in maritime transportation in the Balearic and Canary Islands, in their relationships with the closest coastal provinces in the Peninsula (Valencia, Barcelona, Málaga and Cádiz), and the use of Roll-on-Roll-off strategies for the connection of road-ship deliveries from inner provinces (i.e. Madrid) to the islands. Moreover, the positive and significant coefficients obtained between road and aircraft also points out to the fact that both modes are competing in the long distance, but also in the deliveries within the Islands (there are several Islands in each archipelago). One methodological contribution of this paper is the estimation of “neighbor effects” between road and the other modes (implicit transport mode competition schemes) using spatial autocorrelation elements. Regarding this, the autocorrelation term for road is positive and significant for all industries, indicating that flows between any province is positively associated with flows by road from/to the provinces located nearby the trading provinces. Positive and significant effects are also found for train in 6 industries (R1; R2; R7; R8; R10; R11) and aircraft ((R3; R13; R14). By contrast, negative and significant coefficients are obtained for 1 industry (R11), when considering the trade flows by road and the deliveries by ship from/to the neighboring spots of the trading provinces

Further research is needed to consider more detailed sectoral and spatial units, and to explicitly consider incorporate international deliveries alongside the interregional deliveries herein.

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## Annex

This Annex provides a detailed description of the explicit and implicit transport mode schemes modeled in the paper.

**<<<Figure A.1. about here>>>**

**Figure A.1.** shows scatterplots for flows by *road* and by the other three modes, and considers outflows (interprovincial exports) and inflows (interprovincial imports) separately. *Road* is always represented on the abscissa. The main conclusions to be drawn from these graphs are the following: There are two clear cases of positive and significant correlation between the flows by *road* and by the other modes: namely, outflows and inflows by *train* (Panels A and B). The rest of the modes (Panels C through F) show no clear relationship between the main provinces receiving (delivering) products by *road* and the main provinces receiving (delivering) products by *ship* or *aircraft*. In this figure, the three island provinces appear in red. As expected, they are clear outliers in several panels (B, C, E, F).

**<<<Figure A.2. about here>>>**

Finally, **Figure A.2.** illustrates the presence of the previously described *neighbor effects*, which are captured by the spatial lag terms $\rho_1 WF_{ij}^{R}$ , $\rho_2 WF_{ij}^{T}$ , $\rho_3 WF_{ij}^{S}$ and $\rho_4 WF_{ij}^{A}$ . Note that each of these elements is a vector with dyadic elements (*i-j*) of dimension (n*n=50*50;1), since each flow vector has dimensions (n*n=50*50;1) and W=Wi+Wj has dimension (n*n; n*n). Because dyadic flows cannot be represented in maps or analyzed in the standard spatial-econometric/GIS packages, we have displayed the effects separately by exporting province (first column) versus importing province (second column). Note that this analysis focuses on *within-mode effects,* but cannot show *cross-mode implicit competition* as in the specification defined by Eq. (4). For example, the map in Panel A shows how a province *i* exporting products by *road* to all the other provinces can have competing flows (by *road*) from the neighbors of *i* to *j* and from *i* to the neighbors of *j*. Several results are remarkable:

i) The intensity of flows from/to the neighbors of i/j (denoted by intensity of color), is higher for *road* and *train* than for the non-ground modes (*ship, aircraft*). This is reasonable given the large number of provinces involved in non-zero flows for these ground-transport modes.

ii) For *road* (Panel A), the exporting provinces associated with a high intensity of deliveries from/to their neighbors are Madrid, Alicante, Tarragona, Navarra and the three Basque provinces. Note that in this case the neighbors (Alicante and Tarragona) of two main exporters/importers, Barcelona and Valencia, appear in dark colors. In Panel B, more provinces are shown in dark colors, to indicate the presence of clusters of provinces that are important receptors of deliveries by *road* from the rest of the country.

iii) The results for *train* are also remarkable: the highest intensities of deliveries (Panel C) by *train* to/from neighbors are clustered in northern Spain (Asturias, León, Cantabria, Vizcaya and Guipuzcoa). Note that these provinces specialize in heavy industry (mining, metallurgy, equipment, etc.) and use rail as the best way to move heavy products through mountainous terrain. For provinces importing by *train* (Panel D), it is Sevilla and Cádiz, in the southwest, and Tarragona and Barcelona, in the northeast, that show the highest intensities of flows by *train* to or from neighbors.

iv) For *ship*, the main neighbor effects, for both exports and imports, are found in the islands and in the southwest provinces of Spain, Huelva, Sevilla and Cádiz.

v) For *aircraft*, finally, the main neighbor effects are obtained for the islands, as well as Madrid and Barcelona.

