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Analysis of the relevance of location for port activity

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RESUMEN (en español)

Los puertos son una infraestructura clave para el comercio internacional. Por un lado, su rendimiento interesa a todos los actores involucrados en la cadena global de suministro ya que sirven de enlace entre el medio terrestre y el marítimo y, en consecuencia, prestan sus servicios tanto a los cargadores como a las compañías navieras. Por otro, también tiene interés para los gestores públicos en tanto su actividad influye en el coste de transporte, de manera que afecta tanto a la competitividad nacional como a la regional.

Desde el punto de vista terrestre, la distribución interior de los flujos marítimos depende de la dotación de infraestructuras y del éxito del puerto correspondiente a la hora de competir por el tráfico. En este proceso, el resultado de las estrategias de las autoridades portuarias depende de sus propias capacidades de gestión, pero también de factores que escapan a su control. Muchos estudios concluyen que las características geográficas de los puertos juegan un papel clave en su atractivo. Así pues, cabe esperar que las características vinculadas a la ubicación geográfica de sus instalaciones repercutan en sus actividades. Este es el punto de partida de la investigación que aquí se presenta, centrada en el sistema portuario español como caso de estudio.

La tesis se estructuró como sigue. El Capítulo 2 se dedica a delimitar el alcance del área de influencia de los puertos. Este es un primer paso útil para los responsables portuarios y los gestores públicos a la hora de diseñar las estrategias portuarias y el mapa de infraestructuras. Para alcanzar el objetivo propuesto, se propuso una adaptación del Modelo de Huff, que es un modelo de interacción espacial desarrollado para delimitar áreas de comercio. Como factores de atracción y repulsión se consideraron, respectivamente, el volumen de tráfico del puerto y el tiempo de viaje por carretera entre las provincias y las instalaciones portuarias.

El punto de partida del Capítulo 3 es la posible relación entre dos hechos muy diferentes: la creciente influencia de las economías asiáticas en el comercio internacional y el incremento del peso de los puertos mediterráneos dentro del conjunto de instalaciones europeas. Muchos trabajos analizan el papel de la infraestructura de transporte en el desarrollo económico y la competitividad regional. Sin embargo, se ha prestado poca atención al impacto de la evolución de los patrones de comercio internacional en el uso de la infraestructura. Con este propósito, se planteó un modelo de interacción espacial restringido en el origen para verificar si la evolución del patrón geográfico del comercio exterior influye en la distribución inter-portuaria de los flujos marítimos.

Los resultados obtenidos permitieron constatar que la estructura espacial de los flujos analizados es importante. Por ello, el propósito del Capítulo 4 es verificar la presencia de efectos de interacción espacial, tanto exógenos como endógenos, en la distribución inter-portuaria del tráfico marítimo. Para abordar esta tarea, se adoptó el enfoque de los modelos de interacción econométrica espacial y se aplicó un modelo Durbin espacial.

En el Capítulo 5 cambia el punto de vista del análisis de la relevancia de los factores geográficos en la actividad portuaria, y el enfoque pasa a situarse en la costa en lugar de en el interior. Este capítulo se dedica a estudiar el impacto de las olas y el viento en la eficiencia técnica de los puertos a través de una función de distancia al producto. Esto es recomendable a la hora de planificar la dotación de infraestructura de los puertos, especialmente en un contexto de cambio climático.

Por último, en el Capítulo 6 se resumen las principales conclusiones derivadas del análisis realizado, y se sugieren algunas cuestiones para su resolución en investigaciones futuras.

RESUMEN (en Inglés)

Ports are a critical infrastructure for international trade. On the one hand, their performance is of interest to all the stakeholders involved in the global supply chain

because they act as a gateway and, consequently, their services are offered both to shipping lines and shippers. On the other hand, they are also of interest to policy- makers since their activity influences transport costs and, hence, affects both the national and regional competitiveness.

From the perspective of the hinterland, the inland distribution of maritime flows depends on the infrastructure endowment and the success of the corresponding port when competing for the traffic. In this process, the result of the strategies of port authorities depends not only on their own management skills, but also on factors beyond their control. Many studies conclude that the geographical features of ports play a key role in their attractiveness. Thus, the characteristics linked to geographical location of ports can be expected to influence port performance. This is the starting point of this research, focused on the Spanish port system as a case study.

The structure of the work is as follows. Chapter 2 is devoted to delimiting the scope of the hinterland of ports. This is a useful first step for port managers and policy-makers when designing port strategies and the map of infrastructures. To achieve this goal, an adapted Huff Model, a Spatial Interaction Model developed to measure trade areas, was applied. As repulsion and attractiveness factors, the province-port travel time along the road network and the port's container throughput were considered, respectively.

The starting point of Chapter 3 is the potential relationship between two very different facts: the increasing influence of Asian economies in international trade and the increasing share of the ports of the Mediterranean region in the European port system. Many papers analyse the role of transport infrastructure in the economic development and competitiveness of regions. However, the literature has paid little attention to the impact of the changing patterns of international trade on the use of the infrastructure. To that end, an origin-constrained Spatial Interaction Model was applied to verify whether the evolution of the geographical pattern of foreign trade influences the inter-port distribution of maritime flows.

From the results obtained, it became clear that the spatial structure of the studied flows is of considerable importance. Consequently, the purpose of Chapter 4 is to verify the presence of spatial interaction effects, both exogenous and endogenous, on the inter-port distribution of maritime traffic. To address this task, the Spatial Econometric Interaction Modelling framework was followed, and a Spatial Durbin Model was applied.

In Chapter 5, the viewpoint of the analysis of the relevance of the geographical factors in port activity changes, and the focus shifts from the inland side to the coast. It is devoted to studying the impact of waves and wind on the technical efficiency of ports by means of an output distance function approach. This is recommendable when planning the port endowment, particularly important in a context of climate change.

Finally, Chapter 6 summarises the main conclusions drawn from the analysis conducted and suggests lines of research to be considered in the future.

SR. PRESIDENTE DE LA COMISIÓN ACADÉMICA DEL PROGRAMA DE DOCTORADO EN Economía Instrumentos del Análisis Económico

Fdo: Marta Escapa García

Fdo. Juan Francisco Canal Domínguez

Bilbao, 12 de marzo de 2019

Perhaps this is the hardest part of writing a thesis because a life does not fit into a regression analysis and it is not the p-value that makes us discover the significance of people along our path.

This thesis began many years ago, long before we arrived in Oviedo when my husband, Daniel, bought into the idea and encouraged me to bravely go in search of that goal. The indecisions were many, the difficulties enormous, but nothing kept us from trying to achieve it. He has lent me his pragmatism many times and I am grateful for the way he paused his life for the simple purpose of seeing me happy. I cannot fail to also thank our daughter, Luiza, who, though so small and with no choice, accompanied us on this great adventure (or a little madness). She stepped out of her comfort zone and adapted incredibly well. My family, thus, ends these four years equally sharing the degree which was bestowed upon me.

I cannot forget friends and family who have walked with us during every part of the journey. It is impossible to mention everyone, but some are great representatives of others, so I name them: my mother, Renusa; my father, Jose Maria; my godmother, tia Cleide; my aunt Lolô (Regina) and my uncle Milton. To my grandparents, represented by vovó Didia (Luiza), you are my guides.

Such gratitude deserves to be extended to Lorena, my friend and my thesis advisor. I am grateful, first and foremost, for your friendship, for your listening moments and for your openness so that I could enter into your personal life. In addition, I appreciate your guidance and confidence in my ability as a researcher as well as the generous amount of freedom of action, which helped me to grow on my own as well.

Talvez esta seja a parte mais difícil de escrever uma tese, porque uma vida não se encaixa em uma análise de regressão e não é o valor p que nos faz descobrir o significado das pessoas ao longo do caminho.

Esta tese começou há muitos anos, muito antes de chegarmos a Oviedo, quando o meu marido, Daniel, acreditou na ideia e encorajou-me a ir bravamente à procura desse objetivo. As indecisões eram muitas, as dificuldades eram enormes, mas nada nos impedia de tentar alcançá-lo. Ele me emprestou seu pragmatismo muitas vezes e sou grata pela maneira como ele pausou sua vida pelo simples propósito de me ver feliz. Não posso deixar de agradecer também a nossa filha Luiza que, embora tão pequena e sem escolha, nos acompanhou nesta grande aventura (ou um pouco de loucura). Ela saiu de sua zona de conforto e se adaptou incrivelmente bem. Minha família, portanto, termina esses quatro anos igualmente compartilhando o grau que me foi concedido.

Não posso esquecer amigos e familiares que andaram conosco durante cada parte da jornada. É impossível mencionar todos, mas alguns são grandes representantes dos outros, então os nomeio: minha mãe, Renusa; meu pai, José Maria; minha madrinha, tia Cleide; minha tia Lolô (Regina) e meu tio Milton. Aos meus avós, representados vovó Didia (Luiza), vocês são meus guias.

Tal gratidão merece ser estendida a Lorena, minha amiga e minha orientadora de tese. Sou grata, em primeiro lugar e acima de tudo, por sua amizade, por seus momentos de escuta e por sua abertura para que eu pudesse entrar em sua vida pessoal. Além disso, agradeço sua orientação e confiança em minha capacidade como pesquisadora, bem como a generosa quantidade de liberdade de ação, o que me ajudou a crescer por conta própria também.

Resumen en español

Los puertos son una infraestructura clave para el comercio internacional. Teniendo en cuenta que a través de sus instalaciones se canaliza más del 80% de los flujos de comercio mundial (en términos de valor, se supera el 70%) (UNCTAD, 2017), la relevancia de los puertos resulta evidente. Por un lado, su rendimiento interesa a todos los actores involucrados en la cadena global de suministro ya que sirven de enlace entre el medio terrestre y el marítimo y, en consecuencia, prestan sus servicios tanto a los cargadores como a las compañías navieras. Por otro, también tiene interés para los gestores públicos en tanto su actividad influye en el coste de transporte, de manera que afecta tanto a la competitividad nacional como a la regional (Limao and Venables, 2001; Wilmsmeier et al., 2006).

Desde el punto de vista terrestre, la distribución interior de los flujos marítimos depende de la dotación de infraestructuras y del éxito del puerto correspondiente a la hora de competir por el tráfico. En este proceso, el resultado de las estrategias de las autoridades portuarias depende de sus propias capacidades de gestión, pero también de factores que escapan a su control. Entre ellos, Martínez Moya and Feo-Valero (2017) encontraron que muchos estudios concluyen que las características geográficas de los puertos juegan un papel clave en su atractivo. Así pues, cabe esperar que las características vinculadas a la ubicación geográfica de sus instalaciones repercutan en sus actividades. Este es el punto de partida de la investigación que aquí se presenta, centrada en el sistema portuario español como caso de estudio.

Inicialmente se prestó especial atención al análisis de las circunstancias portuarias analizadas desde la perspectiva interior; es decir, al estudio de la distribución inter-portuaria de los flujos atendiendo a la ubicación de las instalaciones. Esta tarea se abordó desde la perspectiva metodológica de los modelos de interacción espacial, y se extrajeron varias conclusiones relevantes. Posteriormente se tuvo en cuenta que las características geográficas de los puertos también están condicionadas por su ubicación con relación a la costa, particularmente por aspectos tales como las olas y el viento al que están expuestos. Por lo tanto, con el fin de analizar cómo estos condicionantes naturales pueden influir en el rendimiento portuario, también se llevó a cabo un análisis de la eficiencia técnica de los puertos.

Todo lo anterior se estructuró como sigue. El Capítulo 2 se dedica a delimitar el alcance del área de influencia de los puertos. Este es un primer paso útil para los responsables portuarios y los gestores públicos a la hora de diseñar las estrategias portuarias y el mapa de infraestructuras. Para alcanzar el objetivo propuesto, se propuso una adaptación del Modelo de Huff, que es un modelo de interacción espacial desarrollado para delimitar áreas de comercio. Como factores de atracción y repulsión se consideraron, respectivamente, el volumen de tráfico del puerto y el tiempo de viaje por carretera entre las provincias y las instalaciones portuarias.

El punto de partida del Capítulo 3 es la posible relación entre dos hechos muy diferentes: la creciente influencia de las economías asiáticas en el comercio internacional y el incremento del peso de los puertos mediterráneos dentro del conjunto de instalaciones europeas. Muchos trabajos analizan el papel de la infraestructura de transporte en el desarrollo económico y la competitividad regional. Sin embargo, se ha prestado poca atención al impacto de la evolución de los patrones de comercio internacional en el uso de la infraestructura. Con este propósito, se planteó un modelo de interacción espacial restringido en el origen para verificar si la evolución del patrón geográfico del comercio exterior influye en la distribución inter-portuaria de los flujos marítimos.

Los resultados obtenidos permitieron constatar que la estructura espacial de los flujos analizados es importante. Por ello, el propósito del Capítulo 4 es verificar la presencia de efectos de interacción espacial, tanto exógenos como endógenos, en la distribución inter-portuaria del tráfico marítimo. Para abordar esta tarea, se adoptó el enfoque de los modelos de interacción econométrica espacial y se aplicó un modelo Durbin espacial.

En el Capítulo 5 cambia el punto de vista del análisis de la relevancia de los factores geográficos en la actividad portuaria, y el enfoque pasa a situarse en la costa en lugar de en el interior. Este capítulo se dedica a estudiar el impacto de las olas y el viento en la eficiencia técnica de los puertos a través de una función de distancia al producto. Esto es recomendable a la hora de planificar la dotación de infraestructura de los puertos, especialmente en un contexto de cambio climático.

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1

Introduction

Ports are a critical infrastructure for international trade. With more than 80% of the global volume of freight transported by sea (and more than 70% in terms of value) (UNCTAD, 2017), the relevance of ports becomes clear. On the one hand, their performance is of interest to all the stakeholders involved in the global supply chain because they act as a gateway and, consequently, their services are offered both to shipping lines and shippers. On the other hand, they are also of interest to policy- makers since their activity influences transport costs and, hence, affects both the national and regional competitiveness (Limao and Venables, 2001; Wilmsmeier et al., 2006).

From the perspective of the hinterland, the inland distribution of maritime flows depends on the infrastructure endowment and the success of the corresponding port when competing for the traffic. In this process, the result of the strategies of port authorities depends not only on their own management skills, but also on factors beyond their control. Among them, Martínez Moya and Feo-Valero (2017) found that many studies conclude that the geographical features of ports play a key role in their attractiveness. Thus, the characteristics linked to geographical location of ports can be expected to influence port performance. This is the starting point of this research, focused on the Spanish port system as a case study.

Initially, particular attention was paid to the analysis of the port circumstances from the inland viewpoint; i.e. the distribution of flows between port facilities with regard to their location. This task was approached from the methodological perspective of the spatial interaction models, and several relevant conclusions were drawn. Later, it was taken into account that the geographical features of ports are likewise linked to their location at sea, in particular to factors such as waves and wind. Therefore, in order to analyse how these natural constraints can influence port performance, an analysis of the technical efficiency of the ports was also carried out.

The structure of the work is as follows. Chapter 2 is devoted to delimiting the scope of the hinterland of ports. This is a useful first step for port managers and policy-makers when designing port strategies and the map of infrastructures. To achieve this goal, an adapted Huff Model, a Spatial Interaction Model developed to measure trade areas, was applied. As repulsion and attractiveness factors, the province-port travel time along the road network and the port's container throughput were considered, respectively.

The starting point of Chapter 3 is the potential relationship between two very different facts: the increasing influence of Asian economies in international trade and the increasing share of the ports of the Mediterranean region in the European port system. Many papers analyse the role of transport infrastructure in the economic development and competitiveness of regions. However, the literature has paid little attention to the impact of the changing patterns of international trade on the use of the infrastructure. To that end, an origin-constrained Spatial Interaction Model was applied to verify whether the evolution of the geographical pattern of foreign trade influences the inter-port distribution of maritime flows.

From the results obtained, it became clear that the spatial structure of the studied flows is of considerable importance. Consequently, the purpose of Chapter 4 is to verify the presence of spatial interaction effects, both exogenous and endogenous, on the inter-port distribution of maritime traffic. To address this task, the Spatial Econometric Interaction Modelling framework was followed, and a Spatial Durbin Model was applied.

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Finally, Chapter 6 summarises the main conclusions drawn from the analysis conducted and suggests lines of research to be considered in the future.

2

Delimiting the scope of the hinterland of ports: proposal and case study

Abstract

The purpose of this chapter is to propose a methodology to delimit the scope of the hinterland of ports as accurately and simply as possible. To achieve this goal, the Huff model was adapted. In order to verify the validity of the proposal, it was applied to the Spanish case. As repulsion and attraction factors, both key aspects in the Spatial Interaction Models, the province-port travel time along the road network and the container throughput of the ports were considered respectively. The estimated hinterland of the analysed container ports fits well the observed flows. The obtained results confirm that the proposal made allows to identify the scope of the hinterland of ports in an effective an easy way, which is of interest both to stakeholders and policy-makers.

2.1 Introduction

In general terms, the port hinterland is the geographical area where the port has the substantial part of its business (that is, where the bulk of its traffic is generated) (Notteboom, 2008), and also the zone mainly served by that port (Guerrero, 2014). Traditionally, the hinterlands were concentrated around the port facilities because the proximity of ports to the production/consumption centres was key for their choice. Nevertheless, the situation has changed owing to the dematerialization and containerization process of the transport flows (Fleming and Hayuth, 1994)[1]. Traffic flows now have large volatility due to the progress of physical and organizational connectivity of the transportation system. That volatility means that the average distance covered by cargo has increased significantly, allowing both the overlap of the hinterlands and their discontinuous spatial expansion through inland islands developed around inland terminals[2]. Furthermore, the port-hinterland relationship has a renewed interest both because inland transport costs constitute a significant fraction of logistics costs and most bottlenecks take place in the hinterland[3] (van Der Horst and De Langen, 2008). Consequently, the analysis of this topic is relevant as it contributes to identify where and how the land transport infrastructure needs to be improved.

As Notteboom (2008) and Notteboom and Rodrigue (2005) state, drawing the port hinterland bearing in mind this new reality is not a simple

[1] These authors were pioneers in recognising the relevance of the hinterland in the port activity despite the process of containerization.

[2] Notteboom and Rodrigue (2005) developed the concept of port regionalization to explain this new reality. See Rodrigue and Notteboom (2006) for a deeper understanding of this concept, and Santos and Soares (2017) for a literature review on articles based on the port regionalization process.

[3] See van Der Horst and De Langen (2008) for a review of the main challenges regarding the coordination problems in hinterland transport chains.

task[4], but the understanding of the underlying process has an increasing interest because it contributes to uncover the dynamics of the inland distribution of the maritime flows (which channel the bulk of international trade). This is a convenient first step for stakeholders and policy-makers involved in decision making regarding both the design of port strategies and the map of infrastructures. For the former, it is possible to have a clearer understanding of the actual closest competitors regarding new targets, to discover potential customers in undeveloped markets regarding the port capabilities and, consequently, to reach them in terms of accessibility enhancement and/or services improvement offered by port facilities. For the latter, this additional knowledge allows them to take optimal decisions from the perspective of both the regional development and the budget constraints. In that sense, Ng et al. (2014) and Santos and Soares (2017) suggest as possible suitable initiatives for port regionalization the setting-up of a network of inland terminals, the planning of rail services or the improvement of large intermodal corridor efficiency.

The scope of the hinterland of ports is directly linked to the ability of ports to attract traffic, since both the origin and the final destination of the maritime flows are on the inland side (Garcia-Alonso et al., 2016). That means that the hinterland configuration depends on the success of the corresponding port when competing for the traffic on the landside[5] and, consequently, both aspects can be seen as two sides of the same coin. This is why the topic of port hinterlands has been analysed from the perspective of the Discrete Choice Theory (see, for instance, Garcia-Alonso and Sanchez-Soriano, 2009). However, this chapter proposes an alternative

[4] Notteboom and Rodrigue (2007) point out that hinterlands are a complex spatial and functional structure resulting from the mixture of three components, namely the macro-economic, physical and logistical components.

[5] In the same way, the quality of hinterland connections has become a relevant key aspect for the port choice (Ferrari et al., 2011; Nazemzadeh and Vanelslander, 2015; Ng et al., 2014).

approach.

The goal of this chapter is to propose a methodology to delimit the hinterland of ports as accurately and simply as possible. The underlying hypothesis is that the scope of the hinterlands can be drawn simply taking into account the location of the ports and their throughput. The proposal is to adapt the Huff model, including as explicative variables the province-port travel time and the port's container throughput. This adapted version was applied to a case study in order to verify the stated hypothesis and the effectiveness of the proposed model. Specifically, it was implemented to draw the hinterland of a set of Spanish container ports regarding the national export flows in 2012 (the last year with all data available).

