Spatial interaction effects on inland distribution of maritime flows

Abstract:

The relationship between the regional economy and the infrastructure endowment has long been discussed in the literature. In this context, it can be said that ports play an important role for regions, as they affect their competitiveness, while the regional economic activity has an effect on port traffic. Both circumstances influence the inland distribution of maritime traffic and are interconnected by the configuration of the hinterland of ports. The hypothesis of this paper is that spatial interaction effects, both exogenous and endogenous, shape the inter-port distribution of maritime traffic. The *endogenous interaction effect* arises when the inter-port distribution of the flows is influenced by those of nearby regions, whereas the *exogenous interaction effect* appears when the circumstances of these neighbours affect the flows generated by the region considered.

The inter-port distribution of Spanish maritime flows of foreign trade for the period 1995-2015 was analysed in order to confirm the validity of this hypothesis. To that end, the Spatial Econometric Interaction Modelling (SEIM) framework was followed, and a Spatial Durbin Model (SDM) to origin-destination flows was applied. The results confirm that endogenous and exogenous interaction effects impact the inland distribution of the Spanish container flows and reveal the existence of *direct* and *network effects* regarding the variables analysed.

Keywords: hinterland; inland flows; container traffic; port choice; spatial econometric interaction models.

1. Introduction

International trade is mostly channelled by sea. According to UNCTAD (2017), more than 80% of world trade by volume (70% by value) uses maritime transport. Consequently, understanding how foreign trade flows reach or leave the coastline, i.e. how traffic corridors are configured, deserves attention. The analysis of the relationship between transport infrastructure endowment and the economic performance of regions is a recurring topic in the literature (see, for instance, Dugonjic, 1989; Lakshmanan, 2007; Limao and Venables, 2001; Mačiulis et al., 2009 or Vickerman, 1995) . In this particular case, the focus is put on ports because both the origin and final destination of foreign trade flows are always on the inland side although they are channelled by sea, and ports act as a gateway.

Ports play a crucial role in transport costs and, consequently, affect regional competitiveness (Bottasso et al., 2018; Brodzicki et al., 2018; Limao and Venables, 2001). Specifically, Nijdam and van Der Horst (2017, p. 21) underlines: "Traditionally it has been the task of a port to facilitate trade in the region and create economic prosperity". Thus, it can be assumed that they serve regions. Simultaneously, port activity is directly linked (among other factors) to port location regarding the main centres of both production and consumption (Chapelon, 2006; Notteboom and Rodrigue, 2007). Therefore, it can also be assumed that the economic activity of regions is relevant for ports. Both effects, which could be called *port* and *region effects* respectively, are interconnected through the configuration of the hinterland of ports. On the one hand, the greater the attractiveness of a port, the wider the geographical scope of the resulting hinterland. On the other hand, it is expected that the closer the economic relationship of territories within the hinterland, the stronger the spillovers generated and the greater the magnitude of flows operated by ports. A deeper understanding of all these underlying dynamics would make it easier for policymakers to know how to develop infrastructure to strengthen the competitiveness of territories.

The inland distribution of the maritime traffic has been mostly analysed from the perspective of the Discrete Choice Theory (Martínez Moya and Feo-Valero, 2017), **where** the location (and accessibility) of their facilities **is** a relevant element for port choice. Previous studies have reached very interesting conclusions, but they have paid little attention to the spatial network context where the flows are generated and distributed. This paper contributes to the literature by analysing the inter-port distribution of maritime flows under the scope of Regional Economics and the perspective of Spatial

Econometrics. The hypothesis is that the inland distribution of maritime traffic is influenced by spatial interaction effects: endogenous and exogenous. The *endogenous interaction effect* would arise when the inter-port distribution of the flows is influenced by those of nearby regions, whereas the *exogenous interaction effect* would appear when the circumstances of these neighbours affect the flows generated by the region considered. The former implies global spillovers, since the diffusion of the interaction effect occurs in the whole system, while the latter only generates local spillovers (Elhorst, 2014).

Confirming the presence of these spatial interaction effects is important as they could influence the estimated impact of the variables analysed and reveal the existence of *direct* and *network effects* (LeSage and Fischer, 2016; Lesage and Thomas-Agnan, 2015), which is very useful for a proper planning of the transport infrastructure. As Lee and Hewings (2015) pointed out, the economic structure of neighbouring regions in the generation of trade is a subject which has yet to be fully explored. In addition, it should also be noted that historical, psychological, political or personal factors may also influence the inter-port distribution of maritime traffic (Langen, 2007; Notteboom, 2008). Therefore, this new approach can help policymakers better identify which corridors need to be reinforced and in what way, as the results demonstrate that the generation and the distribution of maritime flows are influenced by spatial interaction effects.