**<<<Figure A.3 about here>>>**

As for cross-mode competition schemes, **Figure A.3.** shows scatterplots for flows by *road* and neighbor effects on each of the modes, for both outflows (interprovincial exports) and inflows (interprovincial imports). Interestingly, *road* shows positive autocorrelation with neighboring flows by *road* and *train* (Panels A through C). However, no significant relationship is observed between *road* and the other non-ground transport modes.

Our main conclusions regarding the presence of transport-mode competition can be summarized as follows:

i) Outflows and inflows show very similar levels of specialization in the four modes considered, *road* and *train* being the main options for inner provinces, *ship* and *aircraft* for the islands. In this regard, high shares for a specific mode (mode specialization) can be a sign of low competition between the preferred mode and the others. As previously stated, this may simply reflect economic (no train deliveries between inner regions) or physical (no trains between islands, no delivery of heavy products like cool or metals by aircraft) constraints.

ii) In general, we can expected transport-mode competition between *train* and *road* within the peninsula, and between *ship* and *aircraft* for deliveries to/from the islands.

iii) Leading provinces are separated by a certain minimum distance (Barcelona, Madrid, Valencia, Sevilla, Zaragoza, Vizcaya). Although the distance between certain pairs is sometimes less than the 600 km threshold for *road*-*train* competition, the distance between others pairs exceeds the threshold. This increases the likelihood of competition effects between these two modes for the longest trips.

iv) The dependence on flow direction (outflows vs. inflows) in the heterogeneity of neighbor effects by mode suggests a certain degree of market and sector specialization.

## Figure A.1. Complementarity between *road* and the other modes. Outflows vs. inflows.

Aggregate flows by sector. Logarithms over figures in millions of euros.

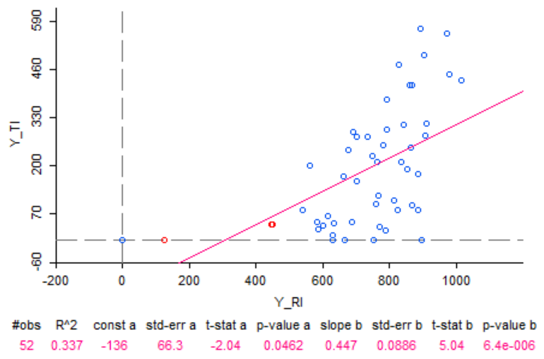
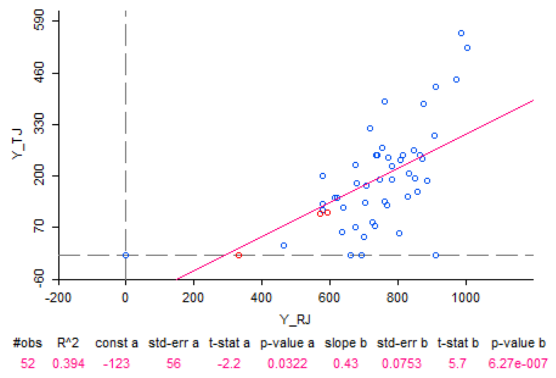
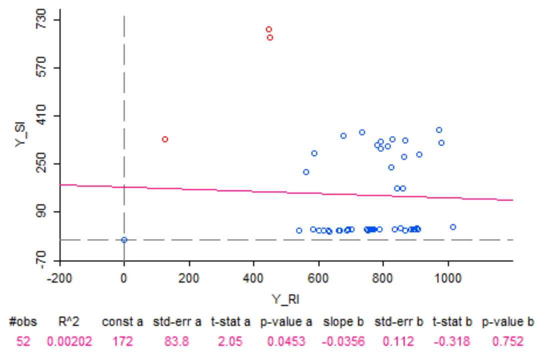
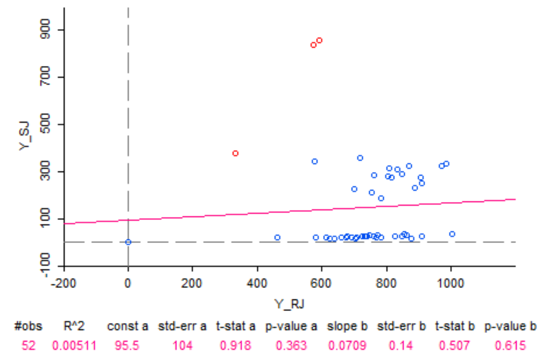
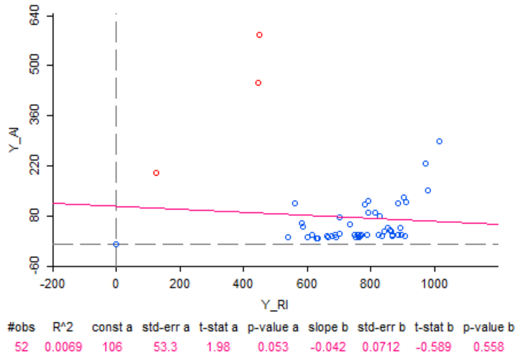
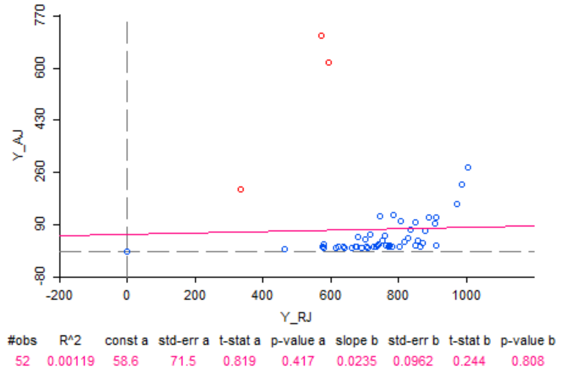
| | By exporting province | By importing province |
|---|---|---|
| **Train** |  |  |
| a) / b) | **Road** | **Road** |
| **Ship** |  |  |
| c) / d) | **Road** | **Road** |
| **Aircraft** |  |  |
| e) / f) | **Road** | **Road** |