Spain is a natural gateway between Europe and both North Africa and Latin America. Nevertheless, the country is a peripheral region in South-Western Europe. In general terms, the Mediterranean ports are heavily penalized for their distance from areas with high population and economic densities (Chapelon, 2006). Additionally, the Spanish ports face a major challenge due to technical difficulties in rail shuttles (Notteboom, 2010). Therefore, the disconnection between the nationality of the gateway and the hinterland observed in Europe (Rodrigue and Notteboom, 2010a) is particularly hard in the Spanish case. However, Notteboom (2008) points out that investments made have led to an increase in the trade flows, benefiting Spain and Italy. Furthermore, Bensassi et al. (2015) state that the advantages of the geographical location of Spain will outweigh the disadvantages once proper logistic improvements have been carried out.

The largest container ports and the main gateways of Spanish foreign trade are the ports of Algeciras, Barcelona, Bilbao and Valencia. However, Algeciras was removed for the analysis because it is specialised in transhipment traffic and, consequently, the traffic coming from its hinterland is much less relevant, and the geographical scope of its hinterland is much more limited, stable and less contestable for the rest of the ports, as described in the literature (Garcia-Alonso et al., 2017, 2016). The port of Bilbao, located on the north coast, is specialised in short-sea and feeder traffic from the northern range ports of Europe, whereas the ports of Valencia and Barcelona, both located on the Mediterranean coast, are the two major ports for Spanish deep-sea cargo (Monios, 2011). It is worth noting that the triangular area delimited by these three ports is the core of the Spanish economy and they compete intensely for the national traffic. In 2012, the ports of Barcelona, Bilbao and Valencia carried respectively 11, 4 and 32% of the total container traffic in Spain.

The remainder of the chapter is organized as follows. Section 2.2 presents the review of literature concerning the study of the hinterland of ports from the spatial perspective. The proposed methodology, its extensions and the data sources are shown in sections 2.3 and 2.4. The obtained results are provided in section 2.5. Section 2.6 proposes a discussion from the results. Finally, section 2.7 summarises the main conclusions and proposes further research in this field.

2.2 Literature review on port hinterland analysis from the spatial perspective

The topic port hinterland has been greatly analysed from the perspective of the Discrete Choice Theory (DCT). Malchow and Kanafani (2001) were pioneers in applying a Multinomial Logit Model (MLM) with disaggregated data to analyse the distribution of maritime shipments among US ports. Since then, many authors have used different MLM to study the inter-port distribution of traffic from the maritime side, but also from the land perspective (Martínez Moya and Feo-Valero, 2017). However, other approaches have also been used. Specifically, geographers have developed numerous models to analyse the spatial evolution of nodes and corridors linked to ports and port systems (Ng, 2013; Wilmsmeier et al., 2014). Nevertheless, empirical research based on the theoretical foundations of the spatial interaction analysis is scarce.

Regarding the analysis of the specific Spanish case, some articles can be found about the port hinterland topic. Their main conclusions are: i) the province-port distance remains a key variable for the port choice (Garcia-Alonso and Sanchez-Soriano, 2009); ii) the hinterland of the Spanish container ports depends mainly on the traffic generated in nearby provinces (Garcia-Alonso and Sanchez-Soriano, 2010); iii) the impact of land transport costs is slightly higher than that of maritime transport (Veldman et al., 2011); and finally iv) the hinterland of the Valencia port was expanded to a greater extent during the last decade (Garcia-Alonso et al., 2016). More than that, this last paper indicates that a spatial interaction approach can help to properly analyse the evolution of the hinterland of ports.

To the best of our knowledge, the first authors to deal with inland distribution of maritime flows from the perspective of Spatial Interaction Model (SIM) were Debrie and Guerrero (2008). They used a doubly constrained model and concluded that distance remains relevant in determining the hinterland of the French ports. They applied the Euclidean distance between the French departments and ports. Ferrari et al. (2011) used maximizing entropy models (origin and doubly constrained) to analyse the rivalry between the Ligurian ports and those of Northern Europe. They also employed the Euclidean distance, but they innovated when considering the most populated cities of inland Italy as centroids. They concluded that distance is not the only determinant to define the distribution of flows. Later, Guerrero (2014), analysing again the French case with a doubly constrained model, concluded that distance is an important determinant of port flows, but that this indicator varies according to the type of merchandise, being the container flows the least sensitive to its influence. He used truck travel time instead of Euclidean distance. Tiller and Thill (2017) employed a reverse doubly constrained SIM to verify, measure and compare the degree of trade impedance in South American exports. They demonstrated that these trade impedance values are disproportionate as related to actual physical distance. More recently, Guerrero (2018) found that, besides distance, quality of inland connections are crucial on determining the port hinterland in France but this influence is conditioned to the value density of flows. As can be seen, all of these works, with some particularities, have as main objectives to analyse the role of distance in the inland distribution process of maritime flows.

Related to the SIM applied to measure an influence area, Zhuang and Yu (2014), as far as we know, were pioneers in propose an adapted Huff model and the use of the GIS tool to map the hinterland of the Shanghai and Ningbo ports. The variables applied were container throughput and distance through the road network, but they did not estimate the parameters of the attractiveness and distance; they just incorporated their standard values (1 and -2, respectively). That could lead to misleading results as they lack their statistical significance. The aim of this chapter is to fill these gaps, taking as a starting point the main contributions of the previously mentioned articles.

In order to go a step further, an adapted version of the Huff model is proposed. This version includes the travel time (repulsion factor) and the container throughput (attractiveness factor) as explicative variables (in line with Zhuang and Yu, 2014), but estimating their corresponding parameters in order to give accuracy and robustness to the model (in line with Debrie and Guerrero, 2008; Ferrari et al., 2011; Guerrero, 2014; Tiller and Thill, 2017; Guerrero, 2018). How the model has been adapted and how the variables have been estimated are questions to be explained in the following section.

2.3 Methodological proposal

The Spatial Interaction Model (SIM)[6] framework has been increasingly used within the scope of Regional Science and Transport Economics[7], but much less in the literature on the analysis of inland distribution of maritime traffic. Nevertheless, SIM is more suitable when working with aggregate data (Roy, 2004) and it allows to take into account simultaneously spatial characteristics and characteristics of the transport chain (Kerkman et al., 2017).

The variables commonly selected as proxies for attractiveness and repulsion factors in SIM are size and distance (see Brodzicki et al., 2018). According to this common approach, the variables considered here are the port's container throughput (attractiveness factor) and the province-port travel time (repulsion factor).

On the one hand, the use of container throughput is compatible with the assumption that the attractiveness of a destination increases with its mass. Its parameter is therefore interpreted according to the principle of agglomeration, which means that larger destinations are disproportionately more attractive than smaller destinations (Spiekermann et al., 2015). Moreover, container throughput is often used in this field because, as Meersman et al. (2010) argued, container traffic is a good measure of port performance and competitiveness. Additionally, Kashiha et al. (2016) found that port size is highly correlated with port connectivity and Wang et al. (2016) concluded that it can represent the port economic

[6] This type of models is also labelled gravity models in reference to the traditional Newtonian denomination (Lesage and Pace, 2009; Patuelli and Arbia, 2016). Wilson (1971) strengthened the SIM by adding a theoretical extension to the traditional model, previously seen only as a mechanical method to analyse interactions (Roy, 2004). A theoretical comparison of DCT and SIM can be found in Anas (1983), where it is confirmed that they have a similar structure.

[7] See, among others, Llano et al. (2010) and Alamá-Sabater et al. (2015). They are examples of this methodology applied to the Spanish case.

capacity.

On the other hand, distance, as proxy for transport costs, is a variable frequently used to study the scope of the hinterland of ports, despite sometimes being controversial (Tongzon, 2009). Many authors consider that port selection is not necessarily related to the inland distance, although others highlight that distance remains a powerful explanatory variable in defining port hinterlands (Ferrari et al., 2011). For instance, Ng et al. (2014) and Rodrigue and Notteboom (2010) pointed out the relevance of the territorial and economic characteristics of the immediate geographical region for ports and their connections with their corresponding hinterlands. Halim et al. (2016) highlighted the port hinterland connectivity as a key determinant for port choice by shippers both because inland transport costs constitute a significant fraction of logistics costs and most bottlenecks take place in the hinterland[8] (van Der Horst and De Langen, 2008). Shi and Li (2016) have recently emphasized that the regional economy has an increasingly significant role in the development of the hinterland of ports, again underlining the importance of this variable. We follow those approaches, although it must be pointed out that distance 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). Consequently, travel time is usually considered nowadays as the main impedance variable (Kerkman et al., 2017).

2.3.1 The Huff model

The first researcher that applied the concept of SIM to measure an influence area was Reilly (1929). He developed a model to identify

[8] See van Der Horst and De Langen (2008) for a review of the main challenges regarding the coordination problems in hinterland transport chains.

geographically commercial areas of two cities in an intermediate region, named Law of Retail Gravitation (Roy, 2004). Of all the alternatives developed later within the SIM field (and referring to the analysis of trade area), this chapter proposes an adapted version of the Huff model as a tool to delimit the scope of the hinterland of ports.

The Huff model was proposed to estimate the area of influence of shopping centres. Nevertheless, the applicability of that model to a wide range of problems and its relative ease of use justify its longevity (Huff, 2003). The goal of this model is to study the patterns of customer choice based on a hierarchical and behavioural process. It measures (in terms of probability) the attractiveness of a specific destination, *j*, for a customer located at a particular origin, i, regarding alternative destinations, n (Huff, 1963, 1964). The model incorporates two variables, both linked to the destination: one concerning the attractiveness force (mass) and one regarding the repulsion force (friction). Mathematically, it was originally formulated as (1):

$$P(C_{ij}) = \frac{S_j}{T_{ij}^{\lambda}} \Bigg/ \sum_{j=1}^{n} \left(\frac{S_j}{T_{ij}^{\lambda}} \right) \qquad (1)$$

Where:

- $P(C_{ij})$ is the probability that a customer at origin i chooses the shopping centre *j;*
- S_j is the square footage of the space devoted to the sale of a specific merchandise at the shopping centre *j*;
- T_{ij} is the travel time to reach the shopping centre *j* from the origin i (obtained from customer surveys);
- λ is the parameter measuring the customers' sensibility to T_{ij}.

The Huff model presents some remarkable features making it an interesting alternative to delimit the hinterland of ports. Firstly, the radial format of the borders of the areas of influence; that is, a curved series with probability levels and overlaps. Secondly, the travel time is used as explicative variable instead of the straight-line distance, which makes the analysis much more realistic. Thirdly, the distance decay parameter can be estimated, since it can vary depending on the context (however, it is usually considered constant and equal to -2). Finally, the spatial behaviour of the customer is assumed to be in line with the opportunity cost concept. Specifically, Huff (1963) highlighted that when a customer faces a set of alternatives, the probability of a particular one being chosen is directly proportional to the perceived advantages obtained from that alternative, which enables to estimate demand surface probabilities. Finally, Huff (2003) emphasizes the interest of estimating the parameters of both variables (the distance decay and the attractiveness), since the customer knows the services and structure of destinations before travelling.

2.3.2 The adapted version of the Huff model

The original Huff model analyses flows of customers to retail locations, whereas the aim of this chapter is to analyse export flows towards port facilities. Though they are different tasks, there is a shipper behind each cargo choosing from among all the possible destinations. Therefore, the changes to the original model only affect the attractiveness and repulsion variables linked to the destination; i.e., to the ports.

Huff (1963) considered the size of the shopping centres to be the attractiveness factor, and the travel time separating them from customers the repulsion factor. In the port selection field, many variables can be considered determinant, but their relevance varies with the analysis approach (see, for instance, Ng, 2006; Sanchez et al., 2011). In this study, the container throughput is considered a proxy of the port attractiveness, and the province-port travel time is introduced as a proxy of the repulsion factors. Therefore, the adapted model is expressed as (2):

$$P(C_{ij}) = \frac{Cont_j^{\gamma}}{T_{ij}^{\lambda}} \Big/ \sum_{j=1}^{n} \left(\frac{Cont_j^{\gamma}}{T_{ij}^{\lambda}} \right) \qquad (2)$$

Where:

- $P(C_{ij})$ is the probability that a shipper at province i chooses port *j;*
- $Cont_j$ is the container throughput of port *j;*
- γ is the parameter measuring the shippers' sensibility to $Cont_j$;
- T_{ij} is the travel time from i to port *j*;
- λ is the parameter measuring the shippers' sensibility to T_{ij}.

2.3.3 Parameter estimation

The parameters γ and λ were estimated to be included in the adapted Huff model. Their estimation took place through a SIM constrained in the origin, following Flowerdew and Aitkin (1982). These authors assert that a Poisson distribution model is applicable when the dependent variable results from a discrete choice probabilistic process[9]. In this particular case, the mean of the dependent variable *(F_{ij})* is a function (linked logarithmically) of the independent variables, and the Iteratively Reweighted Least Squares (IRLS) method is recommended to provide the maximum likelihood estimates of the parameters. The proposed model is expressed through (3):

$$F_{ij} = exp\left(\beta_0 + \mu_i + \gamma lnCont_j + \lambda lnT_{ij}\right) + \varepsilon \tag{3}$$

Where:

- F_{ij} is the outflow from province i channelled through port *j*;
- β_o is the constant;
- μ_i is the fixed effect of province *i*;
- γ is the parameter measuring the sensitivity of flows to $Cont_j$;
- $Cont_j$ is the container throughput of port *j*;
- λ is the parameter measuring the sensitivity of flows to T_{ij};

[9] Wilson entropy-maximising and Poisson-based models, although they were created in different contexts and apparently have diverse structures, are statistically identical (Flowerdew and Lovett, 1988; Yano, 1993).

- T_{ij} is the travel time from province i to port j;
- ε is the error term.

Following this method, although the parameters are robust and consistent, they are not necessarily efficient (Krisztin and Fischer, 2015). Therefore, special attention should be paid to the standard errors and the overall goodness-of-fit of the model (see Baxter 1985; Cameron and Triverdi, 2013; Flowerdew and Aitkin, 1982) because the Poisson distribution assumes that the variance of the observations is equal to its average. This assumption is very restrictive since, in general: i) the population is very heterogeneous, thus the data can provide very extreme values (Baxter, 1985; Zeileis, 2004); and ii) the selections involve more than one specific individual or product (Flowerdew and Aitkin, 1982). When analysing the inland distribution of the maritime traffic, both circumstances take place: i) the volume/type of freight can vary significantly by container; and ii) there are different stakeholders involved in port choice (see, for instance, Meersman et al. (2010) or Sanchez et al. (2011)).

Once the parameters are obtained, they are included in the Huff model, as shown in (2). After that, it is possible to map the potential hinterland of ports by drawing lines connecting all the statistical units by means of the *Market Analysis Tool* for the Huff model incorporated in ArcGIS.

2.4 Data sources

For this particular case study, the 47 Spanish peninsular provinces (NUTS 3)[10] (origins, i) and the ports of Barcelona, Bilbao and Valencia

[10] The Balearic and Canary Islands, as well as the autonomous cities of Ceuta and Melilla, are excluded from the analysis.

(destinations, *j*) are considered. The analysed flows are the Spanish exports channelled by container to America and Asia in 2012[11] – the last year with data available about the status of the road network from García (2013). Figure 1 shows the location of the ports and the provincial share in export flow generation (in tonnes) to the considered destinations. As can be seen in the figure, and was stated before, the Mediterranean corridor, the North-Eastern corner and Madrid accounted for the bulk of traffic generation in Spain in that year (94%) and is delimited by these three ports (making up a contestable hinterland for them).

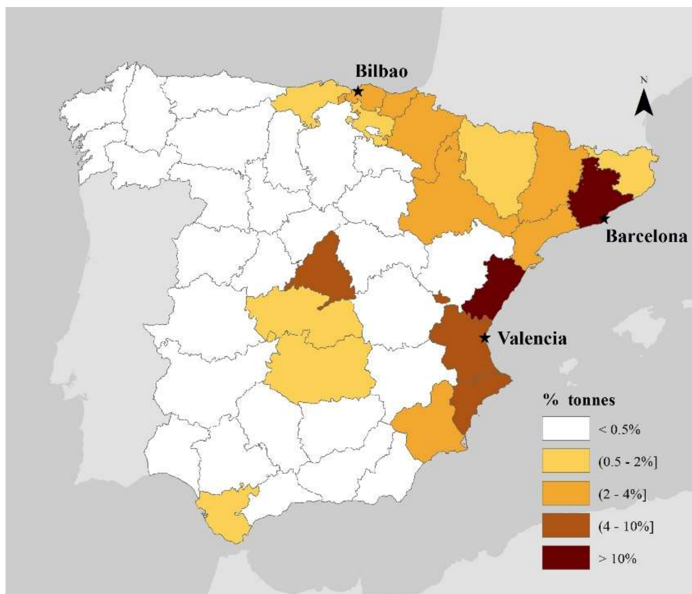

Figure 1. Provincial share in export flows generation (in tonnes) to Asia and America (2012).
Source: based on data from Customs and Excise Duties Department of the Spanish Tax Agency (2016).

Flow data were obtained from Customs and Excise Duties Department of the Spanish Tax Agency (2016). This database only provides data of the Spanish foreign trade, what means that the data do not include transhipments. Moreover, the traffic generated outside the Spanish

[11] So long as the analysis is focused on deep-sea traffic, intra-EU maritime traffic is excluded.

borders is ignored, despite the fact that the ports' hinterland can transcend national boundaries. The main reason is the lack of traffic data from France and Portugal. However, it should not affect the analysis because the bulk of the traffic of the Spanish ports comes from Spanish trade (and vice versa: the bulk of the Spanish foreign trade is channelled through the Spanish ports)[12]. 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)[13]. The attention is focused on container flows since they can be transported easily and is the one for which ports more compete. The hinterland of bulk traffic is much more captive and stable over the years.

Port's container throughput was provided by Ente Público Puertos del Estado (2016) and the province-port travel time was obtained from the road network[14] for 2012 (García, 2013). The fastest path (by road) through this actual existing network has been obtained from the *Network Analyst Extension* tool of ArcGIS. The data sources corresponding to the variables used in ArcGIS are summarised in Table 1. All these data are open access.

Table 1. Sources of data used in the ArcGIS tool.

Data	**Type**	**Source**
Ports	Points	GISCO Ports 2013 dataset (European Commission, 2016)
Provinces	Polygons	NUTS 2013 dataset (European Commission, 2016)
Provinces' capitals	Points	NUTS 2013 dataset (European Commission, 2016)

12 A recent article about the Portuguese ports and their poor hinterland capture in Spain and the negligibility of Portuguese flows to Spanish ports can be found in Santos and Soares (2017).

13 The inclusion of all these details in a single database is very uncommon in trade and shipping statistics (Guerrero et al., 2016).

14 The railway transport was not considered because it is insignificant compared to the road transport in Spain.

2.5 Results

The results were obtained following two steps. Firstly, the parameters of attractiveness (γ) and repulsion (λ) were estimated by an origin-constrained model using a Poisson distribution, as explained before. Secondly, the estimated parameters were incorporated into the proposed Huff model in order to delimit the scope of the hinterland of the analysed ports.

The results corresponding to the first step are displayed in Table 2. To assess a model performance, Likelihood Ratio, Akaike Information Criterion (AIC) and residual deviance are frequently used. Nevertheless, they can be miscalculated when data are over dispersed, as is the case. To avoid that problem, robust standard errors (RSE) were calculated (Zeileis, 2004, 2006). The coefficient of determination associated with the correlation of observed and predicted flows (R-squared) was also accounted.

Table 2. Results of the parameter estimation.

Variables	**Results**	**RSE**
Container throughput (γ)	0.69***	0.11
Travel time (λ)	-1.48***	0.26
R-squared	97.85%	

Level of significance: 1%***.

The parameters are significant, and their sign is as expected: negative for the travel time and positive for the container throughput. Therefore, the former variable acts as a repulsion factor, whereas the second favours the hinterland expansion. The obtained values of the parameters allow to fit the observed outflows from provinces to ports with 97.85% accuracy. However, the explanatory power of the considered variables differs considerably[15]: the impact of the travel time variable

[15] When a Poisson regression is handled, the coefficients should be interpreted as an elasticity (Wooldridge, 2009).

greatly surpasses the impact of the container throughput. A similar value for the distance decay parameter was obtained by Ferrari et al. (2011) for the hinterland of the Ligurian ports (-1.38). That result is in line with Parola et al. (2016), who point out that shippers tend to consider "port location" and "hinterland connections" as the most important factors in port choice. Unfortunately, the parameter of the attractiveness variable cannot be compared with previous estimates because we are not aware of studies measuring it with a similar methodology.

