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Spillover Effects From Inland Waterway Transport Development: Spatial Assessment of the Rhine-Alpine Corridor

Abstract

Inland waterways are crucial in enhancing port-hinterland connectivity and fostering sustainable freight transport. Their development as transport corridors is geographically dependent, yet spatial spillovers are often overlooked. In Europe, the configuration of inland container terminals can lead to cross-border spillovers. This paper analyzes inland container throughput between 2007 and 2021 in the Rhine-Alpine Corridor to quantify its spatial dependence and economic spillover effects. The assessment involves 43 regions from Belgium, France, Germany, Netherlands, Luxemburg, and Switzerland. A Spatial Durbin Model is developed accounting for economic conditions, fixed effects, and time trends. The results suggest that throughput exhibited spatial concentration patterns, which intensified after water levels dropped in 2018. Secondly, we identified heterogeneous spatial dependence between transport performance in tonne-km vs. TEU-km. Thirdly, changes in technological resources and population density were associated with a positive impact on throughput, while employment and motorways with adverse effects. Fourthly, the spillovers of technological resources and employment are considerably higher than the local impact. The paper advises on spatially oriented policies to address low water levels, employment decline, and the need for new business models in the sector.

Keywords: Inland waterway transport; Spatial regression; Regional development; Spillover effects; Europe.

1. Introduction

A corridor of inland waterway transport (IWT) refers to a network of navigable rivers, canals, locks, and other waterways used for transporting goods and passengers between ports. It can facilitate transport connectivity between regional markets and support hinterland access to seaports with higher economies of scale than other transportation modes (Konings et al., 2013; Shobayo & van Hassel, 2019). With barges able to transport 200 times more cargo per unit of distance than trucks on average, developing IWT corridors contributes to mitigating freight transport negative externalities that have increased in recent years, such as traffic congestion, noise, air pollutants, and accidents (INE, 2016).

Precisely, the external costs of IWT in cents per tonne-km transported (TKM) are estimated to be around three and seven times lower than rail and road transport, respectively. Regarding energy efficiency, with the same energy consumption, an inland vessel can transport one tonne of cargo almost four times further than a truck (ECA, 2015). However, competitive IWT requires reliable navigability conditions and resiliency upon unexpected events, as it is highly dependent on geography and less flexible for rerouting (Sys et al., 2020). A comprehensive understating of IWT development is relevant to foster sustainable transport, especially concerning container IWT as the segment with higher potential and spare capacity for market uptake (European Commission, 2017).

Almost all inland containerized cargo in Europe goes through the Rhine-Alpine Corridor (RALP), connecting Belgium, France, Germany, Netherlands, and Switzerland. The corridor links over 40 terminals to the major ports of Amsterdam, Antwerp, and Rotterdam, transporting more than 500 million tons annually

(Eurostat, 2022). Moreover, the RALP is connected to other major inland waterways, such as the Danube Canal, providing access to Eastern Europe. In 2020, the RALP remained part of the EU's Trans-European Transport Network (TEN-T) as one of nine priority transportation routes, aiming to develop and integrate the European transportation network by 2030 towards a sustainable transition. Several improvement projects were undertaken to upgrade the water transport infrastructure in the RALP. These included the expansion of locks and the deepening of river canals to accommodate larger vessels, the construction of new terminals and intermodal facilities, and the implementation of digital technologies to improve the efficiency of logistics operations (European Commission, 2014).

Despite the potential for mitigating freight transport's negative externalities and fostering regional integration, the bulk of literature on IWT development has mainly been oriented by the Outside-In model. This model conceives IWT development from sea-driven strategies influencing operations, determined by actors such as port authorities and terminal operators (Wilmsmeier et al., 2011). Most of the studies under this model focused on operational processes to enhance terminals' competitiveness (Witte et al., 2020). Meanwhile, the Inside-Out model suggests that developing IWT corridors is also determined by land-driven strategies involving regional influencing conditions, such as the availability of labor force and transport infrastructure (Witte et al., 2019).

There are limited studies of spatially oriented development strategies from the Inside-Out model in Europe. Available research focuses on intensely used corridors within a single country, such as the Yangtze River in China. In contrast, within Europe IWT has been the principal transport mode for cross-border freight traffic between countries connected by the RALP, with 50% of the modal share (European Commission, 2017). The geographical regional setting and nature of inland flows are expected to be associated with spatial dependence of IWT, i.e., the amount of cargo loaded and unloaded in one port may be influenced by the activity of neighboring ports. According to competition patterns, this spatial dependence can be positive or negative (Merkel, 2017). Previous literature reviewed the existence of spatial dependence in the RALP inland network, concluding that it evolves due to nautical, economic, and institutional conditions. These changes over time can be referred to as the spatial dynamics of inland cargo (Notteboom et al., 2020).