To verify the hypothesis, the Spatial Econometric Interaction Modelling (SEIM) framework was followed, and a Spatial Durbin Model (SDM) was applied to a panel data of origin-destination (OD) flows: the inter-port distribution of Spanish maritime flows of foreign trade for the period 1995-2015. The remainder of the paper is structured as follows: Section 2 provides a literature review and Section 3 the methodological proposal. Section 4 presents the data and variables included in the study. The hypothesis confirmation procedure is shown in Section 5, and *direct* and *network effects* are detailed in Section 6. Finally, the main conclusions are summarised in Section 7.

2 Literature review

Interactions between social and economic agents over space were extensively studied from the perspective of Spatial Interaction Models (SIM)[1]. This approach considers that the intensity of flows is influenced by both sizes and spatial separation

[1] This type of models is also labeled *gravity models* in reference to the traditional Newtonian denomination (Lesage and Pace, 2009; Patuelli and Arbia, 2016).

between origins and destinations (Griffith and Fischer, 2016). Additionally, it assumes that the inclusion of variables representing this spatial separation (distance being the most commonly used) would neutralize the spatial dependence on flows (LeSage and Fischer, 2016). However, in the early ´70s a theoretical discussion arose about the role of neighbours on the generation of such flows (see Curry, 1972). In the ´80s some methods started to be developed to identify the spatial dependence on SIM estimations (see Griffith and Jones, 1980), but the problem did not receive proper attention (Behrens et al., 2012). Such concern has recently attracted renewed interest, leading to the so-called Spatial Econometric Interaction Modelling (SEIM), which combines spatial econometric techniques with conventional SIM specifications (Patuelli and Arbia, 2016).

Regarding maritime transport, articles can be found applying spatial econometric techniques or conventional SIM. The spatial econometric techniques have been employed to certify the economic influence of a region and its neighbourhood on ports, and vice versa. In particular, Bottasso et al. (2014) observed the impact of ports on regional development (GDP) using an SDM for Europe. They concluded that the variables are positively correlated, and a great part of these effects occur outside the region where the port is located. For the Spanish case, Fageda and Gonzalez-Aregall (2014) found through an SDM that port traffic has a significant and positive impact on the manufacturing sector employment. More recently, Tsekeris (2016) employed a Dynamic SDM to examine the role of transport on regional export trade. He suggested that indirect effects play a key role in the regional exports in Greece. The constraint of these studies is that they do not verify the pattern of interaction where the port is involved, since they do not work with dyads of flows.

Conventional SIM are usually applied to analyse the pattern of foreign trade of regions on the inland side, focusing on the evaluation of the port hinterland and its determinants. More precisely, Debrie and Guerrero (2008) observed that distance is a relevant variable for exports, explaining to a great extent freight distribution in France. Ferrari et al. (2011) analysed the rivalry between the Ligurian ports and those of Northern Europe and concluded that additional variables other than distance are needed to properly explain the distribution of export flows. Guerrero (2014) concluded that the friction of distance varies according to the type of merchandise and that container flows are the least sensitive to its influence. Moura et al. (2017) identified that the province-port travel time and the container throughput of ports are two determinant variables to delimit the scope of the hinterland of the Spanish ports. Moura et al. (2018) came to the conclusion that the evolution of the geographical pattern of countries' foreign trade impacts the inland distribution of maritime traffic and, consequently, the use of the infrastructure. Guerrero (2019) found that, besides distance, quality of inland connections is crucial in determining the port hinterland in France, but this influence depends on the density of flows.

Conventional SIM are also used to analyse the role of port infrastructure as a driver of the international trade of regions. For instance, Wilson et al. (2004) concluded that port and airport facilities affect positively the bilateral trade of 75 countries. Artuc et al. (2014) found a positive correlation between export performance of Croatian regions and their proximity to ports and border gates, road density and other region-specific characteristics. Bensassi et al. (2015), evaluating the impact of transport infrastructure and logistic services on Spanish export trade, inferred that the number, size and quality of logistic facilities positively influence export flows. Guerrero et al. (2016), analysing the flows between coastal countries, found that distance is still a very important variable to understand the pattern of their links. Finally, Bottasso et al. (2018) proposed to measure the impact of transport infrastructure on Brazilian foreign trade and concluded that the influence is positive and much greater for exports than imports. These studies draw very interesting conclusions, but they ignore the fact that regional generation and distribution of flows can also be influenced by what is happening in neighbouring locations; that is, a broader geographical context must be considered. The first insight into this issue, as far as we know, was carried out by Tiller and Thill (2017). They applied a reverse SIM to analyse inland export flows in South America, and concluded that the geographic pattern found in their results requires further research.