Once obtained, the parameters were included in the adapted version of the Huff model. This second step allows us to delimit the scope of the hinterland of the ports, which is the goal of this article. The corresponding results are summarized in Table 3 and illustrated in Figure 2.

Table 3. Observed vs Estimated market share (2012).

Ports	**Observed**	**Estimated**	**Difference**
Barcelona	35.7%	34.6%	1.1%
Bilbao	10.9%	11.7%	-0.7%
Valencia	53.4%	53.8%	-0.4%

Source: based on data from Customs and Excise Duties Department of the Spanish Tax Agency (2016) and model results.

As can be seen, the model fits well the observed flows by port, and only small discrepancies exist between those and the estimated flows. Specifically, the observed flow of the port of Barcelona surpasses the estimated 1.1%, whereas those of the ports of Bilbao and Valencia are overestimated 0.7% and 0.4% respectively. These outcomes mean that the relationship provinces-Barcelona port is stronger than expected, but it is slightly weaker regarding the ports of Bilbao and Valencia.

The maps in Figure 2 show the probabilistic scope for the hinterland of the ports allowing their overlap. They are drawn by means of a Kriging process to interpolate both the observed and the estimated flows through ArcGIS. Visually, the maps for the observed and the estimated flows show very similar hinterlands (regarding size and intensity), although small

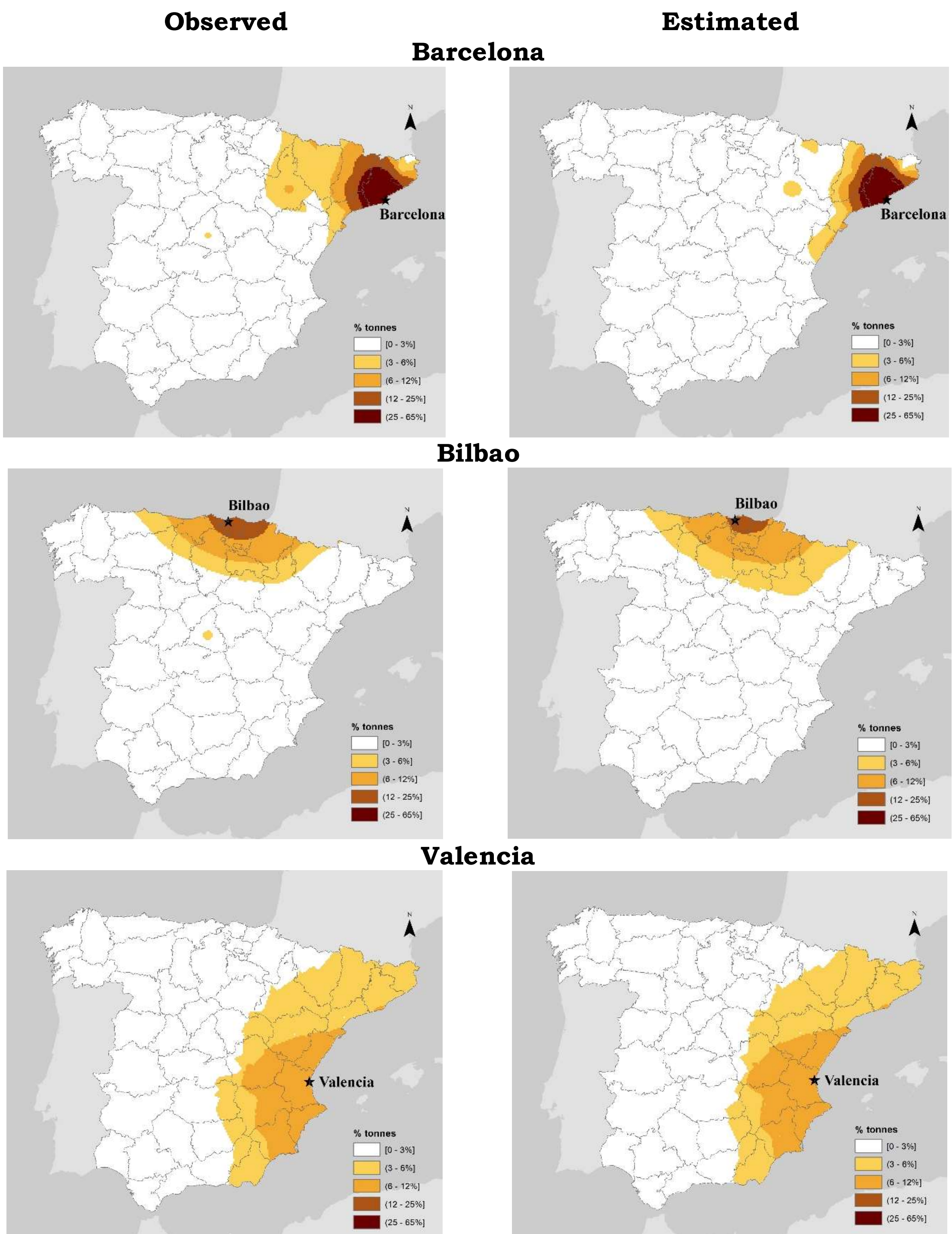

Figure 2. Estimation surface for observed and estimated port hinterlands, in percentage of tonnes (2012).
Source: based on data from Customs and Excise Duties Department of the Spanish Tax Agency (2016) and model results.

differences exist between them, as presented in Table 3. Therefore, additional factors other than the explicative variables considered here should be taken into account, although that is beyond the scope of this study[16].

The maps in Figure 2 confirm the importance of the local hinterland, as Notteboom (2010) observes for the major European ports. He also states that Western Mediterranean gateway ports have improved their connectivity and, consequently, they benefit from economies of scale resulting from a higher volume of traffic. These economies of scale are linked to larger vessels and the geographical concentration of logistics companies. Maybe these factors, key for the success of the Northern European ports in the regionalization process, could also explain the success of the Spanish Mediterranean ports with respect to Bilbao. Furthermore, Oliveira and Cariou (2015) point out that ports with large market shares are usually more efficient. That could be the case of the port of Valencia. As stated above, that port carries much more container traffic and is less dependent on its immediate surrounding hinterland; that is, its relevant hinterland is much more expanded. The same argument, but in the opposite way, could also be applied to the port of Bilbao: its market share is by far the smallest and its hinterland is the most overestimated. However, once again, that discussion is outside the scope of this study.

To provide a more accurate picture of the discrepancies between the observed and the estimated flows, the port perspective must be replaced by the provincial perspective. Figure 3 shows the maps with the corresponding deviations by province (observed flows minus estimated).

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[16] For instance, the quality of hinterland accessibility of a port is a key factor. The increasing logistical pressure concerns not only the infrastructure, but also the efficiency in freight distribution strategies (Rodrigue and Notteboom, 2010a). Van Der Horst and De Langen (2008) state that accessibility depends on factors as variable as the behaviour of the terminal operators, freight forwarders, container operators or the port authority. Furthermore, Rodrigue and Notteboom (2010b) point out that the hinterland borders also depend on the characteristics of the foreland.

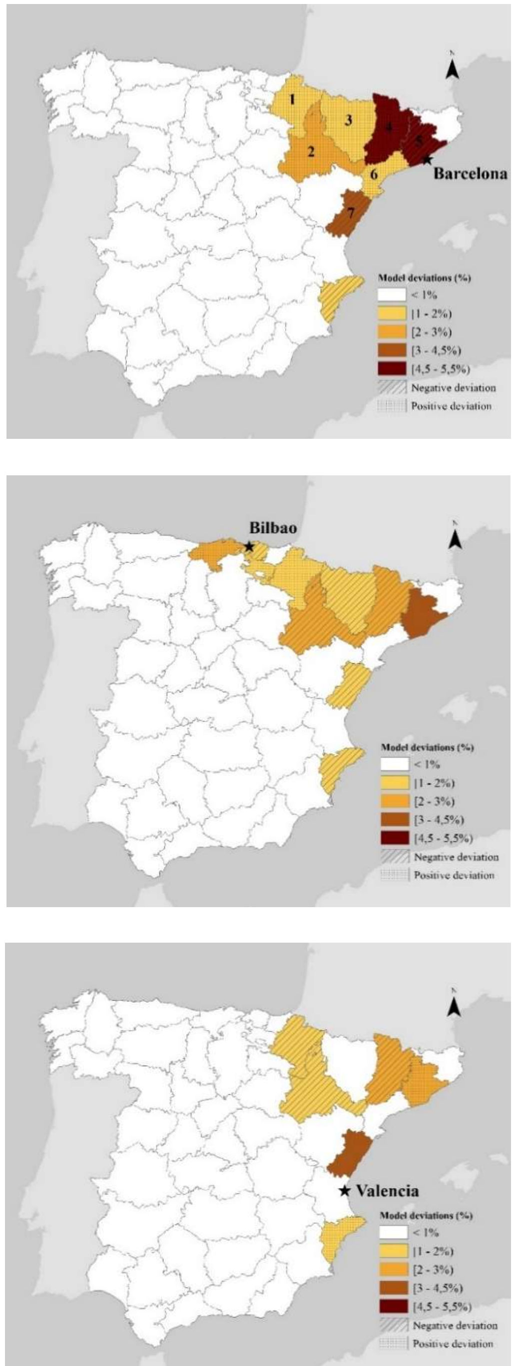

Figure 3. Discrepancies between the observed and the estimated flows by province in terms of tonnes (2012).
Source: based on data from Customs and Excise Duties Department of the Spanish Tax Agency (2016) and model results.

In general terms the deviations are negligible, confirming once again the robustness of the results. The biggest mismatches are linked to the port of Barcelona: provinces 4 (Lleida, 4.6%), 5 (Barcelona, -5.5%) and 7 (Castellón, -4.1%). Bilbao is the port with the highest number of provincial discrepancies over 0.1%, although they are majorly under 1%. Finally, the provincial mismatches regarding the port of Valencia are minor, both in number and value. They only surpass 2% for provinces 4 (Lleida, -2.6%), 5 (Barcelona, 2.8%) and 7 (Castellón, 3%). These 3 provinces are among those generating the greatest amount of flows in Spain. However, the most remarkable fact is that the greatest mismatches are found in the provinces conforming the contestable area for the three analysed ports. Taking into account the sign of the discrepancies, it is particularly interesting to pay attention to provinces 2 (Zaragoza), 3 (Huesca) and 4 (Lleida), where the observed flows of the port of Barcelona surpass the estimated, and the ports of Bilbao and Valencia are in the opposite situation. It is convenient to highlight here that TMZ, the main Spanish inland terminal is located in Zaragoza (province 2), and more than 90% of its container traffic is linked to the port of Barcelona (Garcia-Alonso et al., 2017; Monios, 2011). The flow overestimation of the provinces of Barcelona and Bilbao with respect to their own ports also deserve attention. The destination of flows is probably key in these cases. In Figure 3 we can see that the flows of Barcelona (5) are particularly underestimated for the port of Bilbao. There it also can be seen that the mismatches for the flows generated in the province of Bilbao are negligible for the ports of Barcelona and Valencia.

2.6 Discussion

The more we know about how the hinterlands of the ports are configured, the better the decisions will be made. This chapter contributes to reinforce the existing knowledge on this topic. The proposed methodology not only allows to obtain an accurate picture about the maritime traffic distribution on the inland side, it also contributes to the debate due to the particular characteristics of the case study carried out. The obtained results highlight that it is necessary to face a difficult question about the infrastructure planning: the trade-off between efficiency and the territorial cohesion.

An efficient transport network must alleviate bottlenecks and complement missing links, reinforcing the competitive opportunities of the best positioned ports (Bensassi et al., 2015). As Márquez-Ramos et al. (2011, p. 573) state: "Although concentrating investments in a few ports and promoting their role as import/export gateways may be difficult from a political point of view in large countries with many kilometres of coast, as is the case in Spain, investing in several small or medium sized ports all aiming at the same container segment of the market may not be a strategy that leads to increasing the competitiveness of the country's exports". Additionally, Márquez-Ramos (2016) concludes that port investment generates important spillovers for the neighbouring regions. She highlights that the more efficient a port, the greater the regional spillovers, giving as an example the wide indirect effect of the port of Valencia (confirmed here in Figure 2). Therefore, these effects should be considered when planning port investment, as concentrating the improvement in more efficient ports maximises the investment return. This is in line with the Trans-European Transport Network (TEN-T), which aims to connect the Iberian Peninsula to the rest of Europe through the Mediterranean Corridor, but not through a Northern axis. That initiative will probably favour the isolation of the median Spanish ports, located on the Northern coast, and hinder the export capability of their neighbouring regions. Should, therefore, an additional corridor be incorporated to link those ports/regions to the European core although their traffic generation does not currently justify the investment? But what will the future be of those ports/regions without such investment?

2.7 Concluding remarks

This chapter contributes to the literature by adapting a Spatial Interaction Model to the analysis of the hinterland of ports. The obtained empirical results confirm the stated hypothesis: it is possible to draw the scope of the hinterlands taking into account only the throughput and location of the ports. Therefore, the goal of the chapter is achieved: to propose a suitable methodology to delimit the scope of the hinterland of ports in a simple and accurate way. Simple, as the explicative variables are usually available; accurate, as their parameters can be estimated for each case study.

The throughput and port location represent the attractiveness and repulsion forces supporting the spatial models. This is of special interest due to the usual scarcity of data regarding both efficiency levels and port costs. The study demonstrates that the throughput of the ports works as a proxy of their attractiveness in the adapted version of the Huff model. We also know that the friction of the distance varies with the inland infrastructure improvements, although the port location is fixed. Therefore, travel time is a better proxy than distance for repulsion forces. Furthermore, for instance, it allows to anticipate the evolution of the scope of the hinterlands resulting from a specific infrastructure improvement.

From this chapter, we can conclude that travel time contributes more than port throughput to explain the inter-port traffic distribution in the Spanish case. Therefore, it should be concluded that location is more relevant than the port throughput for the inter-port traffic distribution. However, it is possible that the geographical scope of the analysis modifies the results. Following previous papers analysing the success of Northern with respect to Mediterranean ports, it is expected that the greater the geographical scope of port competence (supranational vs national level), the smaller the impact of the inland proximity and the greater the relevance of alternative factors, such as connectivity or the quality of services.

Additionally, there are relevant factors that have not been considered and could reinforce the study. For instance, it would be interesting to analyse how the scope of the hinterland evolves over time. The chapter 3 addresses this question by taking into account the evolution of the destination of the foreign trade.

3

Influence of the geographical pattern of foreign trade on the inland distribution of maritime traffic

Abstract

Many papers analyse the role of transport infrastructure in the economic development and competitiveness of regions. However, the literature has paid little attention to the impact of the changing patterns of international trade on the use of the infrastructure. The hypothesis of this work is that the evolution of the geographical pattern of countries' foreign trade influences the inland distribution of maritime traffic and, consequently, the use of the infrastructure. The inter-port distribution of the Spanish exports in 2000 and 2015 was analysed in order to confirm the validity of this hypothesis. To that end, the Spatial Interaction Models approach was adopted. The results suggest that the final destination of the flows does influence the inland distribution of the Spanish container flows and, consequently, that the use of the inland transport infrastructure has evolved in line with the geographical pattern of foreign trade.

3.1 Introduction

There is ample literature on the role of the transport sector in trade and competitiveness, both at regional and national levels. Recent relevant examples can be found in Bensassi et al. (2015), Bottasso et al. (2018), Brodzicki et al. (2018), Tiller and Thill (2017) or Tsekeris (2016). The relationship between the transport sector and foreign trade is also studied here, but the perspective of analysis has been reversed. It is well known that the activity of ports depends on the dynamism of their geographical surroundings, as well as on the international relevance of the sea routes in which their facilities are included (Ducruet et al., 2013; Notteboom and Rodrigue, 2007). However, the question addressed here is whether changes in the geographical links of such surroundings with the rest of the world have an impact on the inland distribution of the maritime traffic and, consequently, on the use of the transport infrastructure.

Over the past two decades, Asian economies have been gaining prominence. China and India lead this process, but other neighbouring countries, such Korea or Indonesia, are also increasing their relevance (see Hanson, 2012; O'Neill and Terzim, 2014). Using data from the World Bank (2017), the share of the Asian countries in world GDP (in current dollars) went from 7.2% in 2000 to 20.7% in 2015. At the same time, the relative weight of America in world GDP fell from 30.6 to 24.3% (hereafter, America refers to both North and South America). According to the basic logic of the gravity equation (see, e.g., Head and Mayer, 2014), exports rise in proportion to the economic size of the destination and imports rise in proportion to the economic size of the origin. Thus, the global shift in economic size should be reflected in trade flows. The European Union (EU) foreign trade confirms this eastward shift in trade flows: EU trade with America fell from 33.2 to 26.1%, whereas trade with Asia grew from 38.6 to 47.2% (Eurostat, 2017).

Seaborne trade is heavily dependent on prevailing economic trends (Valentine et al., 2013). In this sense, the Review of Maritime Transport

(UNCTAD, 2017) underlines that the demand for maritime transport services is closely linked to the evolution of the world economy, with Chinese import demand being particularly important for maritime trade. Certainly, the global shipping network has its own configuration rules (Ducruet and Notteboom, 2012) and it tends to maintain stability of its overall architecture (Ducruet, 2017). However, the economic conditions and trade flows between world regions remain key factors in the deployment of shipping lines (Mengqiao et al., 2015).

With these considerations in mind, the hypothesis is that the considerable changes in international trade and maritime routes may have consequences for the inland distribution of the maritime traffic, which in turn should be reflected in the evolution of the inland corridors of flows. This is in line with Blauwens and Van de Voorde (1988), who analysed the evolution of inland transport as a result of changes in port choice for the Belgian case, and with Cantillo et al. (2018) and Veldman et al. (2013), who concluded that the port choice depends, among others factors, on the port location regarding the flow destination. This is of particular interest to countries (or regions) bordering two seas, as is the case of Spain. Hence, the case study presented in this chapter focuses on this country.

A Spatial Interaction Model (SIM) was employed to assess whether the port hinterland configuration does actually vary according to the final destination of the shipments. As repulsion and attractiveness factors, the province-port travel time and the container throughput of the ports were considered respectively, two variables identified in the chapter 2 as determinants to delimit the scope of the hinterland of the Spanish ports. The results show that the proposed approach contributes to explain properly the inland distribution of the maritime traffic and confirms that the final destination of flows is relevant for the hinterland configuration of the seaports.

The conclusions of the chapter could be useful for public policy and planning. Our results show that the configuration of hinterlands is influenced by the final destination of the traffic. Therefore, the evolution of the use of the inland transport infrastructure is linked to the evolution of the geographical pattern of foreign trade. This is a factor beyond the control of policy-makers, but it can be tracked and, to some extent, predicted.

The remainder of the paper is structured as follows: Section 3.2 provides a short review of the literature. Section 3.3 presents a descriptive analysis of the case study. Section 3.4 shows the model proposed to test the validity of the hypothesis stated. In sections 3.5 and 3.6 are the data sources and the obtained results. Some additional considerations are highlighted in Section 3.7, and a brief discussion is introduced in Section 3.8. Section 3.9, finally, summarises the main conclusions.

3.2 Literature review

The analysis of the port choice is not the aim of this chapter. However, this is a closely linked issue, as the configuration (and the evolution) of hinterlands relies on the inland distribution of the maritime traffic, which in turn results from the port choice. In this sense, Talley and Ng (2018) underline that the determinants of port choice will also settle the choice of the hinterland transport chain.

In general, port choice is considered to be influenced by cost[17], location, port operations quality and reputation, handling speed and time, facilities, efficiency/frequency of shipping services and hinterland accessibility. The relevance of these variables differs according to the different port players (shippers, forwarders, shipping companies and terminal operators), although the most cited as determinant of port choice both by shippers and shipping companies are costs, port location and reputation, while frequency of shipping services and intermodal

[17] Inland transport costs are often the most significant part of the total transport cost (Notteboom and Rodrigue, 2005).

connections are among the least cited (Aronietis et al., 2010). However, Halim et al. (2016) highlighted the port hinterland connectivity as a key determinant for port choice by shippers[18].

Nowadays, ports are considered as pieces in value-driven logistic chains (Robinson, 2002), thus the determinants of the port choice are now considered to be related to the entire logistic chain in which the port is included as a node (Magala and Sammons, 2008). Ports became pawns in a game (Slack, 1993), and their bargaining power and their influence has been reduced (Meersman et al., 2010) because of the mergers and alliances between large shipping lines, which in some cases also integrate vertically (Notteboom et al., 2017; OECD and International Transport Forum, 2008). Nevertheless, ports continue to play the role of interface between sea and land transportation. Their success depends on their ability to attract traffic from the major economic centres and their inclusion in the main shipping routes (hinterland and foreland connections, respectively). According to Fleming and Hayuth (1994), seaports are still characterised by two spatial qualities with complementary dynamics, *centrality* and *intermediacy*[19], which continue to stand out as factors responsible for the heterogeneity of maritime services and port traffic in recent articles (see, for instance, Guerrero et al., 2015 or Ducruet and Itoh, 2015).