However, various knowledge gaps remain regarding the spatial dynamics of container IWT development, partially because there is limited quantitative research from diverse geographical contexts and mixed evidence from recent studies. Looking at the last two decades, Wu & Lee (2022) and Shi et al. (2023) studied the spatial dynamics of inland cargo flows in the Yangtze River with an econometric approach. While Wu & Lee (2022) found a positive spatial dependence for the Yangtze River, considering total ports' throughput in tonnes, Shi et al. (2023) reported the opposite pattern regarding the number of TEUs. To the authors' knowledge, no other studies have quantified the spatial dependence of IWT in a cross-border setting. Further evidence from Europe can provide insight into a broader understanding of the spatial dynamics influencing container IWT development.

The existence of spatial dependence on container IWT may also lead to spatial spillover effects, i.e., the economic conditions influencing the throughput of one port would influence the throughput of neighboring ports. There is a limited understanding of regional economic spillovers influencing IWT development in Europe. Moreover, among the recent quantitative analyses of spatial spillover effects related to IWT, the role of technological resources is not accounted for, although existing studies highlight the relevance of this factor by following descriptive and explanatory approaches (Barros et al., 2022; Notteboom et al., 2020). In light of these considerations, the research question of this study is: What characterizes the spatial dependence and spillover effects of container IWT in the RALP?

Once the spatial dependence of container IWT transport in the RALP is measured and characterized, the study explores how such spatial dependence facilitates spillover effects of local economic conditions on ports from neighboring regions. It builds on previous literature to develop a Spatial Durbin Model (SDM) that allows accounting for the spatial dependence of container throughput and economic influencing conditions, including technological resources, infrastructure, employment, and population density while controlling for fixed effects and time trends. Quantifying the spillover effects of economic conditions would allow the elaboration of more comprehensive assessments of IWT development and regional integration (Wu & Lee, 2022).

There are three main contributions to the literature. First, the study quantifies and characterizes the spatial dependence of container IWT in a cross-border setting by comprehending the entire RALP, expanding the understanding of transport spatial dynamics from the European context. Second, it compares the spatial dependence of tonne-km and TEU-km between 2007 and 2021, providing consensus from recent mixed literature on the Yangtze River. Third, it assesses the role of technological resources with an econometric approach and disaggregates the spillover effects at the regional level.

The policy implications are discussed around the critical challenges of IWT in Europe, following the framework proposed by van Hassel (2023). First, the impact of climate change. The consequences of low water levels in 2018 confirmed the need for solutions to increase transport flows' resiliency to prevent permanent modal shifts when facing highly probable similar disruptions in the future. Accounting for spatial dynamics of container transport performance along the RALP, the study offers insights for policy action during potential episodes of low water levels. Second, socioeconomic trends are leading to a decline in the IWT workforce. The study discusses the role of employment and technological resources during the last decade, focusing on the implications for cross-border spatial agglomerations. Finally, new business models are required to attract stakeholders willing to cover the costs of the innovational developments. Specifically, the study points to the demographical trends that would enhance the attractiveness of IWT and can be leveraged to achieve a more sustainable transition of freight transport.

The rest of the paper is organized as follows: Section 2 briefly reviews available studies concerning the spatial dependence of IWT, spillover effects, and regional development. Section 3 provides an overview of the RALP and the study's contextual framework. Section 4 describes the data and method to quantify the spatial dependence spatial and spillover effects in the RALP. Section 4 presents the results and robustness checks. Section 5 discusses the policy implications of the results, and Section 6 concludes this manuscript.

2. Literature review

Since the 2000s, early studies concerning IWT development analyzed organizational changes in the European inland industry and its spatial dynamics. The network configuration of barge terminals was discussed by evaluating the availability and navigability of inland waterways, the cargo dispersion patterns, and distances between seaports and economic centers (Notteboom & Konings, 2004). Subsequent research framed the concept of port regionalization, linking the development of deep-sea ports to their interactions with inland ports (Notteboom & Rodrigue, 2007). Studies on port regionalization discussed the interrelated dynamics between ports from a transportation network perspective (Notteboom, 2017). Consequently, IWT development was assessed by measuring the performance features of inland ports as part of a network, focusing primarily on the operational and planning perspectives (Monios & Wilmsmeier, 2012).