The SEIM approach surpasses the highlighted shortcomings of both SIM and spatial econometric models. To the best of our knowledge, Márquez-Ramos (2014) was a pioneer in the use of a SEIM model in this field. Verifying the determinants of Spanish foreign trade, she concluded that ports, among other factors, play a positive role in promoting exports of regions where ports are located as well as in their neighbourhood. That is, she verified the existence of an endogenous interaction effect. Methodologically, we intend to go further to verify the existence of both spatial interaction effects, the endogenous and the exogenous. Thus, the model to be proposed should include: features of origins and destinations, characteristics of the transport chain, added with the concern of considering spatial dependences between regions and between flows.

The proposal made here uses the Spanish context as a case study. Several relevant conclusions have already been reached from the analysis of the inland distribution of the

Spanish maritime traffic. In addition to those previously referred to, from Veldman et al. (2011) we know that land transport costs are more influential for port choice than maritime costs, but from Veldman et al. (2013) we also know that the final destination influences the inter-port traffic distribution. From Garcia-Alonso and Sanchez-Soriano (2010, 2009) and Garcia-Alonso and Márquez (2017) we learn that distance is a determinant variable for the inland distribution of maritime traffic and that the activity of ports is directly linked to the traffic generated in nearby provinces. Finally, from Garcia-Alonso et al. (2016) we also know that the hinterland of the port of Valencia has experienced the best recent evolution. So once the key role of location has been proved, the aim here is to assess the presence of spatial interaction effects on the generation and inter-port distribution of the inland flows.

3. Methodological proposal

As stated above, the SEIM framework allows to relax the independence assumption between flows. The most common methods used to take this into account are those using eigenvector spatial filtering techniques (Chun, 2008; Griffith, 2000) and also those including spatial lag variables (Fischer and Griffith, 2008; LeSage and Pace, 2008). The former approach is interesting since it uses a subset of eigenvectors to filter the spatial dependence, but it does not clearly allow its measurement (Lambert et al., 2010), which is possible with the latter, used here.

Three different spatial interaction effects can be considered: endogenous, exogenous and among the error terms (Elhorst, 2014). The endogenous interaction effect is captured through the spatial lag of the dependent variable. The underlying idea is that neighbouring regions have similar inertias concerning flows as they are supposedly affected by similar circumstances. Any change could cause adjustments that would impact the entire network, generating global spillover impacts. In turn, the exogenous interaction effects are captured through the spatial lag of independent variables. This effect takes place when characteristics of neighbours influence the amount of flows generated by a specific region, giving rise to local spillovers (LeSage and Fischer, 2016). Finally, the spatial interaction effect among the error terms is captured using a spatial lag of the error term. This last effect does not induce spillovers and appears when some omitted determinants of the dependent variable are spatially correlated[2].

The Spatial Durbin Model (SDM) specification is proposed since it avoids the bias from omitted variables and nests the Spatial Autoregressive (SAR), the Spatial Error (SEM) and the Spatial Lagged X (SLX) models, preventing restrictions before estimations. Then, both endogenous and exogenous interaction effects can be explicitly modelled and formally tested (Lesage and Pace, 2009). Considering endogenous dependence implies accepting that trade takes place through a network of flows, and dealing with exogenous interaction makes the impact of the independent variables on flows unbiased (Lesage and Fischer, 2017).

The SDM applied here to a panel data to investigate the presence of spatial dependence on inland maritime flows takes the form of (1):

$$Y_{ODt} = \rho W_t Y_{ODt} + \alpha \iota_{n^2} + X_{Ot}\beta_O + W_t X_t \theta + X_{Dt}\beta_D + g_{ODt}\gamma + \delta_t \iota_{n^2} + \varepsilon_{ODt} \qquad (1)$$

Where:

- Y_{ODt} is the vector of logged flows between each *OD* dyad in year *t*;
- ι_n^2 is an $n^2 \; x \; 1$ vector of ones;
- X_{Ot} and X_{Dt} are respectively the matrices of logged independent variables of origin and destination in year *t*, resulted by the multiplication of the vectors of origin and destination characteristics by Kronecker product ($X_{Ot} = \iota_n \otimes X_t$; $X_{Dt} = X_t \otimes \iota_n$);
- X_t is the logged independent variable of origins, in the case of exports, and destinations, in the case of imports, in year *t*.
- W_t is the spatial weight matrix between provinces (row standardized) in year *t*;
- g_{ODt} is the matrix of logged travel time between *OD* dyad in year *t*;
- $\delta_t \iota_n^2$ is the year fixed effect, proxy for macroeconomic shocks;
- ε_{ODt} is the disturbance in year *t*; and
- ρ, α, β_O, θ, β_D and γ are the coefficients to be estimated.