All of the above reinforces the interest of the debate about whether "the ship follows the cargo" or "the cargo follows the ship" (see Notteboom, 2009). Such debate is still on-going, and Berli et al. (2018) highlighted that is still not clear whether the sea-land connectivity determines or is determined by port activity. It can be said that the services of the shipping companies contribute to attract traffic from the inland side to the port facilities and, simultaneously, port choice by shipping companies is

[18] A recent synthesis of the most influential factors for shippers can also be found in Shi and Li (2016).

[19] *Centrality* is related to the location of ports regarding the traffic generation centres, whereas *intermediacy* refers to their inclusion in the main maritime routes.

influenced by the availability of cargo, which is directly determined by the hinterland. In this sense, Hayuth (2007) observed that port choice is increasingly being influenced by landside factors and, more recently, Guerrero et al. (2016) found that the impact of shipping services on the geographical pattern of trade is much less important than that of distance. However, as Lee et al. (2008) illustratively stated, ships can move and ports cannot. From this perspective, ports would depend on shipping companies, which is in line with Ducruet and Itoh (2015), who found that port activity is increasingly explained by shipping routes where the ports are included. In addition, Wilmsmeier et al. (2011) noted that corridors now depend more on strategies of vertical cooperation than on the location of the infrastructure.

It is important to note that the activity of transport service providers (both on the sea and land sides) exists because of the trade demand, i.e. transport demand is a derived demand that reacts to changes in trade looking for a rational integration of sea and land segments of traffic flows (Robinson, 2002). According to this, Guerrero et al. (2015) found that maritime transport supply depends to a large extent on the hinterland and highlighted that the maritime services vary as a function of the foreland.

The aim of this chapter is not to delve deeper into the analysis of the relevance of the determining variables of port choice, but to study whether the final destination of flows influences the inland distribution of maritime traffic (which certainly results from the port choice). For this purpose, the following case study has been carried out.

3.3 Descriptive analysis

The geographical pattern of the Spanish foreign trade follows the same trends observed internationally, i.e. Spanish flows have experienced an eastward shift. Figure 4 shows the evolution of the Asian and American shares of the Spanish trade (imports plus exports) for the period 2000-

2015[20]. The Asian share was already higher than the American share at the beginning of the study period (42 vs. 40.3%), but at the end of the period the difference between both shares was 28.4 percentage points.

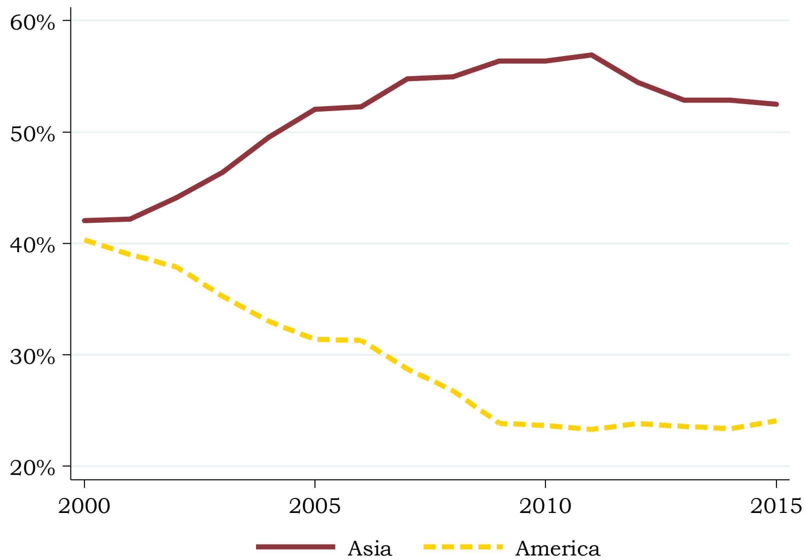

Figure 4. Evolution of the share of Spanish container flows with America and Asia (2000-2015).
Source: based on data from Customs and Excise Duties Department of the Spanish Tax Agency (2017).

To appreciate whether this evolution in the geographical pattern of the Spanish trade has had consequences for the inland distribution of the freight flows, it is necessary to observe what has happened at the provincial level (NUTS 3). For this purpose, Figure 5 shows the change in American trade share plotted versus the change in the Asian trade share for the 47 Spanish peninsular provinces. Each province is represented with a circle proportional to its share of Spanish trade. As can be seen, the majority of the provinces (and the most important in trade generation) are situated in

[20] More than three-quarters of the Spanish containerised deep-sea traffic is linked with Asia and America, this share remaining quite stable during the period of the sample. In the rest of the chapter containerised flows with Asia and America will be analysed.

the fourth quadrant, showing an eastward shift in the trade flows.

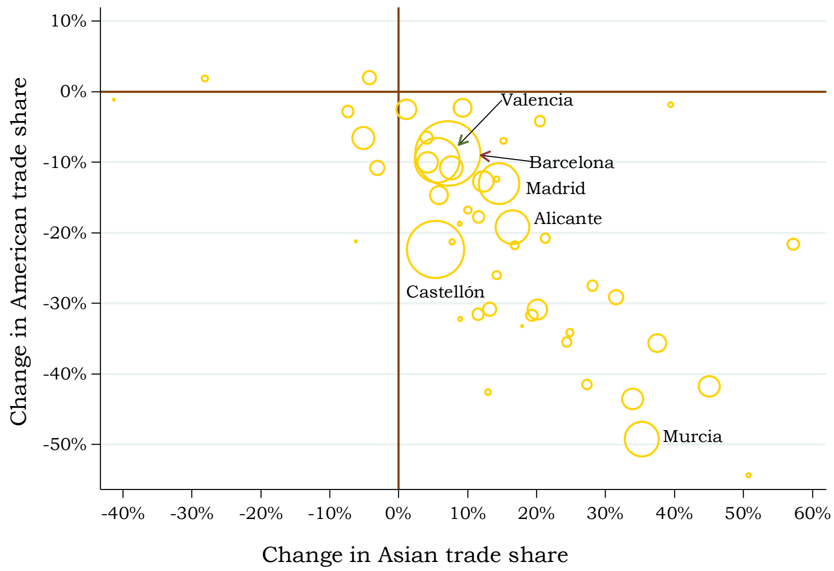

Figure 5. Change in American and Asian trade shares by province (2000-2015).
Source: based on data from Customs and Excise Duties Department of the Spanish Tax Agency (2017)

The analysis of the evolution of the hinterland was carried out regarding the export flows. The seaports considered here are Barcelona, Bilbao and Valencia, which represent a sample-period average of 76.5% of Spanish container traffic with America and Asia. These ports have been chosen because of the same reason as they were in chapter 2: they compete for the national traffic generated in the northeast peninsular quadrant, which is where the bulk of the maritime flows is originated (together with Madrid)[21].

Table 4 shows the share of each destination taking into account only the Spanish containerised exports channelled to America and Asia. As can

[21] As in the Chapter 2, the port of Algeciras was omitted from the analysis. Arguably, the characteristics of the port of Algeciras make it equally suitable for channelling traffic from its traditional hinterland to both America and Asia.

be seen, the flows were balanced in 2000 in the ports of Barcelona and Valencia, but not in Bilbao. At the end of the period, the maritime flows to America accounted for only a third in Mediterranean ports but continued to be predominant in Bilbao. This indicates that the increased ties with the Asian countries have had a greater impact on the ports located in the Mediterranean region.

Table 4. Share of Spanish containerised exports to America and Asia by port.

	2000		2015	
	America	**Asia**	**America**	**Asia**
Barcelona	46%	54%	29%	71%
Bilbao	81%	19%	63%	37%
Valencia	50%	50%	33%	67%

Source: based on data from Customs and Excise Duties Department of the Spanish Tax Agency (2017).

However, these findings are relevant, they do not indicate if the inland distribution of the maritime traffic has experienced any change. This fact can be seen in Figure 6[22]. Although the set of the provinces that generate the bulk of exports remains the same, the province-port ties have changed. In particular: i) the hinterland of the port of Barcelona experienced a considerable expansion and its share grew notably; ii) the port of Bilbao reduced both its relevance and its hinterland; and iii) the port of Valencia, despite consolidating its broad hinterland, lost traffic share, as can be seen in Table 5.

Table 5. Changes in port share by destination.

	America			Asia		
	Barcelona	**Bilbao**	**Valencia**	**Barcelona**	**Bilbao**	**Valencia**
2000	22.05%	20.84%	57.11%	29.70%	5.60%	64.80%
2015	33.92%	16.38%	49.69%	43.00%	5.00%	52.10%

Source: based on data from Customs and Excise Duties Department of the Spanish Tax Agency (2017).

[22] The legend intervals were defined following Yang et al. (2016).

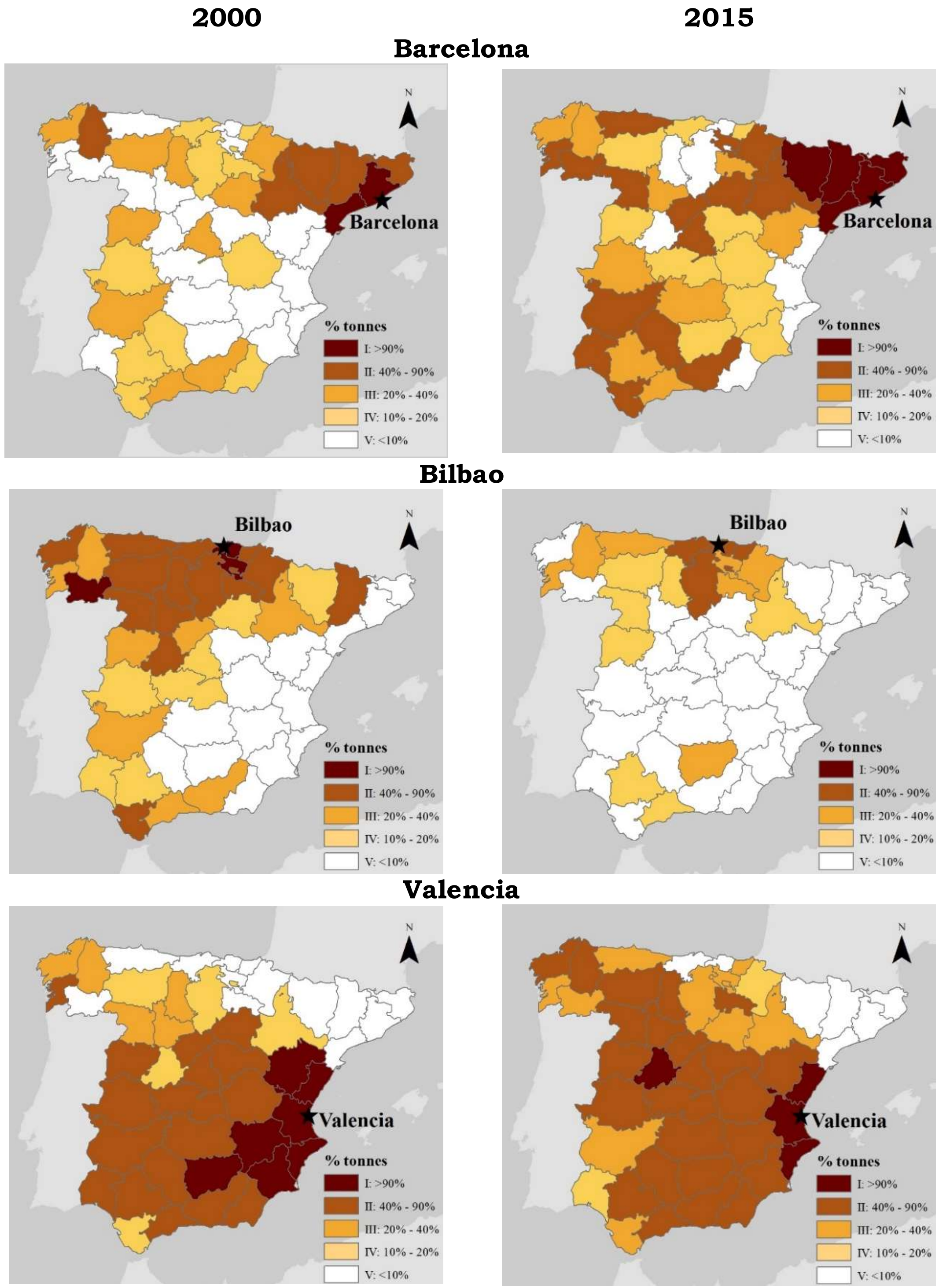

Figure 6. Port share in the provincial export flows (in tonnes).
Source: based on data from Customs and Excise Duties Department
of the Spanish Tax Agency (2017).

In short, all the above seems to indicate that the port location regarding the flow's destination may have some influence on port choice. If this assumption is true, the explanatory capacity of the determining variables for the inland distribution of the maritime traffic should vary according to this fact. To confirm this, we propose a Spatial Interaction Model to carry out the analysis.

3.4 Methodological proposal

As mentioned before, the use of SIM in the literature on the analysis of the inland distribution of maritime traffic is very limited, but it is increasing the application of the methodology in the last years (Debrie and Guerrero, 2008; Ferrari et al., 2011; Guerrero, 2018, 2014; Moura et al., 2017; Tiller and Thill, 2017).

In this chapter, it is proposed an origin-constrained panel SIM to test if the parameters of the variables vary according to both the final destination of shipments (America or Asia) and over the years. This segmentation of flows concerning their destination is in line with Wilson (1971), who suggested that this is a proper approach to verify the existence of different selection behaviours. The model proposed is (4):

$$F_{ijct} = exp\left(\beta_0 + \mu_{ict} + \gamma_{ct} lnCont_{jt} + \lambda_{ct} lnT_{ijt}\right) + \varepsilon_{ic} \tag{4}$$

Where:

- F_{ijct} is the outflow from province i channelled through port j towards continent c in year t;
- β_o is the constant;
- μ_{ict} is the fixed effect of province i by continent c and year t;
- γ_{ct} is the parameter measuring the sensitivity of flows to $Cont_{jt}$;
- $Cont_{jt}$ is the container throughput of port j in year t;
- λ_{ct} is the parameter measuring the sensitivity of flows to T_{ijt};

- T_{ijt} is the travel time from province i to port j in year *t;*
- ε_{ic} is the clustered errors at province-continent (i-c) pair level.

The estimation of the parameters (γ_{ct}, λ_{ct}) in Eq. (4) follows the approach of Flowerdew and Aitkin (1982), which was described in the section 2.3.3. According to this method, Iteratively Reweighted Least Squares (IRLS) method is recommended to provide the maximum likelihood estimates of the parameters.

3.5 Data sources

The empirical analysis addressed in this chapter is focused on the Spanish containerised exports channelled towards America and Asia through the ports of Barcelona, Bilbao and Valencia. Therefore, the origins *(i)* considered were the 47 Spanish peninsular provinces, the destinations *(j)* were the stated Spanish ports, and flow data was extracted from Customs and Excise Duties Department of the Spanish Tax Agency (2017).

The volume of container traffic of ports was obtained from Ente Público Puertos del Estado (2017) and the province-port travel time from the actual existing road network (García, 2013)[23]. The source has no more recent data on the road network than 2012, but we look at 2015 because it is closer in time and it can be assumed that the province-port travel time has barely improved since then[24].

[23] During that period, the road network improvements provided a reduction in province-port travel time of 25% on average.

[24] The assumption is based on the important reduction of infrastructure investment caused by the budget constraints that have taken place in Spain over the last few years.

3.6 Results

Table 6 shows the results of the maximum likelihood estimation (IRLS procedure) of model of Eq. (4). The estimates of the parameters of interest, i.e. the elasticities of export flows with respect to container port throughput (γ_{ct}) and with respect to travel time (λ_{ct}), are displayed for the years 2000, 2012 and 2015, and for the destinations America and Asia. In all cases except one, these estimates have the expected sign and are statistically significant at the 1 percent level, with robust standard errors (RSE) (Zeileis, 2006, 2004) clustered by province-final destination pair level. The R-squared (computed as the square of the correlation between observed and fitted values) reveals that the overall fit of the model is quite good. The results of Table 6 show that the sensitivity of exports with respect to container throughput and travel time varies according to the final destination, and also that such sensitivity evolves over time.

Table 6. Results of parameter estimations.

		America		**Asia**	
		Coef.	**RSE**	**Coef.**	**RSE**
2000	Container throughput	-0.24	0.17	1.89***	0.56
	Travel time	-1.94***	0.59	-1.92***	0.57
2012	Container throughput	0.49***	0.14	0.79***	0.14
	Travel time	-1.34***	0.36	-1.55***	0.35
2015	Container throughput	0.54***	0.10	0.76***	0.15
	Travel time	-1.22***	0.16	-1.16***	0.19
Number of observations		846			
R-squared		96.96%			

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

Regarding America, the container throughput (proxy for connectivity) was not a significant variable in 2000. The shipments to America generated that year in the northwest quadrant of Spain were mainly channelled through Bilbao (see Figure 7) although its volume of

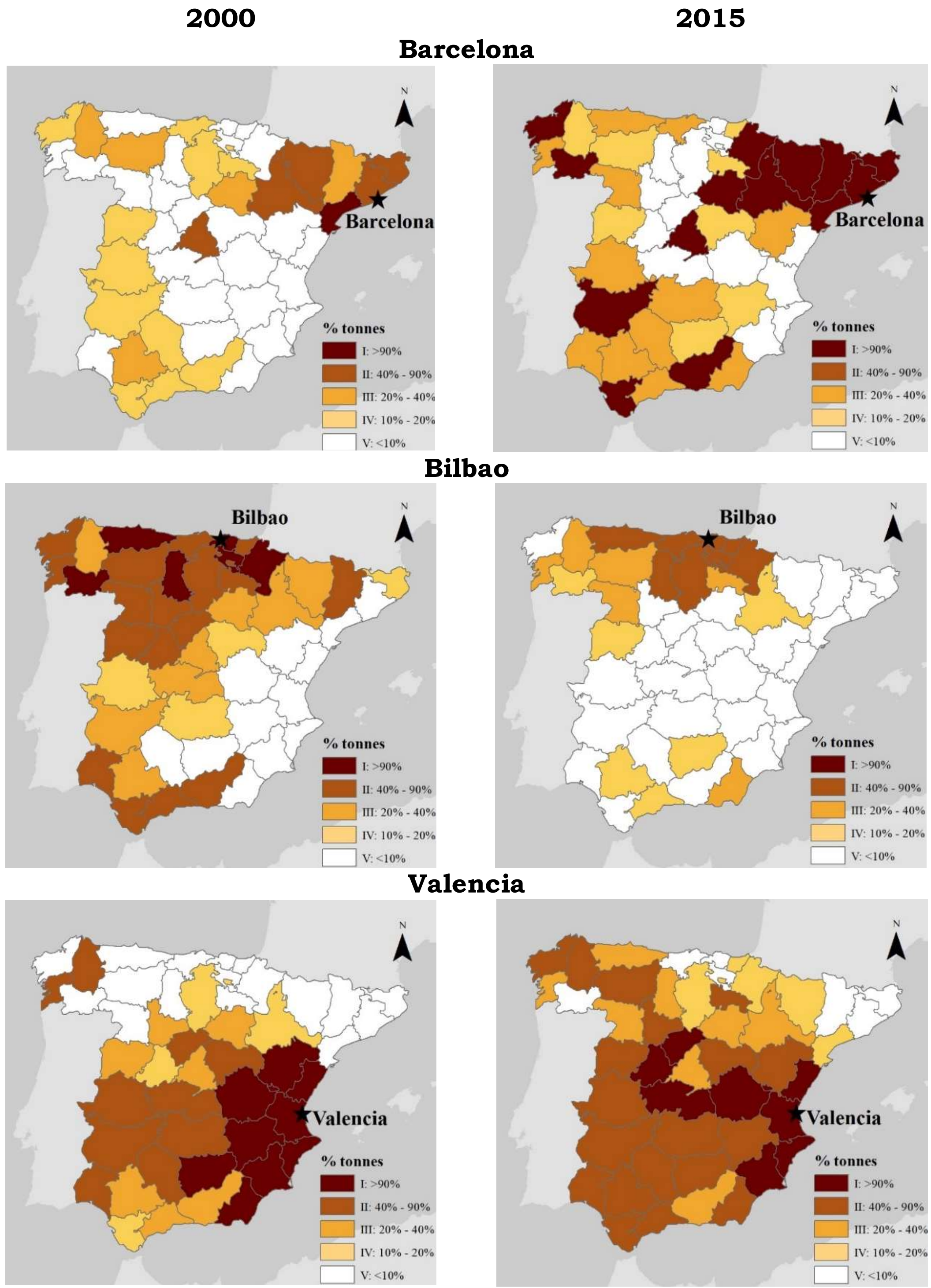

Figure 7. Port share in the provincial export flows (in tonnes) to America.
Source: based on data from Customs and Excise Duties Department of the Spanish Tax Agency (2017).

container traffic was three times lower than the rest of the ports[25]. This indicates that when the accessibility circumstances are not good enough, the travel time is key for the port choice. It should also be noted that the traffic generated in provinces located between the ports of Bilbao and Barcelona was mainly channelled through the latter, meaning that when travel time is similar, the port throughput is relevant. Similarly, once accessibility is improved, the container throughput becomes more relevant in the port choice, and its relevance tends to increase as the province-port travel time reduces its explanatory power. These results show that the link between these two forces (attractiveness and repulsion) is intense. In this particular case, the attractiveness of the bigger facilities was reinforced as a consequence of a reduction of the province-port travel time (*centrality*); that is, improvements in transport infrastructure can make a place more attractive (Krugman, 1991). This may explain several facts. Firstly, the hinterland of the port of Bilbao was smaller in 2015 than in 2000 in terms of the share of traffic that each province channels through it. Secondly, the hinterland of the rest of the ports expanded towards the northwest quadrant. Thirdly, the hinterland of the port of Valencia, the largest in terms of container traffic[26], was expanded in a greater extent. And fourthly, it can also be seen that the traffic contestability increased (because of the improvement in accessibility): the port of Barcelona reinforced its position in the south-west corner, as did Valencia in the north-east.