Two conceptual models were developed to classify studies concerning IWT development: the Outside-In and the Inside-Out models (Wilmsmeier et al., 2011). The studies related to the former model continue researching the operational development of inland terminals and their impact in the hinterland, discussing the optimal role of port authorities and terminal operators (Wilmsmeier et al., 2015). In contrast, studies with the Inside-Out approach treated inland ports as interrelated actors influencing and influenced by regional development (Veenstra et al., 2012; Witte et al., 2019). There is a growing number of empirical studies concerning the Inside-Out perspective. In Europe, Wiegmans et al. (2015) collected data at the municipal level in the Netherlands and used a statistical model to assess the determinants of inland port growth. The authors highlighted the relevance of a container terminal, freight diversity, and regional road network accessibility for inland waterway port development. Witte et al. (2016) discussed the role of inland municipal port governance by comparing four countries along the RALP. They concluded that increasing capacity is required to prevent upcoming negative externalities in cities along the corridor.

From a qualitative perspective, Raimbault (2019) conducted semi-structured interviews to analyze the relationship between the port governance of inland logistics infrastructure and urban development in Paris. The study documented the fragmented policies of logistics zones and the role of spatial planning in enhancing port regionalization. Additionally, Lu et al. (2023) explored the causes of IWT development in China between 1978 and 2018, concluding that institutional reforms, infrastructure development, fleet standardization, financial diversification, and the development of human resources were among the main factors of growth. The authors stressed that since 1983, China had identified the infrastructure and educational requirements to drive IWT development in the following decades. They also noted the role of technological applications and innovations developed in the last 40 years, such as the progress in developing autonomous and new fuel-powered inland vessels.

With a quantitative approach to the Inside-Out perspective, the spatial dynamics of inland ports are still under research as it involves a multiplicity of direct and indirect effects on neighboring localities (Witte et al., 2017). However, the Yangtze River has been the primary inland corridor of study. Qi et al. (2020) estimated spatial regressions with data between 2003 and 2017 in China to assess the role of logistics infrastructure in regional economic growth. An SDM model is developed to account for the spatial dynamics in dependent and independent variables. Although positive spillover effects were reported at the national level, the authors found mixed spillover effects at the regional level. Specifically, the study concluded that water infrastructure constrained the economic growth of central provinces due to a lack of north-south connectivity compared to road and rail infrastructure. With a similar econometric approach, Wu et al. (2022) assessed the impact of inland port throughput, measured as total tonnes transported, on regional economic growth between 2000 and 2018. The results indicated a positive impact on local and neighboring cities, with a more significant effect on the latter.

At the port level, other studies looked at the competitive dynamics of IWT in the Yangtze River associated with its spatial dependence. Wu & Lee (2022) implemented a SDM with yearly data from 22 inland ports in the Yangtze River in the same timeframe (2000-2018). They concluded that complementarity mainly characterizes the spatial relationship of ports along the corridor, especially after the Three Gorges Dam construction in 2006. However, opposite evidence was found by Shi et al. (2023), who developed a similar econometric approach looking at container inland throughput between 2001 and 2021. The authors indicated that competition between close and distant ports in the corridor has increased, intrinsically linked to a negative spatial dependence. They also noted that the dominant inland container port imposes a restraining effect on surrounding ports, and competition is more intense in underdeveloped areas. This analysis differs from the one of Wu & Lee (2022) as they took the number of TEUs as the dependent variable instead of the total tonnes transported.

Literature assessing the existence of spatial dynamics in European inland corridors from a quantitative approach is still limited. The exception is the study conducted by Witte et al. (2017), who estimated the competitive landscape of inland ports in the Netherlands at the municipal level with data from 2006. The authors developed spatial econometric models and concluded that the Dutch inland port network is characterized by competition as an indication of overproximity. This result led the authors to discuss the need for a better integrated and coordinated governance approach for IWT development. Nevertheless, minimal current research on spatial spillover effects comprehends the entire RALP, which involves regions of multiple countries and is less sensitive to the overproximity concerns highlighted by Witte et al. (2017).

Notteboom et al. (2020) widely compared the containerized shipping network between the Yangtze River and the RALP. Regarding spatial dynamics, the authors concluded that both corridors show a high degree of temporal dependency on IWT development at the regional scale. The path dependence concept explains how recent decisions of inland terminals are restricted by a sequence of events in the past. They suggested that a similar trend is likely to be observed in subsequent years, consolidating the spatial structure of the inland network. Furthermore, they concluded that differences in outcome trajectories are subject to contextual characteristics, including macroeconomic settings and the involvement of public and private actors.