The spatial weight matrix, *W*, was specified based on queen neighbourhood criterion with the inverse travel time between region centroids as the weighting scheme. Export and import flows were analysed here separately. For exports (flows from regions to ports), spatial dependence at origin was considered, while for imports (flows from ports to regions), spatial dependence at destination was assumed[3]. Specifically, the spatial dependence relationships were captured by the parameters of the endogenous interaction

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[2] Elhorst (2014) suggests ignoring the spatial interaction effect regarding the error term because this procedure should not affect the consistency of parameters and it can cause problems in the statistical inference, not justifying its application.

[3] Following LeSage and Pace (2008), three types of dependence can be considered: origin-based ($W_O = \iota_n \otimes W$), destination-based ($W_D = W \otimes \iota_n$) and origin-destination-based ($W_O * W_D$). Depending on the analysis, they can be applied together or not.

effect *(ρ)* and the parameters of the exogenous interaction effect *(θ)*. The former are associated with the spatial lag of the dependent variable, both for exports ($\rho_O W_{Ot} Y_{ODt}$) and imports ($\rho_D W_{Dt} Y_{ODt}$)[4]; the latter are linked to the spatial lag of the independent variable, both for the origin of flows in the case of exports *($W_{Ot} X_{Ot} \theta_O$)* and for the destination of flows in the case of imports *($W_{Dt} X_{Dt} \theta_D$)*[5].

4. Data sources

This paper evaluates the inter-port distribution of the Spanish maritime flows of foreign trade. In particular, it analyses the container flows (in tonnes) generated by the 47 peninsular provinces and channelled through the ports of Algeciras, Barcelona, Bilbao and Valencia in 1995, 2000, 2005, 2007, 2012 and 2015[6].

These four ports have been chosen for two reasons: (i) they are the main Spanish container ports on the peninsula and, in addition, (ii) they are the ports that compete most fiercely for the Spanish traffic, mainly generated in the northeast quadrant of the peninsula (Madrid included) (Garcia-Alonso et al., 2017; Garcia-Alonso and Márquez, 2017)[7]. The port of Algeciras is specialised in transhipment traffic; therefore, the national traffic is less relevant for its activity than for the rest of the ports. The port of Bilbao is particularly important for feeder traffic from the European ports of the northern range. Meanwhile, the ports of Valencia and Barcelona are the major ports, specialised in deep-sea cargo in Spain (Monios, 2011). They together accounted for approximately 75% of the container traffic of the Spanish port system in 1995 and 83% in 2015 (State-Owned Port System, 2018).

Flow data were provided by Customs and Excise Duties Department of the Spanish Tax Agency (Departamento de Aduanas e Impuestos Especiales de la Agencia Tributaria Española, 2018). This customs database is especially reliable for the study of extra-EU maritime traffic and suitable for delimiting the hinterland of ports because it allows to identify the province of origin, gateway port, final destination, mode of transport and container use (Escamilla-Navarro et al., 2010).

The independent variables representing provinces and ports are the Gross Domestic Product (GDP) and the volume of container throughput, respectively from

[4] These terms were shown in Eq. (1) in generic form as $\rho W_t Y_{ODt}$.
[5] These terms were shown in Eq. (1) in generic form as $W_t X_t \theta$.
[6] These years were selected due to the availability of data.
[7] The Portuguese ports were omitted because they hardly attract Spanish traffic (Santos and Soares, 2017).

Spanish Statistical Office (Instituto Nacional de Estadística, 2018) and State-Owned Port System (Ente Público Puertos del Estado, 2018). GDP is a proxy for the size of the economy commonly used for the analysis of maritime flows[8] (see, for instance, Bottasso et al., 2018; Garcia-Alonso and Márquez, 2017 or Márquez-Ramos, 2014). Meanwhile, container throughput is often used as an ideal proxy for port performance and competitiveness, port connectivity or port economic capacity (see, respectively, Meersman et al., 2010; Kashiha et al., 2016 or Wang et al., 2016). Finally, distance, as proxy for transport costs, is frequently used when analysing the hinterland of ports. However, it is being progressively replaced by travel time, given that the improvements made in infrastructure, as well as the technological advances, cause the friction of the distance to vary over time (Rodrigue, 2012). Thus, following Moura et al. (2018, 2017), travel time between provinces and port was used here as proxy for hinterland accessibility[9], as well as to construct the spatial weight matrix between provinces in order to capture the interregional connectivity. This variable was calculated through a specific network routine using GIS for the computation of the fastest paths each year, based on the actual existing Spanish road network[10] provided by García (2013).

These three variables, province´s GDP, port´s container throughput and travel time between province and port, are involved in the identification of the endogenous interaction effect for the selected years[11], as all of them influence the inter-port distribution of flows (Y_{ODt})[12], while the GDP is the only variable whose spatial lag is considered to identify the exogenous interaction effect, both for exports *($W_{Ot}X_{Ot}\theta_O$)* and imports *($W_{Dt}X_{Dt}\theta_D$)*. Hence, in accordance with the hypothesis, the three variables are expected to generate global spillovers, whereas local spillovers are only expected from GDP.