Concerning the shipments to Asia, container throughput was already significant in 2000, with a similar influence to that of travel time. Contrary to what happened with America, the value of container throughput was reduced (although at the end of the period it was still

[25] The share of the ports of Barcelona, Bilbao and Valencia concerning the Spanish container traffic in 2000 was 19.43, 6.53 and 21.14%, respectively (Ente Público Puertos del Estado, 2017).

[26] In 2015, the share of the ports of Barcelona, Bilbao and Valencia concerning all the Spanish container traffic was 11.75, 4.06 and 32.81%, respectively (Ente Público Puertos del Estado, 2017).

higher for Asian destinations), underlining that the sensitivity of flows to the explicative variables varies depending on the export destination. In this case, the largest ports are located on the most favourable coast in terms of shipment destination. It could be said that the link with Asia is easier from the Mediterranean ports due to their inclusion in a greater number of routes connecting them to this destination (*intermediacy*), which reinforces the concentration of services providers. As can be seen in Figure 8, the port of Barcelona was predominant in the northern third, and Valencia from the centre to the south. In 2012, the explanatory power of the container throughput declines more than the travel time. Arguably, the ports of Barcelona and Bilbao maintain strong links with their nearest provinces despite the fact that the container throughput was already considerably smaller there than in the Valencian port. However, those links were much more important with the port of Barcelona, whose container traffic more than doubled that of Bilbao. This fact continued in 2015, but the explanatory power of the travel time decreased from 2012. The reason is that some provinces located in the northern third of the peninsula strengthened their links with the port of Valencia although the share of the ports of Barcelona and Bilbao concerning container traffic recovered slightly from 2012.

In short, from the results it can be said that Valencia has great potential. When export flows to Asia are reinforced, being located in the centre of the Spanish Mediterranean coast, close to the main centres of consumption/production, and being the most important port, is particularly beneficial. All this potential (*centrality* and *intermediacy*) results in a larger hinterland, which reinforces the attractiveness of the port as it allows it to operate as a true gateway (Ducruet et al., 2010). At the same time, Bilbao necessarily loses out due to several factors. First, being the smallest port is particularly unfavourable when shipments evolve in favour of Asian destinations. Second, its location, although apparently suitable for exports destined to America, becomes less attractive when accessibility improves. Third, there are fewer shipping companies offering

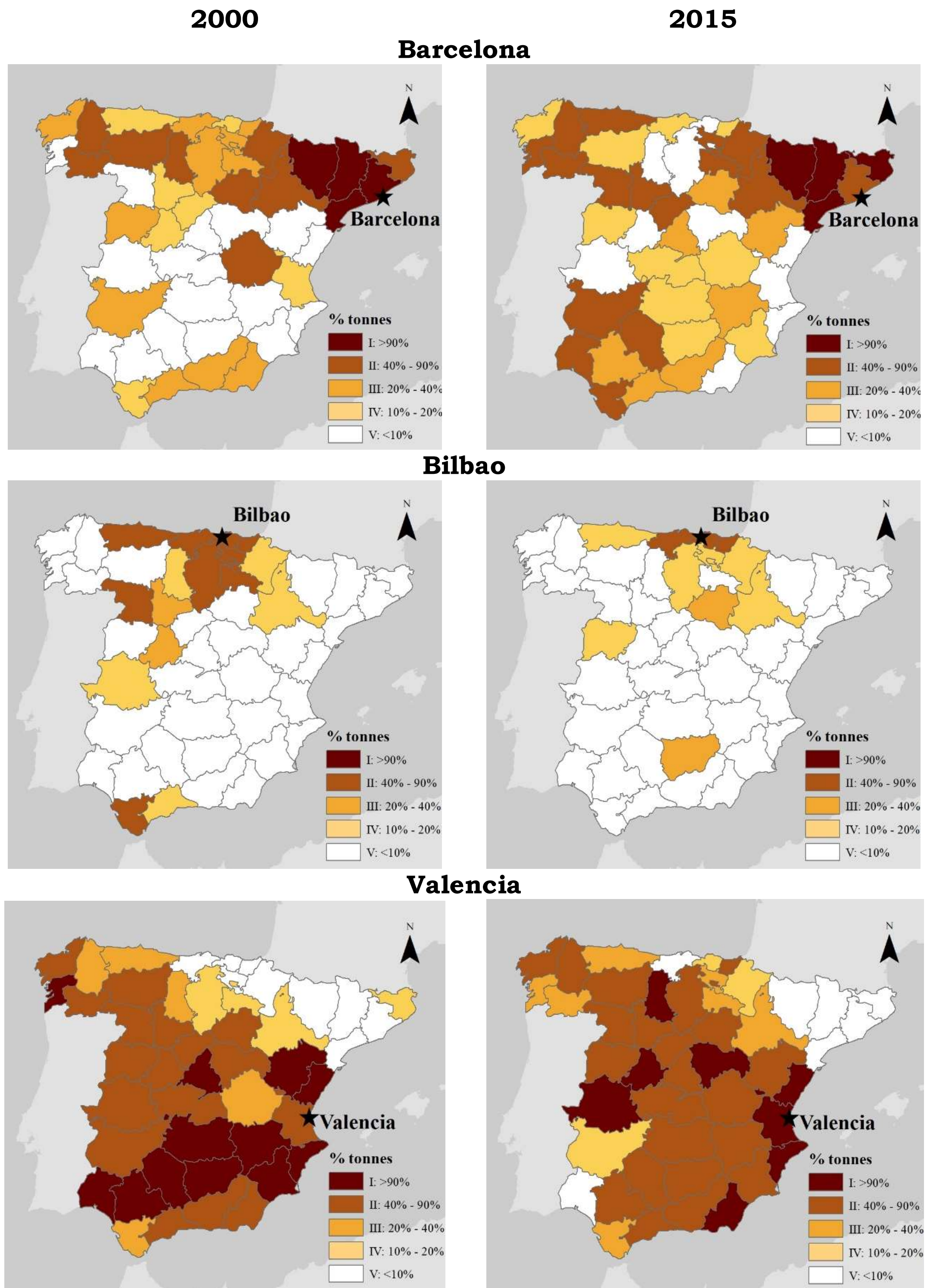

Figure 8. Port share in the provincial export flows (in tonnes) to Asia.
Source: based on data from Customs and Excise Duties Department of the Spanish Tax Agency (2017).

transport services at this port, thus its connectivity is not so good. And fourth, the north-western quadrant is losing share in traffic generation whereas the north-eastern is reinforcing its position (poorer *centrality* and *intermediacy*). This is the reason why Barcelona has a renewed potential.

3.7 Additional consideration about the results

The results show that, in general terms, the estimated parameters contribute to explain the inland distribution of the maritime traffic accurately. We now go a step further and consider the discrepancies at the provincial level. Table 7 shows the existing discrepancies about the provincial share in the traffic of ports (observed *minus* estimated) for the provinces representing about 90% of the export flows generation in 2000 (see Figure 9).

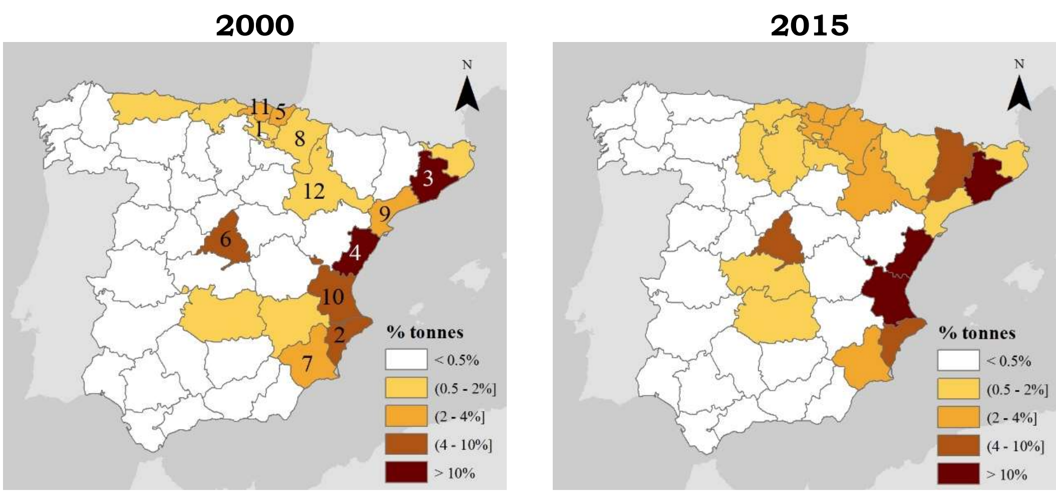

Figure 9. Provincial share in export flows generation (in tonnes) to Asia and America
Source: based on data from Customs and Excise Duties Department of the Spanish Tax Agency (2017).

Considering all the Spanish peninsular provinces (47), the discrepancies are below 1% in more than three quarters of the cases (85%), and between 1 and 2% in less than 8%. Very few cases (4%) have a discrepancy of over 5%, and only 3% of the cases exceed 10%. The more

Table 7. Discrepancies concerning the provincial origin of the port traffic (observed *minus* estimated).

	2000						2015					
	America			Asia			America			Asia		
	BCN	**BIL**	**VAL**	**BCN**	**BIL**	**VAL**	**BCN**	**BIL**	**VAL**	**BCN**	**BIL**	**VAL**
Alava (1)	-0.08%	-0.01%	-0.04%	0.19%	0.40%	-0.13%	-0.19%	1.57%	-0.37%	3.18%	-11.10%	0.15%
Alicante (2)	-2.20%	-1.70%	0.60%	-0.86%	-0.75%	0.16%	-0.82%	-0.74%	0.81%	-0.82%	-1.10%	1.36%
Barcelona (3)	11.70%	6.27%	1.18%	3.14%	4.13%	0.87%	-3.28%	3.50%	0.74%	-12.44%	5.50%	0.85%
Castellón (4)	-13.27%	-3.17%	1.26%	-13.19%	-2.15%	4.27%	-4.48%	-0.46%	3.27%	-5.25%	-2.40%	6.56%
Guipúzcoa (5)	0.43%	-1.47%	0.25%	0.66%	1.09%	-0.42%	-0.60%	3.51%	-0.71%	-0.23%	5.52%	0.40%
Madrid (6)	0.32%	3.39%	-1.68%	2.48%	5.63%	-1.71%	1.81%	-0.86%	-0.92%	1.42%	1.84%	-0.59%
Murcia (7)	-1.50%	-1.19%	0.59%	-0.17%	-0.21%	0.04%	-1.18%	-1.07%	1.17%	-0.23%	-1.31%	0.65%
Navarra (8)	-0.40%	1.03%	-0.23%	1.76%	-2.19%	-0.60%	2.66%	0.26%	-1.88%	1.45%	-1.63%	-0.72%
Tarragona (9)	2.03%	-0.11%	-0.23%	2.11%	0.23%	-0.63%	1.03%	-0.22%	-0.64%	0.95%	-0.57%	-1.07%
Valencia (10)	0.57%	0.67%	-2.11%	2.53%	0.03%	-1.67%	1.07%	0.04%	-0.67%	1.39%	0.20%	0.24%
Vizcaya (11)	0.59%	-1.35%	0.10%	0.97%	-6.85%	0.02%	0.31%	-1.66%	0.40%	0.11%	10.92%	0.08%
Zaragoza (12)	1.37%	-0.70%	-0.17%	0.68%	0.78%	-0.33%	1.16%	-0.36%	-0.67%	1.02%	3.67%	-1.05%

prominent discrepancies concern the port of Barcelona regarding the American destinations in 2000, and the Asian destinations for the provinces of Castellón and Barcelona (in 2000 and 2015 respectively). The provinces of Alava and Vizcaya also present a biased result for the port of Bilbao concerning Asia in 2015. In this last case, both provinces constitute the surroundings of the port of Bilbao (indeed, the port is located in the province of Vizcaya), and the errors compensate each other.

Two different types of discrepancies can be found: overestimation (observed share < estimated) and underestimation (observed share > estimated). Following Ferrari et al. (2011), overestimation occurs when the link between the port and its hinterland is weaker than expected, showing that there are still potentialities to be exploited. On the other hand, underestimation suggests that the hinterland is more particularly linked to a specific port than expected; that is, it shows some degree of captivity.

Wilson (1971) highlighted that the sensitivity to travel time depends on income, and it is expected to decrease as income increases. Fotheringham and Webber (1980) added that different spatial opportunities could generate non-stable parameters specific to origin in a regional system, proving that masses and flows are spatially correlated. Concerning this case study, the main discrepancies were for the provinces of Barcelona and Castellón, the two provinces in which the largest volume of maritime exports is generated.

It is clear that the spatial structure of flows is important. This is a phenomenon evaluated in the seminal work of Curry (1972), and later corroborated by the literature over the years (Sheppard et al., 1976; Tiefelsdorf, 2003). These authors highlighted that there is a very close relationship between the spatial (geographical) structure of the analysed system and the spatial interactions, which generates spatial autocorrelation and impacts on the estimations (Griffith and Jones, 1980). Additionally, many authors have found that exporters are clustered by destination. Particularly, Cassey and Schmeiser (2013) further found that this concentration of exporters occurs given firms output and the location of ports, using Russian customs data. More related to our study, Ramos and Moral-Benito (2017) analysed the Spanish export flows and concluded that there are agglomeration economies by destination. Based on these findings, a possible explanation for the observed discrepancies can be found in Figure 10, where a great concentration of export flows to America in 2000 both in Barcelona and Castellón can be seen. For the latter province, the concentration was particularly intense for both destinations that year. Figure 10 also shows that the concentration of export flows to Asia strengthened in 2015. Precisely, discrepancies were more numerous for this destination that year because they also stand out for the provinces surrounding the port of Bilbao (Álava, Guipúzcoa and Vizcaya).

Besides the issues just mentioned, the sectoral dimension of Spanish trade must also be taken into account. The Spanish trade pattern has evolved, favouring the exports of wood pulp and plastics in detriment to articles of stone, both towards America and Asia. The province of Barcelona is the main origin of the exports of plastic and wood pulp. It experienced a huge increase in the shipments of plastics to Asia, and an important reinforcement of exports of wood pulp towards both continents, but particularly to Asia. Sectoral considerations can also contribute to explain the discrepancies of the province of Barcelona with the port of Bilbao. Exports of chemical products from Barcelona through the port of Bilbao have increased to all destinations, arguably associated to some economies of scale in this particular sector in the port of Bilbao. Idiosyncratic sectoral considerations can also shed light on the discrepancies of the province of Castellón. This province is highly specialised in articles of stone. Exports of this product have been notably deviated from America to Asia, but also to other destinations (e.g. Africa and Oceania). As the analysis was focused on America and Asia, the particular importance of destinations of the rest of the world for the province of Castellón would contribute to explain the discrepancies shown.

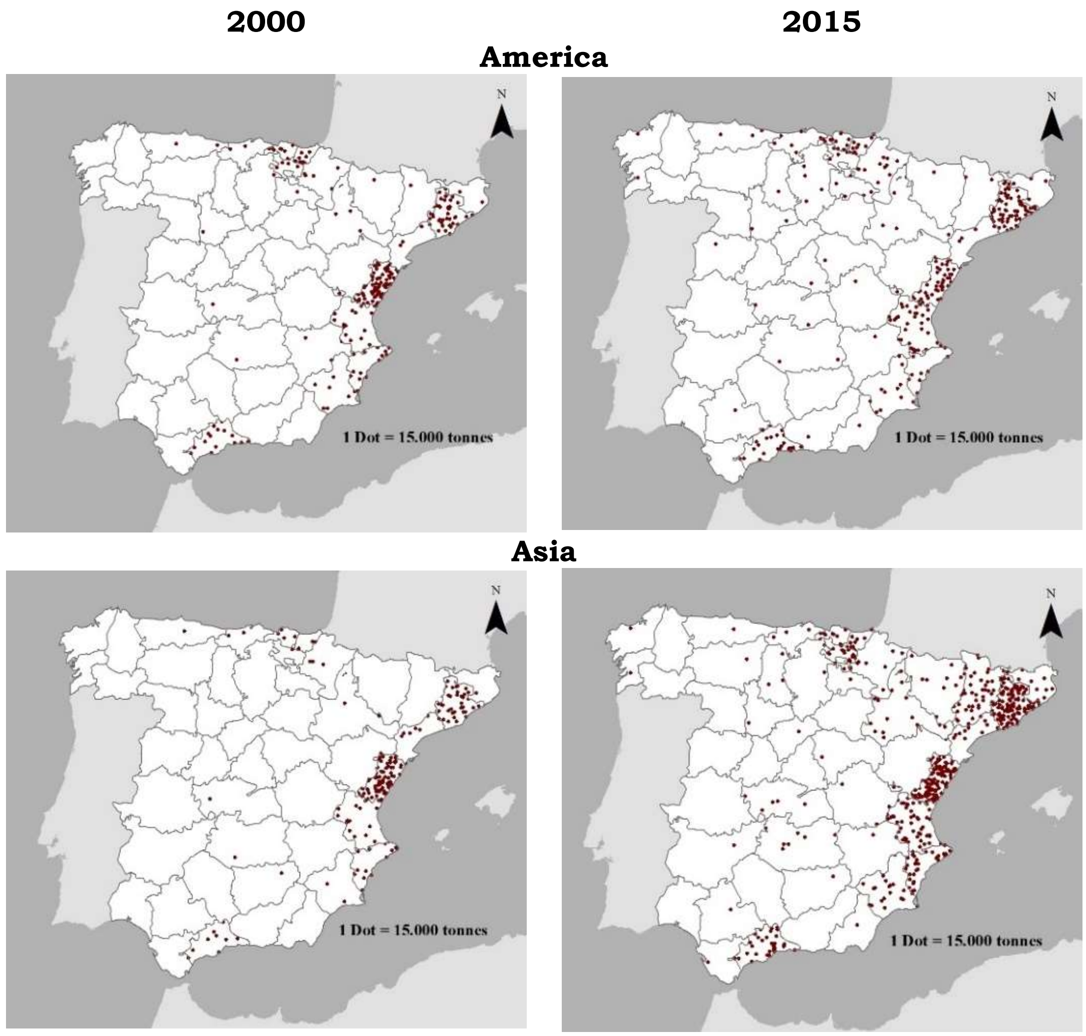

Figure 10. Dot density of provincial export flows (in tonnes), by continent.
Source: based on data from Customs and Excise Duties Department bof the Spanish Tax Agency (2017).

3.8 Discussion

Additional research is needed to assess whether these conclusions could be extrapolated to other countries, such as France or USA, or to a broader context, such as the EU. For instance, concerning the EU case as a whole, the largest and best-connected ports are also those that have grown the most during the analysed period. However, unlike what happens in Spain, these ports are located in the north. This is in line with the obtained results: the container throughput (proxy for connectivity) is particularly important to shipments to Asia, and accessibility is not a problem for the northern ports, as they are closer to the main European production/consumption centres (unlike Bilbao in regard to the main Spanish centres). Nevertheless, it should also be noted that ports located in the Mediterranean region have increased their share (Notteboom, 2017).