**Figure A.2. Flows to/from neighbors (origin+destination base) by province and mode.**
Aggregate flows by sector. Logarithms over figures in millions of euros.

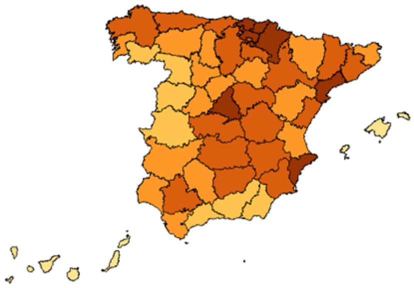
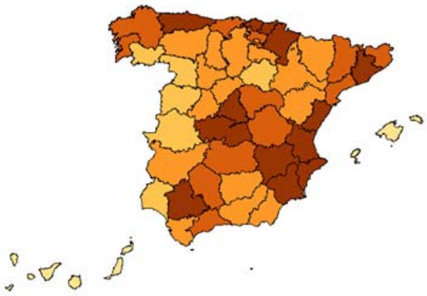
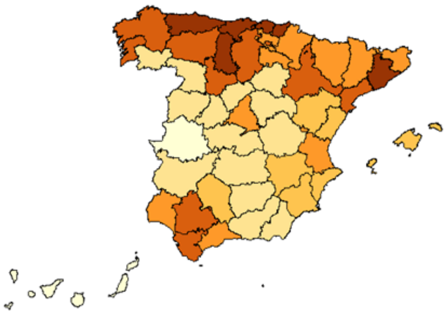
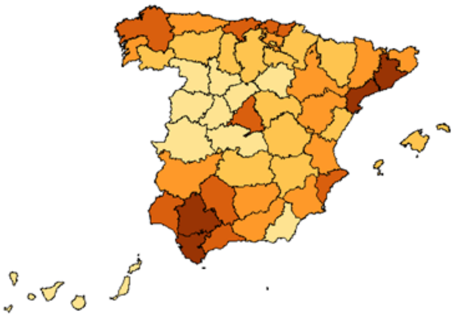
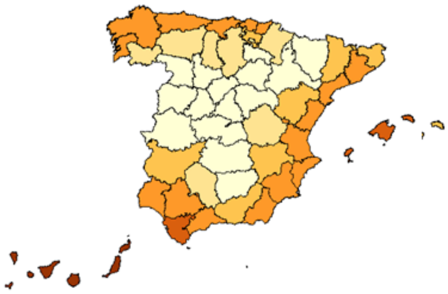
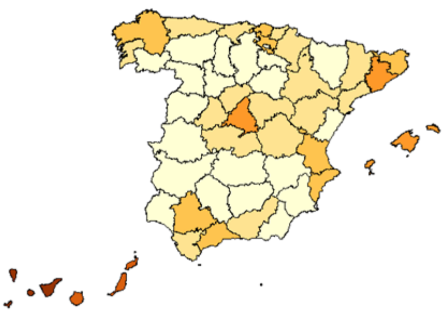
| | By exporting provinces | By importing provinces |
|---|---|---|
| **Road** |  a) $\sum_i (WF_{ij}^R)$ |  b) $\sum_j (WF_{ij}^R)$ |
| **Train** |  c) $\sum_i \left(WF_{ij}^T\right)$ |  d) $\sum_j \left(WF_{ij}^T\right)$ |
| **Ship** |  e) $\sum_i \left(WF_{ij}^S\right)$ |  f) $\sum_j \left(WF_{ij}^S\right)$ |
| **Aircraft** |  g) $\sum_i \left(WF_{ij}^A\right)$ |  h) $\sum_j \left(WF_{ij}^A\right)$ |

**Figure A.3. Road flows vs. neighbor effects by mode. Outflows vs. inflows.**

Aggregate flows by sector. Logarithms over figures in millions of euros.