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[8] Ducruet and Itoh (2016) stated that socio-economic characteristics are crucial in the study of the volume and nature of the maritime flows.

[9] During 1995-2012, the road network improvements experienced a reduction in province-port travel time of 28% on average.

[10] The province-port travel time is considered only for road transport because, for the Spanish case, the rail transport to ports is less than 8% than that of the road transport (State-Owned Port System, 2018).

[11] The road network is provided until 2012. Nevertheless, 2015 was also analysed to expand the period under consideration and to bring it closer to the present. The estimation of 2015 was done considering GDP and port throughput for this year and travel time for 2012. It is important to note that, besides being close in time, the province-port travel time scarcely improved due to the dramatic reduction of infrastructure investment caused by the budgetary constraints experienced in Spain during this period.

[12] These variables were chosen because they were already successfully used before: GDP in Garcia-Alonso and Márquez (2017) and container throughput and travel time in Moura et al. (2017).

5. Hypothesis confirmation procedure and result

In order to verify the existence of both exogenous and endogenous interaction effects, a formal data-driven model selection procedure must be followed. In the field of spatial econometrics, there are two approaches widely accepted: specific-to-general and general-to-specific.

The specific-to-general approach was developed in the earlier stage of spatial econometrics (Anselin et al., 1996). It starts with the simplest possible model, usually OLS. Detecting spatial dependence on the residuals, Lagrange Multiplier (LM) tests are run to determine the proper spatial model specification, usually SAR or SEM. However, this procedure has been challenged recently, and the general-to-specific approach has been promoted instead (Elhorst, 2014). Two main reasons contribute to this evolution. First, the increasing accessibility of strong computational power makes the computational consideration less critical. Second, there is a new generation of spatial model specifications which are beyond the application scope of the specific-to-general approach.

In practice, LeSage (2014) suggested starting with general spatial models, such as the Spatial Durbin Model (SDM) and the Spatial Durbin Error Model (SDEM). However, these models are not nested; therefore, they cannot be ruled out according to the standard general-to-specific procedure. We argue that this constraint can be easily addressed: the robust LM test (central piece of the old specific-to-general approach), applied to SLX residuals can be used as formal selection guidance between SDM and SDEM. For this purpose, it must be taken into account that SDM is basically an SAR with SLX, and SDEM is nothing more than an SEM with the same SLX. To sum up, this paper suggests the following 3-step procedure in order to establish the validity of the SDM (based on actual data).

Step 1. Following the traditional specific-to-general procedure, a non-spatial model by pooled Ordinary Least Squares (OLS) was estimated, and the goodness-of-fitness measures (R-squared, Log-likelihood and AIC) were calculated. Then, a Moran's I test was conducted on the OLS residuals to verify the presence of spatial dependence.

Step 2. Once the spatial independence assumption is rejected, the robust LM test based on SLX residuals was applied to determine which model (SDM or SDEM) better fits the data.

Step 3. Considering the results of Step 2 and the general-to-specific approach, the SDM was applied to the panel data. To confirm the superiority of this model, the Likelihood Ratio (LR) and Wald tests were calculated to verify whether SDM can be reduced to SAR or SEM. The goodness-of-fitness measures (R-squared, Log-likelihood and AIC) were also conducted. Finally, the Moran's I test was applied again to check whether the spatial dependence on residuals remained.

The results of Step 1 from OLS when $\rho_O = \theta_O = 0$ in Eq. (1) are reported in columns 1 (exports) and 3 (imports) of Table 1. The Moran's I test rejects the null hypothesis (the average p-value is 0.001 both for exports and imports) attesting that there is significant spatial dependence on OLS residuals.

The results of Step 2 confirm that SDM fits the data better than SDEM. The robust LM test for SAR amounts to 49.21 (exports) and 52.05 (imports); whereas for SEM it amounts to 12.82 and 2.72, respectively[13].

The results of Step 3 of the SDM proposed in Eq. (1), including the goodness-of-fitness measures, are displayed in columns 2 (exports) and 4 (imports) of Table 1[14]. To address the issue of heteroskedasticity, besides the log transformation of the variables, Heteroskedasticity-Consistent Covariance Matrix (Andrews, 1991; White, 1980) is used for statistic inference. Additionally, it is confirmed that the SDM cannot be reduced to SAR or SEM since the results of LR and Wald tests have p-value of 0.001. It means that the null hypothesis is rejected; that is, spatial lags of the dependent and independent variables are different from zero, which implies that endogenous and exogenous effects are statistically significant. Finally, from Moran's I test, spatial independence assumption on SDM residuals cannot be rejected (the average p-value is 0.87 for exports and 0.80 for imports).