Monios et al. (2016) have observed that the centre of gravity of European distribution has shifted slightly to the south-east. This shift favours the increase of competition between the Northern and Mediterranean European ports, already anticipated by Notteboom (1997) for the traffic generated in Northern Italy, Switzerland, Southern Germany, Spain and the centre and South of France. Actually, central European shippers tend to choose northern ports to channel their traffic because of their shorter distance to the market, the economies of scale reached at their facilities and their higher level of regional integration, highlighted by Brooks et al. (2010) and Ducruet and Zaidi (2012).

However, despite their poorer centrality, a priori, Mediterranean ports are better located for reaching Asian destinations[27]. Acciaro et al. (2017) and Kramberger et al. (2018) pointed out that better hinterland transport services would enable them to capitalise on that advantage. Following these authors, the best strategy for southern ports to compete with the northern facilities should be based on cooperation[28]. This leads to *coo-petition*, a term introduced in the port sector by Song (2003). It is a mixture of competition and cooperation which facilitates agreements among ports to build up a stronger position in contestable markets or to develop a common marketing strategy, which could drive growth in total traffic for the port range. The aim is to reach benefits than could otherwise not be reached.

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[27] This is important because the growth of container traffic in Asia is ahead of the global average, particularly in South Asia (Wong, 2016).

[28] A typology of port cooperation activities can be found in Brooks et al. (2010).

The results of this chapter suggest that southern ports would need to reinforce their size (which means attracting more shipping lines services and improving their connectivity) to be able to divert traffic from the ports of the north of the EU, and a strategy of *coo-petition* could be useful for this purpose. This would have consequences not only in terms of the inter-port competition with the northern ports, but also in relation to the inland corridors within each territory. In this sense, Kashiha et al. (2016) reached two important conclusions: i) shippers from landlocked countries value more highly port efficiency and port connectivity, and ii) the larger the shippers, the more important these port characteristics are, so crossing national borders to reach their facilities becomes less relevant.

3.9 Concluding remarks

The purpose of this chapter is to analyse whether the geographical pattern of foreign trade influences the inland distribution of maritime traffic and, therefore, the use of the transport infrastructure. The Spanish case has been studied in order to test the validity of this hypothesis. The results indicate that the impact of the variables determining the inter-port distribution of shipments varies depending on the final destination of flows. Therefore, it can be said that the geographical pattern of foreign trade does influence the inland distribution of maritime traffic.

Concerning the Spanish case, several conclusions can be drawn. First, the size and scope of the Spanish ports located along the Mediterranean coast have been reinforced. Second, the impact of the province-port travel time as a repulsion factor is higher than the influence of the port throughput as an element of attractiveness (as it was already attested in chapter 2). Third, the influence of this variable (size/connectivity) is higher for flows destined to Asia, despite having increased for flows destined to America. For this particular destination, the improvement of accessibility has benefited the port of Barcelona in detriment to Bilbao (despite its apparent better location to reach America, its connectivity is not so good). And fourth, and in addition to the port throughput and the province-port travel time, the trade creation in the geographical surroundings of ports is a key issue for the increase of their activity (Barcelona). Regarding this last point, the evolution of the foreign trade pattern can doubly influence as changes could lead both to trade creation and diversion in the surroundings of the ports.

An additional and more general conclusion can be drawn from the analysis carried out. It is well known that the inland distribution of maritime traffic depends on many variables, some of which are beyond the control of the port authorities and policy-makers. Among them, one of the most relevant is the design of the maritime lines network; another, focused on here, is the geographical destination of the trade flows. Arguably, the latter is more predictable than the former, especially in the medium/long term. The maritime lines network may depend on the decisions of a handful of stakeholders, whereas world economic trends are well tracked and forecasted. This argument makes the results of this chapter more relevant, in the sense that the use of the inland infrastructure is linked to the destination of trade flows. Paying attention to global trade trends may help to avoid overcapacity/congestion of ports and inland corridors, thus improving the efficiency in the allocation of resources and reinforcing the competitiveness of domestic exports.

The primary contribution of this chapter is to reverse the analysis of the relationship between infrastructure and trade. The case study analysed shows that there is a link between the evolution of foreign trade and the use of the inland infrastructure. However, more research is needed to further explore relevant queries. It would be interesting to repeat the analysis in other geographical areas. It would be also desirable to extend the analysis carried out by focusing on, for example, the role of shipping lines. Finally, further research is needed into the relationship between flows and masses since the configuration of the spatial structure can influence both the generation and inter-port distribution of flows. This question is analysed in the following chapter.

4

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 chapter 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.

4.1 Introduction

Ports play a crucial role in transport costs and, consequently, affect regional competitiveness (Limao and Venables, 2001; Wilmsmeier et al., 2006). 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 policy-makers 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), the location (and accessibility) of their facilities being a relevant element for port choice. These 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[29]. This chapter 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* arises when the inter-port distribution of the flows is

[29] An exception of this general trend can be found in Garcia-Alonso and Márquez (2017).

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 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*. 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).

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 chapter is structured as follows: section 4.2 provides a literature review and section 4.3 the methodological proposal. section 4.4 presents the data and variables included in the study. The hypothesis confirmation procedure is shown in section 4.5, and *direct* and *network effects* are detailed in section 4.6. Finally, the main conclusions are summarised in section 4.7.

4.2 Literature review

Interactions between social and economic agents over space were extensively studied from the perspective of Spatial Interaction Models (SIM). This approach considers that the intensity of flows is influenced by both sizes and spatial separation 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. 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. On the one hand, the spatial econometric techniques are usually employed to certify the economic influence of a region and its neighbourhood on ports, and vice versa (Bottasso et al., 2014; Fageda and Gonzalez-Aregall, 2014; Tsekeris, 2016). 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. On the other hand, 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 (Debrie and Guerrero, 2008; Ferrari et al., 2011; Guerrero, 2018, 2014, Moura et al., 2018, 2017). They are also used to analyse the role of port infrastructure as a driver of the international trade of regions (Artuc et al., 2014; Bensassi et al., 2015; Bottasso et al., 2018; Guerrero et al., 2016; Wilson et al., 2014). 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.

4.3 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[30].

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 (5):

$$Y_{ODt} = \rho W_t Y_{ODt} + \alpha \iota_{n^2} + X_{Ot}\beta_O + W_t X_t \theta + X_{Dt}\beta_D + g_{ODt}\gamma + \delta_t \iota_{n^2} + \varepsilon_{ODt} \quad (5)$$

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 ($X_{Ot} = \iota_n \otimes X_t$; $X_{Dt} = X_t \otimes \iota_n$);

[30] 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.

- 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
- $\rho, \alpha, \beta_O, \theta, \beta_D$ 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 province 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[31]. Specifically, the spatial dependence relationships were captured by the parameters of the endogenous interaction 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 ($\rho_D W_{Dt} Y_{ODt}$)[32]; 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 ($W_{Dt} X_{Dt} \theta_D$)[33].

4.4 Data sources

This chapter evaluates the inter-port distribution of the Spanish maritime

[31] 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.

[32] These terms were shown in Eq. (5) in generic form as $\rho W_t Y_{ODt}$.

[33] These terms were shown in Eq. (5) in generic form as $W_t X_t \theta$.

flows of foreign trade. In particular, it analyses the container flows (in tonnes) generated by the 47 peninsular provinces and channelled by containers through the ports of Algeciras, Barcelona, Bilbao and Valencia in 1995, 2000, 2005, 2007, 2012 and 2015.

Flow data were provided by Customs and Excise Duties Department of the Spanish Tax Agency (2018). The independent variables representing provinces and ports are the Gross Domestic Product (GDP) and the volume of container throughput, respectively from Instituto Nacional de Estadística (2018) and Ente Público Puertos del Estado (2018). GDP is a proxy for the size of the economy widely used, also valid for this particular analysis[34]. Meanwhile, container throughput, as a proxy for port performance and competitiveness, port connectivity or port economic capacity, and travel times between province and port, as proxy for hinterland accessibility, were used here following the previous chapters. The values of travel time were also employed to construct the spatial weight matrix between provinces in order to capture the interregional connectivity. This variable was calculated based on the actual existing Spanish road network provided by García (2013).

The 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, as all of them influence the inter-port distribution of flows (Y_{ODt})[35], 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

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

[35] 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).

to generate global spillovers, whereas local spillovers are only expected from GDP.

4.5 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 Ordinary Least Squares (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 chapter 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 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 $\rho = \theta = 0$ in Eq. (5) are reported in columns 1 (exports) and 3 (imports) of Table 8. 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[36].

The results of Step 3 of the SDM proposed in Eq. (5), including the goodness-of-fitness measures, are displayed in columns 2 (exports) and 4

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

(imports) of Table 8[37]. 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 8. Estimation results of OLS and SDM for exports and imports.

	Exports		**Imports**	
	(1)	**(2)**	**(3)**	**(4)**
	OLS	**SDM**	**OLS**	**SDM**
Intercept (α)	-3.36* (-2.11)	-4.07** (-2.22)	-16.34*** (-9.52)	-8.48*** (-3.98)
GDP (β)	1.33*** (21.59)	1.34*** (26.04)	1.52*** (22.89)	1.53*** (26.11)
Container throughput (β)	0.18* (2.33)	0.11* (1.72)	0.77*** (9.29)	0.45*** (6.00)
Travel time (γ)	-2.31*** (28.59)	-1.15*** (-14.25)	-2.23*** (-25.62)	-1.35*** (-14.73)
W* GDP (θ)		-0.55*** (-7.18)		-0.70*** (-8.00)
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	4,563.30
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.

[37] 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.

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.

4.5.1 Analysis of the endogenous and exogenous interaction effects

As can be seen in Table 8, 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, the chapter 3 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 location of the exporting firms evolves, drawing cargo corridors to ports. 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 8). This effect takes place when the characteristics of neighbouring territories contribute to explain the flows of a specific place. Natural resources, climate and other characteristics of neighbouring regions are important to explain a region's pattern of productive specialisation. This interaction leads to sectoral linkages that can be either complementary or competitive (LeSage and Llano-Verduras, 2014). 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.

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.

4.6 *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[38]. 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 the outcome of the observation, directly affected by this change, and ii) on the outcome of the

[38] The coefficients of non-spatial models are interpreted directly and represent marginal effects, whereas the coefficients of spatial models do not.

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 9 together with the OLS coefficients (already shown in Table 8)[39].

Table 9. Marginal effects of OLS and SDM for exports and imports.

	Exports			
	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			
	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[40]. 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 models absorbs part of the spatial structure of the

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

[40] 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.

system, hence being biased. With the inclusion of spatial lag variables, the parameter obtained reflects only the behaviour of the economic agent[41] (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[42], 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). This can be explained by the fact that maritime imports are usually grouped in the country of origin taking into account the country of destination. In this sense, the size of container ports is more relevant as it is directly linked to their connectivity (Kashiha et al., 2016). Once the freight arrives at the

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

[42] 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.

port serving as a gateway, it is distributed among the final inland destinations (provinces). On the contrary, the origin of exports are the provinces and their first destination is a port, so their connectivity is less important in relative terms than their accessibility. In short, it can be concluded that 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.

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)[43] 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.

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

- 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.

4.7 Concluding remarks

The results of this analysis are in line with the conclusions reached by other researchers in previous studies. Firstly, it can be said 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, 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, container throughput is a factor to be taken into account to explain the inland distribution of maritime traffic. However, now it is possible to go one step further.

Once the existence of spatial interaction effects in the inland distribution of the maritime flows is confirmed, 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 inland 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. 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 greater positive spillovers for the country as a whole. The provinces with the most dynamic economies are located there, and the main ports are placed along the Mediterranean coast. However, such initiative would 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 analyse the existence of spatial interaction effects when considering improvements to infrastructure.

The analysis 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 effect to the characteristics of cargo. Methodologically, it would also be interesting to contrast the results of this chapter with Poisson variants of spatial interaction models. Nevertheless, a deeper development of these models is still required for this particular purpose.

Besides all this, the relevance of the location of ports goes beyond the potential links they can establish with the territory that generate the maritime traffic; it can also influence how they offer their services. This is what will discussed in the following chapter.

5

The effect of weather conditions on port technical efficiency

Abstract

As maritime transport is one of the sectors most affected by climatic conditions, their influence on port productivity becomes highly interesting given the magnitude of the climatic change predicted for this century. In particular, the effect of wind and waves on the technical efficiency of ports was analysed. These two specific factors deserve special attention as they influence both ship operations and terminal operations. Additionally, bad weather may increase demand variability, which generates the necessity for some overcapacity which will be used only during demand peaks, remaining unused during low-demand periods. In an application to Spanish ports, a stochastic output distance function approach was used to assess the impact of wind and waves on their technical efficiency and to evaluate their impact by means of a simulation analysis. The results confirm the significant impact of weather conditions on port technical efficiency. Moreover, during the sample period (1992-2016) it was found that weather conditions were responsible for a 7% variation in the average technical efficiency of the whole sample.

5.1 Introduction

The interest in improving port performance in a growing global trade situation is clear (Becker et al., 2018; Blonigen and Wilson, 2008). In particular, Clark et al. (2004) shows the importance of improving port efficiency in order to reduce transportation costs. From the port user's perspective, port efficiency is evaluated according to service characteristics provided within their facilities. For this, they tend to use partial performance indicators (Suárez-Alemán et al., 2016). Specifically, rate and productivity of cranes, berths, yards, time required to enter and exit a port, dwell and turnaround times or tons/TEUs per hour, are usually applied because they are simple in terms of both understanding and calculation (Sarriera et al., 2013; Serebrisky et al., 2016; UNCTAD, 2017).

Conversely, in the productivity literature, "the term (economic) *efficiency* refers to the comparison between the real –or observed– values of output(s) and input(s) with the optimal values of input(s) and output(s) used in a production process" (Karlaftis and Tsamboulas, 2012, p. 393). In terms of Wilmsmeier et al. (2013, p. 50), it is understood as "the capacity of obtaining maximum amount of output from certain inputs (output orientation) or, alternatively, as the capacity of obtaining a given output level using the minimum amount of inputs (input orientation)".

Both meanings of efficiency should be positively related for a given demand of port services as the greater the efficiency (in terms of productivity literature), the greater the amount of services provided by the port in a given time. However, Slack et al. (2018) observed a lack of correlation between average vessel turnaround and port efficiency estimations. This lack of correlation can be related with the variability of the demand for port services and the optimizing behaviour of the shipping companies. The demand for port services is characterized by its variability, which becomes enhanced as ship arrivals are commonly delayed[44]. Port facilities must be able to deal with the consequent demand peaks and possible disruptions of services to avoid traffic loss (Notteboom, 2006). That is, port authorities have incentives to invest in their facilities to be ensured against high demand peaks and to prevent congestion, creating some *reserve capacity* (Rodriguez-Alvarez et al., 2012). This is particularly relevant nowadays because the increasing concentration within the shipping industry has contributed to intensify the inter-port competition and, consequently, port operators try to intensify the attractiveness of their facilities to maintain their market shares. In this context, the shorter the vessel turnaround, the more efficient a port will be considered by practitioners, but this quick service could result in a port overcapacity that will only be used during demand peaks (remaining unused during demand valleys) and reducing the ports' efficiency from the productivity analysis perspective[45]. In fact, Tovar and Wall (2014) observed that differences in demand variability cause differences in costs among ports, and concluded that the greater the demand variability of port services, the greater their cost-inefficiency.

The research presented here contributes to the literature by analysing the effect of wind and waves on port efficiency, approached from the productivity analysis perspective. These two specific factors deserve attention as they condition port activity in several aspects. On the one hand, ship operations can be hampered by wind and waves (UNCTAD, 2017). Their empirical relevance on vessels manoeuvrability can be seen, for instance, in Ellot et al. (2010) and Szymonski (2013). On the other hand, winds (and waves to a lesser extent) can also generate difficulties in terminal operations (UNCTAD, 2017). Particularly, high wind speed creates strong handling difficulties in crane operations due to the movement

[44] See Drewry Shipping Consultants (2006).

[45] As Oliveira and Cariou (2015) or Lu et al. (2016) highlighted, the higher the competition, the greater the pressure to over-invest in facilities and, thus, the probability of reducing port efficiency.

induced in load, the dispersion of solid bulk cargo as well as potential damage to port infrastructures. Therefore, these factors are also relevant from the standpoint of port users. Additionally, according to Vernimmen et al. (2007), bad weather at sea is a key factor in line-up schedule unreliability increasing the demand variability and the need for a larger *reserve capacity* in order to be competitive. Hence, wind and waves have direct (difficulties in ship and terminal operations as well as their impact in infrastructures) and indirect effects (through their effect on demand uncertainty) on port efficiency.

The assessment of the relevance of wind and waves in port efficiency is particularly interesting nowadays due to the climate change the planet is undergoing[46] (IPCC, 2013). This has motivated the advent of several studies dealing with the effect of weather on the productivity of some sectors particularly influenced by meteorology such as agriculture (Barrios et al., 2008; Demir and Mahmud, 2002; Perez-Mendez et al., 2018) or energy (Anaya and Pollitt, 2017; Llorca et al., 2016; Orea et al., 2015). However, research in this regard on the transport sector is limited, despite being one of the economic activities expected to be most affected by weather conditions (Koetse and Rietveld, 2009; Vajda et al., 2014) and to the authors' knowledge, there is no study using the standard productivity analysis to assess the effect of weather conditions on port productivity.

The purpose is to use an output distance function approach to evaluate the impact of wind and waves on the technical efficiency of the main Spanish ports. The results can be of interest from two perspectives. Firstly, from a single port perspective, an evaluation of the effect of forecasted weather evolution on the technical efficiency of ports should be borne in mind when analysing the convenience of investments in infrastructure, in order to adapt the ports to the effects of weather on port

[46] An exhaustive review on the impact of climate change on the port sector can be found in Becker et al. (2018).

productivity. Secondly, it should be taken into account that weather evolution may differ depending on the geographical locations, especially in a country with ports on different coastlines as in the Spanish case. Then, its effect on port productivity varies depending on their location, which may lead to a different pattern for sea traffic, and this should be considered when planning the transport system.

The rest of the paper is organized as follows. The empirical model used in the analysis is developed in Section 5.2. In Section 5.3 we describe the data used in the estimation. The evolution of wave height and wind speed during the sample period (1992-2016) is analysed in Section 5.4. The obtained results are presented in Section 5.5. A discussion about their relevance can be found in Section 5.6 and finally, Section 5.7 highlights the main conclusions.

5.2 Methodological proposal

In the productivity analysis literature, a firm is considered economically efficient when it takes full advantage of the technology to achieve some economic target (profit maximization or cost minimization). Therefore, economic efficiency could be split into technical, allocative and scale efficiency. Technical efficiency requires taking full advantage of the technology by extracting the maximum output from the input endowment (output-oriented efficiency) or by minimizing the input endowment used to produce some output (input-oriented efficiency). Allocative efficiency requires the use of the input mix that minimizes the cost of producing the output for a technically efficient firm. Finally, a firm is scale efficient if it minimizes the average cost of production. It is worth noting that the estimation of allocative and scale efficiency requires more data than the estimation of technical efficiency as data about input prices are necessary. It may be due to the lack of this kind of data, but most port efficiency analysis focuses on technical efficiency.

Technical efficiency can be analysed following parametric and non-parametric techniques. A deep study on the differences between both approaches applied to the port topic can be found in González and Trujillo (2009). Tovar and Wall (2015) and Tovar and Rodríguez-Déniz (2015) provide a more recent literature review on this field. As can be seen there, the objectives of the studies carried out are vast, addressing a wide range of issues. In particular, during recent years, the main topics of interest remain the same: the consequences of regulatory and economic changes (Coto-Millán et al., 2016), the role of efficiency in port choice (Slack et al., 2018), methodological novelties (Nguyen et al., 2016; Tovar and Wall, 2016) or particular case studies (Coto-Millán et al., 2016; da Cruz and de Matos Ferreira, 2016; Gil-Ropero et al., 2015; Serebrisky et al., 2016; Wanke and Pestana Barros, 2016). However, even though it is known that poor natural conditions can greatly affect port competitiveness (Peng et al., 2018), as far as we know, there is no study evaluating the effect of meteorological conditions on port efficiency.