Table 1. Estimation results of OLS and SDM for exports and imports

	EXPORTS	***IMPORTS***

[13] Results are statistically significant at 1% except LM-SEM for imports.

[14] In order to test robustness and verify if there is an endogeneity problem, the same SDM was estimated considering the container throughput lagged one year. Additionally, the spatial weight matrix (W) was constructed with province-port travel times of 1980. It was concluded that these data do not suffer endogeneity because all parameters remained almost the same and with equal statistical significance. Similar procedures were done by Márquez-Ramos (2014) and Tamesue and Tsutsumi (2016) and Llano and de la Mata (2016) in terms of the lagged independent variable and the W, respectively.

As an additional robustness check, the inverse Euclidean distance matrix between the centroids of the provinces was also considered. Given this alternative, the main conclusions of the paper remain, although the coefficients of travel time and the endogenous and exogenous interaction effects suffer inflation, both for exports and imports. In the case of the two spatial-lag variables, they increase more than their associated main effects, which leads to predict that the importance of the network effect would also increase when the distance-based Euclidean matrix is used.

Certainly, this alternative matrix slightly improves goodness-of-fit measures. However, as Lesage and Fischer (2019) point out, the choice between weight matrices should not be based merely on that. In this particular case, and in terms of measuring the cost of transport between different provinces, we consider that travel time is a more meaningful measure than the pure distance.

	(1)	***(2)***	***(3)***	***(4)***
	OLS	***SDM***	***OLS***	***SDM***
Intercept (α)	-3.36* (-2.11)	-4.07** (-2.23)	-16.34*** (-9.52)	-8.48*** (-3.90)
GDP (β)	1.33*** (21.59)	1.34*** (27.62)	1.52*** (22.89)	1.54*** (27.81)
Container throughput (β)	0.18* (2.33)	0.11* (1.69)	0.77*** (9.29)	0.45*** (5.77)
Travel time (γ)	-2.31*** (28.59)	-1.15*** (-13.29)	-2.23*** (-25.62)	-1.35*** (-17.60)
W* GDP (θ)		-0.55*** (-7.36)		-0.70*** (-7.64)
W*Flows (ρ)		0.55*** (21.39)		0.45*** (15.72)
Corrected R-squared	0.77	0.85	0.73	0.82
Log-likelihood	-2,303.48	-2,133.10	-2,385.99	-2,269.68
AIC	4,626.96	4,290.20	4,791.98	4,563.35
Observations	1,128	1,128	1,128	1,128
Year fixed effect	Yes	Yes	Yes	Yes

Level of significance: *10%, 5%**,1%***; t and z-values in parenthesis.

From these preliminary results it can be concluded that SDM is a proper approach to study the inland distribution of the maritime traffic. They also confirm that spatial interaction effects have to be considered when analysing this type of flows, although this is not the usual practice. Therefore, the hypothesis stated is confirmed and, consequently, a more detailed explanation about the results concerning the endogenous and exogenous interaction effects is required.

5.1. Analysis of the endogenous and exogenous interaction effects

As can be seen in Table 1, the parameter of the endogenous interaction effect *(ρ)* has a positive sign and great significance, both for exports and imports. The existence of this interaction effect implies that a specific change in the system can lead to important adjustments in the general dynamics of flows. In this regard, Moura et al. (2018) concluded that a change of the geographical links of Spanish provinces in terms of international trade altered the inland distribution of maritime traffic, modifying the use of port infrastructure in the country. This positive dependence usually occurs when economic agents share resources, as is the case with transport infrastructure (LeSage and Fischer, 2016). The underlying idea is that the flows channelled through the same corridor face similar circumstances (transport costs and profit opportunities). In this sense, Ramos and Moral-Benito (2017) observed not only that there are agglomeration economies for the Spanish export flows, but also that they are justified by both fixed and variable costs derived from the export process. Additionally, Garcia-Alonso et al. (2016) found that the emergence of new exporting firms is not spatially random but matches the improvement of the inland transport infrastructure. Now, considering the obtained results, it can be concluded that the firms´ behaviour in Spain is positively influenced by the way that neighbouring firms distribute their flows. In short, the existence of a (positive) endogenous interaction effect has been confirmed.

Concerning the parameter of the exogenous interaction effect *(θ)*, it has a negative sign and great significance also for both exports and imports (see Table 1). This effect takes place when the characteristics of neighbouring territories contribute to explain the flows of a specific place. LeSage and Llano-Verduras (2014) found that natural resources, climate and other characteristics of neighbouring regions are important to explain a region's pattern of productive specialisation and concluded that such interaction can lead to sectoral linkages that can be either complementary or competitive. The negative sign of the parameter suggests a certain degree of competition among neighbouring provinces, which outweighs the effects of complementarity or co-operation here. As this sort of dependence refers to the geographic distribution of the variable considered (Griffith and Arbia, 2010), it is important to highlight that the exogenous interaction effect was calculated taking into account the GDP of the Spanish provinces, whose economic size does not follow a geographical pattern[15].