Bad weather conditions may contribute to create a gap between the maximum potential services production and the actual production. It can take place due to both its direct effect on the services offered and its indirect effect through its influence on demand uncertainty, partially caused by bad weather conditions delaying ships arrivals. To assess this gap, the output-oriented distance function was applied (see Coelli et al., 2005; Kumbhakar and Lovell, 2000), which is a tool frequently applied in the analysis of ports' efficiency (Chang and Tovar, 2014; González and Trujillo, 2008; Trujillo and Tovar, 2007). In the stochastic frontier literature, the technical inefficiency degree associated to this gap is commonly associated with a suboptimal management. Nevertheless, in this study, it was considered that it includes both: the "wasted resources" due to a suboptimal management (i.e., "pure" technical inefficiency) and the direct and indirect effects of wind and waves.

The output distance function could be defined as:

$$D_O(x, y) = min\left\{\theta : \frac{y}{\theta}\ can\ be\ produced\ with\ x\right\} \tag{6}$$

where y represents the output vector and x is the input vector. Therefore, $D_O(x, y)$ represents the technology frontier as it represents the maximum potential production attained with each input endowment. That is, each input endowment generates a transformation curve in the space of outputs and these transformation curves define the frontier of the technology. The distance magnitude, θ, refers to the expansion of outputs allowed by the technology within the production possibilities set while the input endowment is held constant (Coelli et al., 2005; Kumbhakar and Lovell, 2000). Faïre and Primont (1995) analyses the properties that the output-oriented distance function must hold. In particular, $D_O(x, y)$ should be decreasing in x and non-decreasing and degree of one and homogeneous in y. In this sense, it is possible to rewrite (1) as:

$$\theta = y_1 \cdot D_O(x, y^*) \tag{7}$$

where y^* is the output vector divided by y_1, what makes the distance function linearly homogenous in outputs. After rearranging and taking logarithms, it takes the following form:

$$-\ln y_1 = D_O(\ln x, \ln y^*) - \ln \theta \tag{8}$$

To define a functional form for the distance function, an approximation to an arbitrary function is necessary since the true technology is unknown. Flexible functional forms (Chambers, 1988) are typically used. The translog form, *D(·)*, one of the most commonly employed in the empirical literature, was applied here. Then, the distance function to be estimated becomes:

$$-\ln y_{1it} = \alpha_0 + \sum_{j=1}^{4} \alpha_j \ln x_{jit} + \frac{1}{2}\sum_{j=1}^{4}\sum_{k=1}^{4} \alpha_{jk} \ln x_{jit} \ln x_{kit} + \sum_{l=2}^{5} \beta_l \ln y^*_{lit} + \frac{1}{2}\sum_{l=2}^{5}\sum_{m=2}^{5} \beta_{lm} \ln y^*_{lit} \ln y^*_{mit} + \frac{1}{2}\sum_{j=1}^{4}\sum_{l=2}^{5} \gamma_{jl} \ln x_{jit} \ln y^*_{lit} + \alpha_t t_{it} + \frac{1}{2}\alpha_{tt} t^2_{it} - v_{it} + u_{it} \quad (9)$$

where subscript i refers to port and t to year; y^*_{lit} is the output y_{lit} divided by y_{1i} ; t_{it} is a time trend. Then, the equation (9) allows for non-linear neutral technical change by permitting the frontier expansion along the sample periods. α's, β's and γ's are the parameters to be estimated. Symmetry restrictions are imposed before the estimation ($\alpha_{jk} = \alpha_{kj}$; $\beta_{lm} = \beta_{ml}$ and $\gamma_{jl} = \gamma_{lj}$). The distance from the observation to the production frontier possibilities is represented by $u \equiv -\ln\theta$. In this study the normal/half-normal model (Estache et al., 2002; Kumbhakar and Lovell, 2000; Liu, 1995) was used. On the one hand, that v is assumed to be a normally distributed error with mean zero. On the other hand, $u \geq 0$ is assumed to be a positive error term following a half-normal distribution, where $u \sim iid\ N^+(0, \sigma^2_u)$. Therefore, the error term u measures the proportion in which each output must increase to reach the frontier of the technology (associated to the maximum potential output represented by the frontier) in order to be technically efficient.

The variance of u was specified as $\sigma^2_u = g(z;\delta)$. The explanatory variables are represented by z and a set of parameters to be estimated by δ (Caudill et al., 1995). Therefore, the greater the variance of the error term u the larger the expected distance to the frontier. The natural logarithm of this variance was modelled as a linear function:

$$\ln \sigma^2_{u\,it} = \delta_0 + \delta_{GDP}\,\Delta GDP_{it} + \delta_{Wave}\,Wave1.5_{it} + \delta_{Wind}\,Wind7.5_{it} \quad (10)$$

ΔGDP_{it} being the percentage change in the gross domestic product of the Autonomous Community (NUTS 2), where the port is located. It is included to control for the effect of drops in demand caused by the two important crises that took place during the period covered by the sample data: the first at the beginning of 90's and the second starting in 2007/08. The weather conditions are included by the variables *Wave1.5,* representing the proportion of days along the year with average wave height greater than 1.5 meters, and *Wind7.5*, expressing the proportion of days with average wind speed faster than 7.5 meters per second[47]. Then, it is supposed that apart from pure technical efficiency associated to suboptimal management, there are two other reasons that can lead the port away from its technical efficient frontier.

5.3 Data sources

The case study addressed in this paper is focused on the Spanish port sector for the period 1992-2016. The port authorities covered by the study are Algeciras, Alicante, Barcelona, Bilbao, Cádiz, Cartagena, Castellón, Gijón, Las Palmas, Málaga, Santa Cruz de Tenerife, Seville, Tarragona, Valencia and Vigo, which managed 85% of total throughput in Spain in 2016.

Historical series of waves and winds are not public data and were provided by the Ente Público Puertos del Estado based on two sources: observation buoys and SIMAR points[48]. As an example, Figure 11 shows the buoys and SIMAR points in the Straits of Gibraltar, where red points indicate the position of buoys and the green indicate SIMAR points. Most of the ports have one or several observation buoys close to the mouth of the port and, then, data on waves and wind correspond to the buoy closest to it. In case there are no buoys near the mouth, as is the case with the ports of Cartagena and Castellón, wave and wind data proceed from the

[47] More details about the construction of these variables will be found in Section 5.3.

[48] SIMAR points conform a network of points where the sea conditions are simulated by computer.

closest SIMAR points. The same occurs in short periods when a buoy did not collect data due to malfunction, damage, substitution, etc., in which case the closest SIMAR point was also used. The port of Seville also deserves special mention as it is not located on the coast but is inland. It is necessary to navigate around 90 km from the mouth of the river Guadalquivir to reach this port. Accordingly, data of this port correspond to the observation buoy closest to the Guadalquivir mouth.

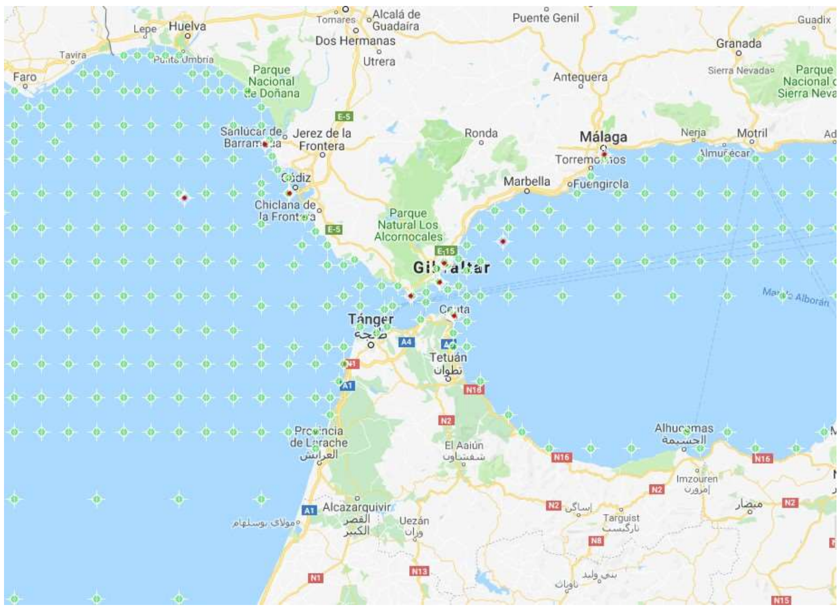

Figure 11. SIMAR points and buoys in the Straits of Gibraltar.
Source: Ente Público Puertos del Estado (2018).

The data from observation buoys and SIMAR points are provided hourly. In relation to wind, the hourly average of the speed is afforded. With regard to waves, the concept of *significant wave height* is considered, which means that once the wave heights of the hour are recorded, only the upper third of these waves is used to determine the average value. From this information, the daily average was calculated for wind speed and wave height. Assuming that below a certain limit the incidence of waves and winds on the technical efficiency of ports could be negligible, limits of 1.5 meters of height for waves and 7.5 meters per second for winds were chosen[49]. From there, the proportion of days throughout the year in which the wave height and the wind speed surpass these values was measured, which generated the variables *Wave1.5* and *Wind7.5*, respectively. In this sense, *Wave1.5* is the proportion of days throughout the year in which the average wave height along the day exceeds 1.5 meters; *Wind7.5* is the proportion of days in which the average wind speed surpasses 7.5 meters per second.

Input and output data proceed from Statistical Yearbooks and Annual Reports, both of the Ente Público Puertos del Estado (2018). Port services were grouped into five outputs that represent the merchandise handled in thousands of tonnes, divided depending on the different types of cargo: liquid bulk cargo (y_1), solid bulk cargo (y_2), general cargo by container (y_3), general cargo non-containerized (y_4); added to the thousands of passengers (y_5). The input variables considered were deposit surface (x_1), infrastructure and buildings (x_2), labour (x_3) and other expenses (x_4). Deposit surface represents the available storage in thousands of square meters at the port. Infrastructure and buildings are measured by the value in thousands of euros of the amortisation of tangible assets of the port authority. In turn, labour represents the cost of port authorities' employees in thousands of euros. Finally, other expenses are other operating costs in thousands of euros that are not included in the other accounts.

Finally, the GDP of Autonomous Communities (NUTS 2) comes from the Instituto Nacional de Estadística (2018). Table 10 shows some statistics describing the variables. Before proceeding to the estimation procedure, 19 observations were ruled out due to the presence of zeros in some output, generally on passengers. The dataset includes 356 observations.

[49] The empirical analysis was developed by using several values for wind speed and wave height. The set of reference values was chosen because they provide the larger likelihood value.

Table 10. Output, input and efficiency determinants statistics.

Variable	**Mean**	**Std. Dev.**	**Min.**	**Max.**
Liquid bulk cargo	7,193	7,630	34	27,300
Solid bulk cargo	3,593	3,837	235	19,700
General cargo by container	6,241	11,000	5	60,200
General cargo non-containerized	2,855	5,922	77	55,500
Passengers	1,000	1,562	0.7	5,618
Deposit surface	1,331	1,311	105	7,957
Infrastructure and buildings	15,901	10,669	2,697	56,536
Labour	11,567	6,701	2,762	37,400
Other expenses	12,105	10,059	942	61,733
ΔGDP (% variation)	1.863	2.541	-5.760	6.400
Wave15 (proportion of days)	0.140	0.164	0	0.611
Wind75 (proportion of days)	0.106	0.090	0	0.364

Table 10 shows the diversity of the different ports considered in the analysis. It is worth noting that differences between outputs are larger than those between inputs, as the standard deviations in outputs are always larger than the average value, while between the inputs the opposite occurs. Regarding the efficiency determinants, it is important to highlight that the economic crises have generated a large variation for ΔGDP values along the sample period. Therefore, the standard deviation is larger than the mean value. Wave and wind conditions are also quite different among the different observations. It should be noted that the ports are in different seas and that the sample period is long enough (25 years) to observe some changes in the evolution of the weather variables, most likely due to the climate change that the planet is undergoing (IPCC, 2014). The following section describes the observed evolution of wave and wind variables.

5.4 Wave and wind evolution during the sample period

The sample was divided into 5 zones, as displayed in Figure 12, in order to consider different evolutions of waves and winds. Zone 1 includes ports located in the northern part of Spain (Bilbao, Gijón and Vigo); Zone 2 refers to the ports in the Canary Islands (Las Palmas and Santa Cruz de Tenerife); in Zone 3, the ports are located in the south-western part of the peninsular Spain (Cádiz and Seville); in Zone 4, the ports are located in the Alboran Sea (western part of the Mediterranean Sea, including Algeciras and Málaga) and Zone 5 includes the rest of the Mediterranean ports (Tarragona, Barcelona, Castellón, Valencia, Alicante and Cartagena).

Figure 12. Zones of the Spanish coast.
Source: based on data from GISCO Ports 2013 dataset (European Commission, 2016)

Tables 11 and 12 show the global and the zonal averages of *Wave1.5* and *Wind7.5*. It becomes apparent that the proportion of days with average wind speed of over 7.5 meters per second increases along the sample period (even for the global sample or for each zone). This result is in line with the increase of wind speed in the Spanish latitude found in IPCC (2014). On the contrary, the evolution of the proportion of days with average significant wave height over 1.5 meters is unclear.

Table 11. Average values of *Wave1.5* by zone.

Year	All	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
1992	0.141	0.486	0.273	0.044	0.074	0.058
1993	0.121	0.479	0.140	0.052	0.086	0.030
1994	0.143	0.498	0.151	0.068	0.051	0.019
1995	0.144	0.427	0.149	0.088	0.082	0.039
1996	0.153	0.436	0.138	0.165	0.057	0.043
1997	0.132	0.419	0.052	0.118	0.081	0.036
1998	0.123	0.427	0.126	0.049	0.066	0.015
1999	0.090	0.392	0.107	0.047	0.052	0.033
2000	0.159	0.493	0.085	0.083	0.071	0.029
2001	0.139	0.390	0.093	0.125	0.074	0.038
2002	0.139	0.504	0.138	0.122	0.053	0.035
2003	0.155	0.392	0.152	0.133	0.074	0.055
2004	0.143	0.441	0.105	0.068	0.055	0.044
2005	0.133	0.398	0.144	0.041	0.086	0.025
2006	0.142	0.409	0.134	0.108	0.047	0.037
2007	0.125	0.422	0.134	0.036	0.036	0.034
2008	0.145	0.444	0.146	0.056	0.063	0.035
2009	0.120	0.379	0.060	0.111	0.040	0.024
2010	0.129	0.345	0.127	0.167	0.059	0.032
2011	0.149	0.467	0.166	0.063	0.070	0.040
2012	0.128	0.432	0.128	0.042	0.022	0.041
2013	0.159	0.472	0.163	0.121	0.041	0.054
2014	0.160	0.493	0.188	0.158	0.036	0.027
2015	0.157	0.489	0.136	0.118	0.058	0.044
2016	0.151	0.425	0.163	0.152	0.049	0.043

Table 12. Average values of *Wind7.5* by zone.

Year	All	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
1992	0.069	0.027	0.153	0.119	0.063	0.053
1993	0.056	0.037	0.064	0.121	0.066	0.034
1994	0.049	0.026	0.107	0.110	0.049	0.020
1995	0.058	0.020	0.067	0.153	0.067	0.039
1996	0.066	0.021	0.077	0.198	0.067	0.042
1997	0.057	0.025	0.022	0.175	0.082	0.036
1998	0.046	0.021	0.081	0.093	0.067	0.025
1999	0.051	0.000	0.084	0.078	0.051	0.028
2000	0.053	0.029	0.059	0.096	0.060	0.042
2001	0.054	0.030	0.084	0.104	0.060	0.035
2002	0.058	0.040	0.075	0.092	0.059	0.045
2003	0.071	0.017	0.179	0.107	0.045	0.057
2004	0.044	0.015	0.094	0.056	0.033	0.040
2005	0.056	0.010	0.194	0.096	0.038	0.019
2006	0.128	0.179	0.242	0.119	0.108	0.063
2007	0.153	0.199	0.289	0.112	0.167	0.092

2008	0.185	0.189	0.328	0.194	0.221	0.107
2009	0.177	0.205	0.266	0.205	0.204	0.102
2010	0.188	0.266	0.221	0.228	0.216	0.114
2011	0.155	0.183	0.238	0.170	0.189	0.098
2012	0.151	0.173	0.262	0.189	0.133	0.096
2013	0.192	0.265	0.278	0.227	0.179	0.119
2014	0.164	0.224	0.251	0.197	0.155	0.097
2015	0.152	0.184	0.296	0.158	0.142	0.090
2016	0.165	0.183	0.317	0.205	0.150	0.098

To identify these time trends, we estimated the equations (11.a) and (11.b):

$$Wave1.5_{it} = \sum_{i=1}^{I} \beta_i D_i + \beta_t t + e_{it} \qquad (11.a)$$

$$Wind7.5_{it} = \sum_{i=1}^{I} \beta_i D_i + \beta_t t + e_{it} \qquad (11.b)$$

where D_i are port dummies, e_{it} is the error term and β's are the parameters to be estimated. The estimations were made for the total sample and for each zone separately. The set of estimations of the parameters β_t along with the R^2 statistics are included in Tables 13 and 14.

Table 13. *Wave1.5* trend.

Wave1.5	**Coef.**	**Std. Err.**	**t-Stat.**	**R²**
Global trend	0.0003	0.0003	0.96	0.946
Zone 1 trend	-0.0001	0.0010	-0.09	0.486
Zone 2 trend	0.0012	0.0009	1.31	0.854
Zone 3 trend	0.0018	0.0009	1.95	0.348
Zone 4 trend	-0.0013	0.0004	-3.59	0.817
Zone 5 trend	0.0002	0.0002	0.96	0.490

Table 14. *Wind7.5* trend.

Wind7.5	**Coef.**	**Std. Err.**	**t-Stat.**	**R²**
Global trend	0.0064	0.0004	16.42	0.655
Zone 1 trend	0.0110	0.0010	11.32	0.680
Zone 2 trend	0.0120	0.0013	9.32	0.687
Zone 3 trend	0.0037	0.0010	3.58	0.555
Zone 4 trend	0.0061	0.0010	6.09	0.747
Zone 5 trend	0.0036	0.0003	11.83	0.660

Table 13 shows that only in Zone 3 and Zone 4 the trend for the evolution of the variable $Wave1.5$ becomes significant (positive in Zone 3 and negative in Zone 4) while in the rest of the zones the trend is not significant. Therefore, in general, it is not possible to identify a pattern in the evolution of the proportion of days in which the average daily height of the waves is over 1.5 meters. However, Table 14 displays a statistically significant increase in the proportion of days in which the average wind speed is higher than 7.5 meters per second. The trend of this variable varies ostensibly from one zone to another, but it is positive and significant for each zone.

Therefore, from this preliminary analysis it can be concluded that different zones show considerable variations in weather conditions. Even more importantly, the evolution of these conditions can have a strong influence on the evolution of the technical efficiency of ports.

5.5 Results

Equation (9), including equation (10), was estimated in one step by maximum likelihood procedure. Inputs and outputs were divided according to their respective geometric means. Then, first order coefficients could be understood as the corresponding elasticities evaluated at the sample geometric mean. The production frontier estimation is reported in Table 15.

All the first order parameters show the theoretically expected sign. Then, first order parameters multiplying $\ln y_{lit}^{*}$ are positive and significant. On the one hand, it demonstrates that the distance to the frontier diminishes when an output increases (while the input vector remains constant), which, in turn, increments the technical efficiency degree of the port. On the other hand, first order parameters multiplying $\ln x_{jit}$ are negative and significant, which implies that, when the input endowment increases (while the output vector remains constant), the distance to the

Table 15. Output distance frontier estimation.

Variable	Coef.	Std. Err.	t-Stat.	Variable	Coef.	Std. Err.	t-Stat.
Const	0.009	0.076	0.12	$\ln y_3^* \ln x_2$	0.127	0.076	1.67
$\ln y_2^*$	0.510	0.025	20.56	$\ln y_3^* \ln x_3$	-0.086	0.091	-0.94
$\ln y_3^*$	0.085	0.020	4.25	$\ln y_3^* \ln x_4$	-0.027	0.050	-0.54
$\ln y_4^*$	0.340	0.028	12.28	$\ln y_4^* \ln x_1$	-0.134	0.043	-3.13
$\ln y_5^*$	0.102	0.012	8.13	$\ln y_4^* \ln x_2$	0.032	0.092	0.35
$\ln x_1$	-0.143	0.030	-4.81	$\ln y_4^* \ln x_3$	0.240	0.108	2.23
$\ln x_2$	-0.297	0.070	-4.26	$\ln y_4^* \ln x_4$	-0.114	0.065	-1.75
$\ln x_3$	-0.545	0.102	-5.36	$\ln y_5^* \ln x_1$	0.031	0.013	2.31
$\ln x_4$	-0.130	0.066	-1.98	$\ln y_5^* \ln x_2$	-0.004	0.032	-0.12
$0.5 \ln y_2^{*2}$	-0.037	0.024	-1.52	$\ln y_5^* \ln x_3$	-0.134	0.035	-3.83
$\ln y_2^* \ln y_3^*$	0.002	0.015	0.14	$\ln y_5^* \ln x_4$	0.095	0.025	3.79
$\ln y_2^* \ln y_4^*$	-0.047	0.025	-1.87	$0.5 \ln x_1^2$	0.188	0.055	3.45
$\ln y_2^* \ln y_5^*$	0.001	0.008	0.08	$\ln x_1 \ln x_2$	-0.157	0.126	-1.24
$0.5 \ln y_3^{*2}$	0.001	0.021	0.06	$\ln x_1 \ln x_3$	-0.324	0.162	-2.00
$\ln y_3^* \ln y_4^*$	0.043	0.028	1.53	$\ln x_1 \ln x_4$	0.154	0.086	1.79
$\ln y_3^* \ln y_5^*$	-0.013	0.009	-1.53	$0.5 \ln x_2^2$	-0.120	0.390	-0.31
$0.5 \ln y_4^{*2}$	0.025	0.038	0.66	$\ln x_2 \ln x_3$	0.314	0.271	1.16
$\ln y_4^* \ln y_5^*$	0.005	0.010	0.45	$\ln x_2 \ln x_4$	-0.274	0.190	-1.44
$0.5 \ln y_5^{*2}$	0.015	0.006	2.43	$0.5 \ln x_3^2$	1.516	0.403	3.76
$\ln y_2^* \ln x_1$	-0.009	0.029	-0.30	$\ln x_3 \ln x_4$	-0.774	0.220	-3.51
$\ln y_2^* \ln x_2$	-0.122	0.062	-1.99	$0.5 \ln x_4^2$	0.732	0.203	3.61
$\ln y_2^* \ln x_3$	-0.074	0.064	-1.16	t	-0.056	0.010	-5.84
$\ln y_2^* \ln x_4$	0.059	0.045	1.32	$0.5\ t^2$	0.003	0.001	4.62
$\ln y_3^* \ln x_1$	0.028	0.029	0.94	$\ln \sigma_v^2$	-3.128	0.132	-23.61

frontier becomes bigger, reducing the degree of technical efficiency. Scale elasticity at the sample geometric mean (calculated as the addition of the input first order parameters) is 1.12. The Wald test was used to test constant returns to scale (scale elasticity equal to 1) and takes a value of 3.68 (p-value 0.055), so increasing returns to scale are significant at 10% level, but not at 5%. The finding of increasing returns to scale in the Spanish port sector is usual in the literature (González and Trujillo, 2008; Núñez-Sánchez and Coto-Millán, 2012). However, diminishing returns to scale can also be found in the literature around the world (Chang and Tovar, 2017; Cullinane et al., 2002; Cullinane and Song, 2003). Finally, the results show a positive but decreasing technical change along the sample period, as the parameter interacting with t is negative but that interacting with t^2 is positive. A similar pattern for technical change could be found in Chang and Tovar (2017).

Table 16 shows the estimation of the efficiency determinants. All the variables considered become significant and have the expected sign. The negative sign of ΔGDP shows that, when the GDP increases, the variance of u diminishes and the expected distance to the frontier and the degree of technical efficiency reduce. Therefore, the economic crises observed during the sample period should have an important impact on port performance, as the drop in the demand for port services would decrease the technical efficiency score. *Wave1.5* and *Wind7.5* are also significant and show the expected sign. The results indicate that the larger the proportion of days with high winds and waves, the larger the distance to the frontier and the lower the degree of technical efficiency.

Table 16. Efficiency determinants estimation.

Ln σ_u^2	**Coef.**	**Std. Err.**	**t-Stat.**
Constant	-4.722	1.066	-4.43
ΔGDP	-0.340	0.078	-4.37
Wave1.5	4.685	1.546	3.03
Wind7.5	6.306	3.196	1.97

The negative effect of waves and wind on technical efficiency are evaluated through a simulation exercise. With the estimated parameters of equation (10), the conditional expectation of $\sigma_{u_{it}}$ was calculated by fixing the value of ΔGDP at its sample mean value. Then, the variability of $\sigma_{u_{it}}$ conditional expectation will depend exclusively on the wave and wind conditions registered for each observation. Once the conditional expectation of $\sigma_{u_{it}}$ was calculated, the conditional expectation of the degree of technical efficiency could be determined using equation (12) (Kumbhakar and Lovell, 2000; Lee and Tyler, 1978):

$$E[\exp(-u_{it})] = 2\left[1 - \Phi\left(\sigma_{u_{it}}\right)\right] \exp\left(\frac{\sigma_{u_{it}}^2}{2}\right) \tag{12}$$

The global and zonal averages of the conditional expected values for the efficiency scores are provided in Table 17. As could be expected, the evolution of the expected efficiency follows a similar pattern to that observed for *Wind7.5,* since it is the weather variable that shows a clearer temporal evolution. It seems that the efficiency of the Spanish ports diminishes along the sample period, especially in Zones 1 and 2 where the variable *Wind7.5* shows a greater increase.

Table 17. Expected efficiency.

Year	All	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
1992	0.906	0.834	0.852	0.914	0.923	0.930
1993	0.911	0.832	0.904	0.912	0.918	0.938
1994	0.906	0.830	0.882	0.912	0.930	0.942
1995	0.907	0.856	0.900	0.895	0.920	0.935
1996	0.902	0.853	0.901	0.859	0.924	0.934
1997	0.910	0.854	0.936	0.881	0.915	0.936
1998	0.914	0.857	0.902	0.922	0.922	0.941
1999	0.922	0.876	0.907	0.926	0.930	0.938
2000	0.905	0.832	0.920	0.916	0.923	0.936
2001	0.910	0.862	0.911	0.905	0.923	0.936
2002	0.907	0.820	0.902	0.909	0.927	0.935
2003	0.904	0.867	0.874	0.901	0.927	0.929
2004	0.913	0.856	0.910	0.927	0.934	0.935
2005	0.911	0.869	0.872	0.922	0.927	0.941
2006	0.883	0.786	0.857	0.901	0.918	0.931
2007	0.879	0.773	0.836	0.920	0.903	0.925
2008	0.863	0.767	0.813	0.894	0.881	0.921
2009	0.874	0.783	0.869	0.876	0.890	0.924
2010	0.868	0.765	0.865	0.850	0.884	0.920
2011	0.872	0.762	0.845	0.899	0.889	0.922
2012	0.880	0.783	0.845	0.897	0.913	0.923
2013	0.851	0.704	0.827	0.864	0.894	0.915
2014	0.859	0.723	0.819	0.863	0.903	0.925
2015	0.868	0.750	0.828	0.885	0.904	0.924
2016	0.866	0.778	0.804	0.859	0.900	0.922

To verify the evolution of the expected efficiency, the equation (13) was estimated in a similar way to equations (11.a) and (11.b):

$$E[\exp(-u_{it})] = \sum_{i=1}^{I} \beta_i D_i + \beta_t t + e_{it} \tag{13}$$

The estimation of equation (13) was made again for the whole sample and for each zone separately. The obtained results are provided in Table 18.

Table 18. Expected efficiency trend.

$E[\exp(-u_{it})]$	**Coef.**	**Std. Err.**	**t-Stat.**	**R^2**
Global trend	-0.0024	0.0002	-11.62	0.798
Zone 1 trend	-0.0056	0.0007	-8.13	0.624
Zone 2 trend	-0.0043	0.0006	-7.49	0.751
Zone 3 trend	-0.0015	0.0005	-3.21	0.527
Zone 4 trend	-0.0015	0.0003	-5.10	0.791
Zone 5 trend	-0.0008	0.0001	-10.06	0.614

As can be seen, on average, the degree of technical efficiency diminishes by 0.24% per year as the weather conditions (wind speed in particular) deteriorate over the sample period. According to Ng et al. (2018), port decision-makers perceive that the impacts of winds, storms and rising sea levels will become more severe in the future. Therefore, weather evolution generates a significant diminution on the efficiency of the Spanish ports. This evolution becomes especially important in Zone 1 (Bilbao, Gijón and Vigo) and in zone 2 (Las Palmas and Santa Cruz de Tenerife). On the other hand, ports in Zone 5 (Tarragona, Barcelona, Castellón, Valencia, Alicante and Cartagena) suffer a significant reduction in their efficiency but to a much lesser extent. The results are in line with Peng et al. (2018), who found that the Mediterranean region is that with better natural conditions for the location of ports.

5.6 Discussion

As Asariotis et al. (2017) pointed out, ports are exposed to the effects of climate change, such as rising sea levels, strong winds and, particularly, changes in the intensity and direction of waves. These phenomena can cause changes both in the patterns of shipping traffic and the navigability of the port access channels, and even increase flooding[50]. Becker et al. (2012) identified two different strategies for addressing these threats: mitigation (which implies articulating initiatives to reduce emissions in order to reduce the strength of the climatic change) and adaptation (which deals with the problem in order to build resilience). They also observed that the former has received much more attention despite being less cost-effective. In fact, the adaptation planning has scarcely been initiated although port managers are aware that strong winds and storms are expected to be reinforced due to climate change[51] (Ng et al., 2018), and they focus on reducing emissions from their facilities by adopting cleaner and greener processes (Becker et al., 2012).

Thus, there is an increasing amount of literature dealing with the specific challenge of reducing emissions, both from shipping[52] and ports[53]

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[50] Asariotis et al. (2017) summarized the major climate variability and change direct impacts on ports by climatic factor. Furthermore, indirect impacts are also expected since climate change effects on trade will likely alter demand for port services.

[51] Some authors, such as Goldenberg et al. (2001) linked this fact to the decreasing atmospheric stability caused by the warmer sea-surface temperature (due to increases within atmospheric CO2 concentration), whereas authors like Dobrynin et al. (2015) concluded that the observed trends could be explained by global warming, but also by the natural variability. In any case, the researchers agree that climate change will intensify their effects at sea.

[52] Sheng et al. (2017) pointed out that maritime shipping has become an important source of carbon emissions, and also of NO_2 and SO_2.

[53] In order to contribute to achieve this objective, the concept of *green port* was proposed in 2009, during the United Nations Climate Change Conference, which refers to those ports "characterized by a healthy ecological environment, reasonable use of resources, low energy consumption and low pollution" (Wan et al., 2018, p. 432). To read more about this topic see, for instance, Chang and Wang (2012), Risitano et al., (2017), Schipper et

(Gonzalez Aregall et al., 2018), but there is very little which deals with the management of green ports and efficiency (Papaefthimiou et al., 2017). Nevertheless, two relevant exceptions have to be highlighted. Firstly, Venturini et al. (2017) deal with the well-known *berth allocation problem* to contribute to reach two major and interrelated objectives derived from the increased containerized trade: a) to achieve a more efficient transport service, and b) to reduce emissions. Secondly, Schipper et al. (2017), proposed a multifunctional approach to assess the performance and sustainability of port management plans in the long term, as they were concerned about the impact of climate change on the activity of ports.

The study carried out here is of interest to the development of adaptation strategies. It shows the relationship between the technical efficiency of ports and two natural factors whose impact is expected to increase due to climate change and, in addition, are beyond the control of port managers. Obviously, good natural conditions are not enough to ensure port competitiveness. However, competitiveness will be hampered when they are worse (Peng et al., 2018), as is the case of the Atlantic ports of the Spanish port system on the basis of the results obtained. Therefore, this circumstance should be considered when planning a country's infrastructure endowment. On the one hand, when planning the infrastructure endowment of ports, it is necessary to understand that the worse the natural conditions concerning wind and waves, the harder to achieve technical efficiency when turnaround time is a key competitive factor. On the other hand, when planning the national transport system as a whole, it is convenient to realise that the reinforcement of the inland corridors linked to the most efficient ports is not necessarily the right option when the observed inefficiency (overcapacity) results from a competitive rational response to natural conditions. In short, the location of ports is relevant concerning the main economic poles, but also because

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al. (2017) or Acciaro et al. (2014), where a list of green strategic objectives for ports is detailed, the adaptation to climate change being one of them.

it imposes natural constraints that, in turn, influence the technical efficiency of their facilities.

5.7 Concluding remarks

Transport, in general, and port activity, in particular, are affected by weather conditions. However, despite the climate change that the planet is undergoing, no study has been found that uses standard productivity analysis techniques to analyse the impact of the weather conditions on port efficiency.

The empirical analysis carried out in this study shows that some weather variables (wave height and wind speed) influence port productivity in a statistically significant way. The simulation exercise shows that the global average of the simulated technical efficiency varies around 7% during the sample period (from 92.2% in 1999 to 85.1% in 2013) due exclusively to weather variability, illustrating the magnitude of the impact that weather conditions could induce in the technical efficiency of ports. Therefore, the magnitude of the assessed impact of weather conditions on port productivity becomes particularly important as weather conditions are expected to experience important changes due to climate change.

Accordingly, our results highlight the importance of improving the forecasts for climatic variability. On the one hand, this information would help to anticipate an adequate response to mitigate climatic influence on the technical efficiency of each port when necessary. On the other hand, forecasts about the expected weather evolution in each location would be valuable information in order to improve the efficiency of the whole system when planning its long-term development.

Finally, other weather variables influencing visibility such as fog and rain can also be expected to affect vessels manoeuvrability and crane operations. Therefore, more research is needed to achieve a better understanding of the influence of weather on maritime transport and its possible impact on traffic location in a period in which the climate is changing.

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Final remarks

Port activity depends on many factors, some of which are beyond the control of port authorities. This thesis contributes to the literature by going deeper into the analysis of one of these factors. Specifically, it focuses on the relevance of the location of port facilities in their activity.

Although location is an unchanging attribute of a port, it is convenient to understand the associated constraints. After all, delving deeper into the comprehension of weaknesses helps port authorities to articulate their strategies and, additionally, reinforcing the knowledge on the way they develop will assist policymakers in the design of a more efficient transport strategy.

The proposed methodology to delimit the scope of the hinterland of ports has proved to be suitable and, at the same time, easily applicable when data are available. From the results obtained, it is worth noting that port accessibility is more relevant than port size in the configuration of hinterlands.

Furthermore, it was confirmed that the location of ports regarding the flow's destination influences port choice. This follows from the observed fact that the impact of the explanatory variables considered, travel time and container throughput, varies according to the final destination of the shipments. Therefore, to the extent that the pattern of national foreign trade evolves along a more or less predictable path, the provision of infrastructure must be made according to the expected evolution of the inland corridors of freight.

The discussion is further amplified since it is confirmed that the inter-port distribution of maritime traffic is shaped by spatial interaction effects. Then, the economic size of the regions, the province-port travel time and the port size are important variables in generating flows of a region, but they are also crucial for the generation and pattern of flows in the neighbouring areas.

Once verified the relevance of the location in the port activity from the inland side, the focus shifted to the coastal side. It was proved that weather conditions (wind speed and wave height, in particular) strongly condition port efficiency. Hence, weather evolution must also be taken into account when planning the transportation system. The location of ports considered from the maritime side can also influence the connectivity of their facilities depending on which maritime routes they are included in. However, this aspect was not considered here because priority was given to the analysis of more static circumstances, such as the availability of inland infrastructure connecting with economic centres and the natural constraints.

All the findings highlight that location matters for port activity. The main conclusions of this research are: i) the accessibility of ports influences their activity; ii) their location concerning the geographical pattern of international trade conditions their attractiveness; iii) network effects are present in the inland distribution of maritime flows, and iv) the weather conditions they face impact their technical efficiency.

From the analysis, some relevant questions arise. For instance, do the most dynamic corridors generate spillovers for the rest of the territory? How should the inland infrastructure planning be dealt with when traffic generation is geographically concentrated, as it is in the Spanish case? Should the infrastructure be reinforced in less dynamic regions in order to boost their competitiveness, or would this result in an inefficient allocation of resources? Should port authorities consciously plan a technically inefficient project solely due to an expected climate change?

These questions lead to a widely debated topic in infrastructure planning, which is the balance between efficiency and territorial cohesion. This trade-off is nowadays of interest because of the recent inclusion of the Spanish North-northwest axis in the Atlantic Corridor, within the project of the Trans-European Transport Network (TEN-T). The specific impact of the enlargement of the Atlantic corridor is beyond the scope of this research, but the analysis conducted here can be useful in this sense. It puts the focus on the link between port location and the inland distribution of maritime traffic and, therefore, it takes a step towards a better understanding of the dynamics underlying the flows of freight.

Conclusiones en español

La actividad portuaria está influenciada por muchos factores, algunos de los cuales no están bajo el control de las autoridades portuarias. En esta tesis se trata de profundizar en el análisis de uno de esos factores. En particular, se trata de estudiar la relevancia de la localización del puerto en su actividad. Aunque la localización es una característica invariable de los puertos, es importante tener en cuenta sus consecuencias ya que esto facilita el diseño de estrategias por parte de las autoridades portuarias y, por otro lado, contribuye a una planificación más eficiente del sistema de transporte. Se ha comprobado que la metodología utilizada para delimitar el área de influencia de un puerto es adecuada y de sencilla aplicación cuando los datos necesarios se encuentran disponibles. En este sentido, se ha verificado que la accesibilidad al puerto es más relevante que su tamaño para establecer su área de influencia.

Se ha confirmado también que la localización de un puerto en relación con el destino final de los flujos de tráfico influye en la elección del puerto. Esto se desprende del hecho de que el impacto de las variables explicativas consideradas, el tiempo de viaje y el volumen de tráfico de contenedores, varía atendiendo al destino final del cargamento. Consecuentemente, dado que el patrón de comercio exterior de un país evoluciona siguiendo una trayectoria más o menos predecible, sería deseable vincular la provisión de infraestructuras a la evolución geográfica esperada de los flujos interiores de mercancía.

Se ha comprobado, asimismo, que la distribución del tráfico de mercancías entre los distintos puertos viene condicionada también por ciertos efectos de interacción espacial. Así, el desarrollo económico de una región, el tiempo de transporte hasta el puerto y el tamaño de éste son variables importantes para la generación de tráfico comercial tanto para la región en la que se encuentra el puerto como para su entorno.

Confirmada la relevancia de la ubicación en la actividad portuaria, la perspectiva del análisis se gira hacia la costa. En concreto, se ha mostrado que las variables meteorológicas (la velocidad del viento y la altura de las olas, en particular) condicionan fuertemente la productividad portuaria. Consecuentemente, la evolución esperada del clima también es un factor a tener en cuenta en el diseño del sistema de transporte. La ubicación de los puertos considerada desde el lado marítimo también puede influir en la conectividad de sus instalaciones, dependiendo de las rutas marítimas en las que se incluyan. Sin embargo, este aspecto no fue analizado aquí porque se priorizó el estudio de factores más estáticos, como la disponibilidad de infraestructura terrestre que conecte al puerto con los centros económicos y los condicionantes naturales.

En conjunto, los resultados derivados del análisis realizado confirman la importancia de la localización en la actividad portuaria. En particular, las conclusiones principales podrían resumirse en: i) la accesibilidad de los puertos condiciona la demanda de sus servicios; ii) su localización en relación a los patrones del comercio internacional influye en el atractivo de los puertos; iii) los efectos red están presentes en la distribución interior de los flujos marítimos; y iv) las condiciones meteorológicas de la zona en que se encuentra el puerto se revelan como un importante condicionante de su eficiencia técnica.

El análisis realizado sugiere otro tipo de cuestiones a abordar en futuros estudios. Por ejemplo, ¿los corredores de tráfico de mercancías más dinámicos generan efectos externos positivos para el resto de regiones? ¿Cómo afrontar la planificación de la estructura cuando la generación de flujos está espacialmente muy concentrada, como se produce en el caso español? ¿Debe diseñarse el mapa de infraestructuras de modo que se dé mayor protagonismo a las regiones menos dinámicas para así reforzar su competitividad, o esto conllevaría una asignación ineficiente de los recursos? ¿Debería abordarse conscientemente proyectos de infraestructura ineficientes desde el punto de vista técnico para atender la evolución prevista de la meteorología?

Este tipo de cuestiones enlazan con una cuestión muy debatida en la planificación del sistema de infraestructuras de transporte, y que tiene que ver con el equilibrio en eficiencia y cohesión territorial. La resolución del necesario equilibrio es de especial interés actualmente dada la reciente inclusión del corredor español del Nor-oeste en la Red Trans-europea de Transporte (TEN-T). El análisis del impacto específico de esta ampliación del corredor Atlántico está fuera del alcance de esta investigación, pero el trabajo realizado aquí puede ser útil en este sentido ya que se centra en el análisis del vínculo entre la ubicación del puerto y la distribución interior del tráfico marítimo y, por lo tanto, da un paso hacia una mejor comprensión de la dinámica que subyace en el movimiento de la mercancía.

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