Once the influence of both spatial interaction effects on the inter-port distribution of the Spanish maritime flows has been confirmed, it is possible to obtain unbiased estimators and identify both *direct* and *network effects* of the variables analysed, as shown in the following section.

6. *Direct* and *network effects* on Spanish maritime flows

A direct comparison between the coefficients of the non-spatial model (OLS) and the spatial model (SDM) is not valid[16]. This is because changes in characteristics of a single observation impact all elements of the flow matrix when using the SDM (Elhorst, 2014). In fact, any change in an independent variable will achieve a double impact: i) on

[15] The insignificant p-value of Moran-I measure indicates that the GDP of the Spanish provinces is randomly distributed (1995: 0.55 and 2015: 0.64).
[16] The coefficients of non-spatial models are interpreted directly and represent marginal effects, whereas the coefficients of spatial models do not.

the outcome of the observation, directly affected by this change, and ii) on the outcome of the rest of the observations (not directly affected by it). The former is known as *direct effect* and the latter is called *network effect.* The sum of both is named *total effect*. These three effects were computed following Lesage and Thomas-Agnan (2015), who extended the original Lesage and Pace (2009) approach to a spatial flow setting (i.e. SEIM). They are displayed in Table 2 together with the OLS coefficients (already shown in Table 1)[17].

Table 2. Marginal effects of OLS and SDM for exports and imports

EXPORTS				
Independent variables	***OLS***	***SDM***		
	Direct effect (Total effect)	***Direct Effect***	***Network Effect***	***Total Effect***
GDP	1.33***	1.36***	0.36***	1.72***
Container throughput	0.18*	0.14***	0.14***	0.28***
Travel time	-2.31***	-1.27***	-1.23***	-2.50***

IMPORTS				
Independent variables	***OLS***	***SDM***		
	Direct effect (Total effect)	***Direct Effect***	***Network Effect***	***Total Effect***
GDP	1.52***	1.53***	0.01***	1.54***
Container throughput	0.77***	0.46***	0.33***	0.79***
Travel time	-2.23***	-1.43***	-1.02***	-2.45***

Level of significance: *10%, 5%**,1%***.

Two similar conclusions can be drawn from the OLS model and the SDM. First, the travel time is by far the most influencing variable for all the container flows; second, the intensity of the reaction of provincial exports and imports to changes in container traffic in ports is clearly different[18]. Beyond these similarities, SDM corrects the potential bias of OLS caused by neglecting the flow/spatial dependence. The most remarkable difference takes place for travel time, as the coefficient of this variable in non-spatial

[17] In the case of OLS coefficients, they do not have network effects as OLS assumes no spatial interactions (Lesage and Pace, 2009). Therefore, the *direct* and *total effect* are the same.

[18] The comparison among variables is valid because the log-log functional form was used and, consequently, all the coefficients can be interpreted as an elasticity.

models absorbs part of the spatial structure of the system, hence being biased. With the inclusion of spatial lag variables, the parameter obtained reflects only the behaviour of the economic agent[19] (Fotheringham, 1981).

Therefore, it is important to pay special attention to the *direct* and *network effects*. Concerning the *direct effect*, two interesting findings can be pointed out. Specifically:

- As expected from previous studies[20], GDP and travel time are key to the inter-port distribution of traffic, although they influence the dependent variable in opposite directions. The important difference between the results of the two models, which must be highlighted here, lies in the magnitude of their relevance: these two variables have a similar influence on flows according to the SDM (for both exports and maritime imports). Specifically, the *direct effect* of GDP on flows is very close to that identified by the OLS model (1.36 vs 1.33 for exports, and 1.53 vs 1.52 for imports); but the *direct effect* of travel time is much smaller (-1.27 vs -2.31 for exports, and -1.43 vs -2.23 for imports). This finding is very important because it reveals that the accessibility of ports is actually relevant to divert traffic from the considered province to their facilities, but not such a determining factor as was assumed.
- The influence of the container throughput is considerably smaller for export flows (0.14 vs 0.46). As can be seen, changes in the port size will have a direct and minor impact for the exports of the considered province, but not so minor for imports. All this means that both flows react differently to the same factor and, consequently, have to be studied separately. One plausible explanation is that maritime imports are likely to have been grouped together in a hub port before reaching the country of destination. Once the freight arrives at the port serving as a gateway, it is distributed among the final inland destinations (provinces). Thus, for imports, the size of container ports is more relevant as it is directly linked to their connectivity (Kashiha et al., 2016). On the contrary, the origin of exports are the provinces and their first destination is a national port, so it is not surprising that the location and accessibility of their facilities are more relevant in relative terms for these flows. Therefore, as the size of the port is less relevant for exports, it could be expected that a larger share of these flows uses ports with fewer direct connections. In other words, for export flows it would be enough for the port to be connected to a major

[19] In this analysis, the reaction of the provincial flow considered.

[20] For instance, Brodzicki et al. (2018) concluded that the size of Spanish regions affects positively their export performance, and Condeço-Melhorado et al. (2013) found that Spanish regions with high accessibility tend to be more productive and developed.

hub for transhipment to the final destination. This raises the question of what the role of transhipment traffic is, depending on whether it is an export or an import flow.

The results of *network effects* are particularly interesting as they are the missing piece in a non-spatial model, and illustrate most clearly the benefits of adopting the SDM framework instead. Taking into account the three independent variables, it can be said that:

- The *network effect* of GDP is important for maritime exports (0.36)[21] but negligible for imports (0.01). This means that changes in the economic size of a province directly influence the exports of the rest, but scarcely affect their imports. The positive evolution of the GDP of a province can generate positive spillovers and reinforce the export flows of its neighbours. However, maritime import flows are more linked to provincial needs arising from the productive specialization. Hence, their evolution does not respond with the same intensity to changes in the GDP of neighbouring provinces.
- The container throughput has a slight *network effect* for maritime exports (0.14), and moderate for imports (0.33). This means that increasing the size of ports reinforces the overall import flows to a greater extent than exports, hence it must be concluded that connectivity is much more influential for the first flows.
- The *network effect* of travel time (-1.23) is nearly as important as the *direct effect* (-1.27) for maritime exports, and considerably high for imports (-1.02). The magnitude of such *network effect* shows that an improvement of the accessibility benefits the overall system. The use of common resources, such as inland corridors, contributes to explain the relevance of the *network effect* for this variable.

7. Concluding remarks

On the basis of the results, it can be said, firstly, that the economic size largely explains the intensity of the provincial maritime flows in Spain, which suggests that the larger the market, the greater the basis for generating those flows. Secondly, that a decrease in travel time between a province and a port leads to an increase in the provincial maritime flows, which confirms the efforts of improving accessibility. Finally, that container throughput is a factor to be taken into account to explain the inland distribution

[21] Garcia-Alonso and Márquez (2017) also found a positive influence of neighbouring regions on the port choice for exports flows in Spain.

of maritime traffic. These conclusions are in line with Garcia-Alonso and Márquez (2017) and Moura et al. (2017, 2018).

Once the existence of spatial interaction effects in the inland distribution of the maritime flows is confirmed, it is possible to go one step further, providing we can distinguish between the *direct* and the *network effects* of changes in the independent variables. This constitutes an interesting contribution to the literature, since the conclusions about the relevance of the factors influencing the internal distribution of these flows must be nuanced. In other words, ignoring the existence of spatial interaction effects can cause misleading conclusions about the evolution of inland corridors of freight and the configuration of the hinterland of ports; i.e., about how to deal with the planning of the transport infrastructure and its effect on the regional flows.

In this sense, the findings reached here have to be considered. First, the provinces with the largest economic growth are not only those that generate greater volume of traffic, but also those that most intensively stimulate traffic generation in their surroundings, although only for outgoing flows. Second, travel time is not only relevant for the configuration of the hinterland of ports, but it also influences the provincial traffic generation. In addition, a reduction in travel time between a particular province and a port also stimulates the generation of maritime cargos in the rest of the country. That is, the existence of regional spillovers should be considered when planning the inland corridors. Finally, container throughput is a factor to be taken into account to explain the spatial interaction effects on the inland distribution of maritime traffic, but to a greater extent for imports than for exports.

Bearing in mind all of the above, and concerning the particular case study carried out here, the conclusion to be drawn is that the improvement of the corridors within the north-east quadrant would have the greatest positive spillovers for the country as a whole; i.e. the return on every euro invested in the transport infrastructure improvement would be expected to be maximum. The reason is that provinces with the most dynamic economies are located there, and the main ports are placed along the Mediterranean coast. However, such initiative would probably contribute to reinforce the isolation of the less dynamic regions. Therefore, and in order to maintain a convenient trade-off between efficiency and territorial cohesion, it is important to further the analysis of the existence of spatial interaction effects when considering infrastructure improvements. In this sense, it would be desirable to analyse the presence of spatial interaction effects when traffic is also channelled through secondary ports, such as Vigo, for instance.

The study presented here confirms the interest of this approach and opens the door to future research into, for instance, the influence of alternative factors or the sensitivity of the spatial interaction effects to the characteristics of cargo. Methodologically, it would also be interesting to contrast the results of this paper with Poisson variants of spatial interaction models. Nevertheless, a deeper development of these models is still required for this particular purpose.

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