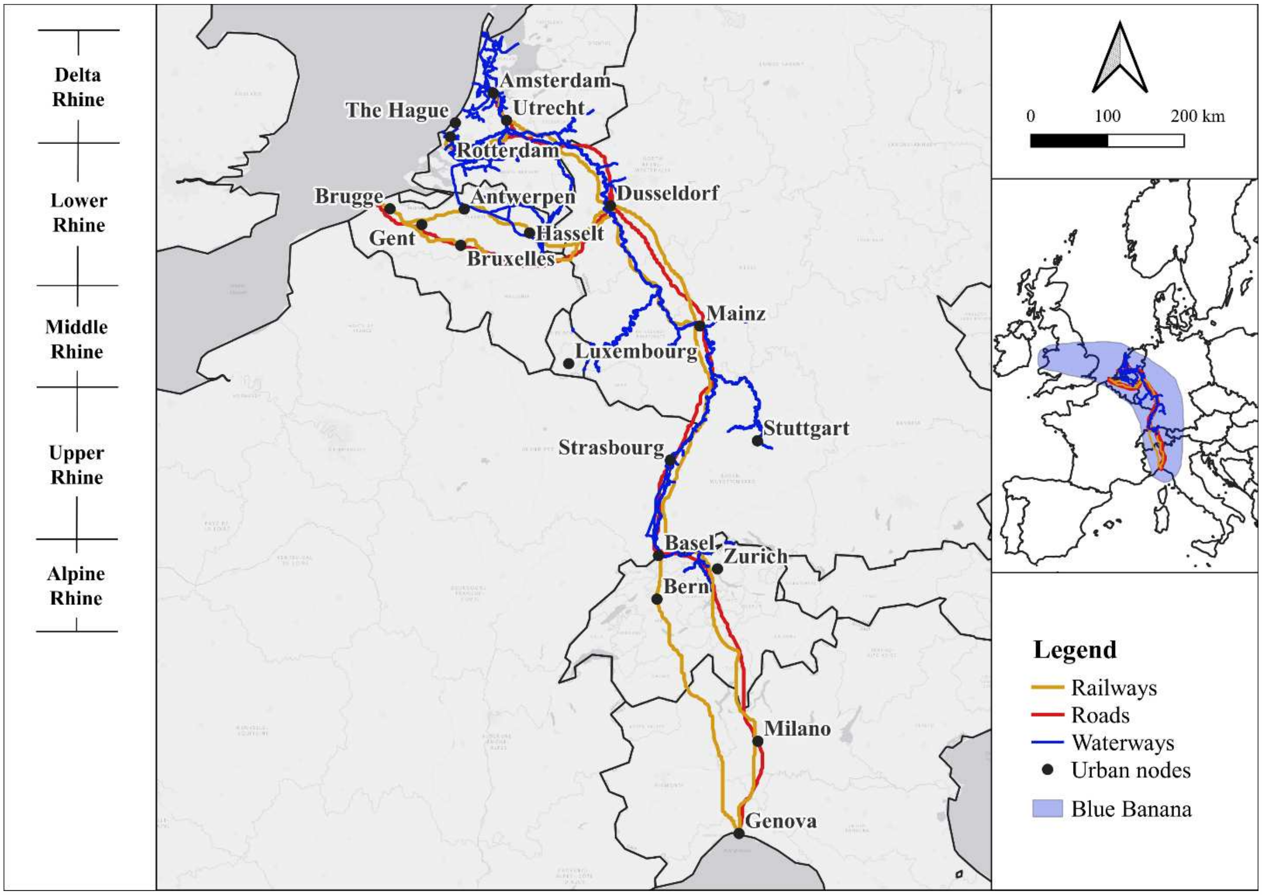
3. Contextual framework

The RALP is one of the key freight routes in Europe, connecting the seaports of Belgium and Netherlands with the port of Genoa in Italy. It involves the denominated “Blue Banana” area, with around 100 million inhabitants in the most relevant economic centers, including Brussels and Antwerp in Belgium, the Randstad region in the Netherlands, the Rhine-Ruhr and Rhine-Neckar regions in Germany, Basel and Zurich in Switzerland, and Milano and Genoa in Northern Italy. The navigable inland waterways include the Mosel and Neckar rivers connecting Germany with Luxembourg. France is also linked primarily by the Alsace region. Although freight transport by waterways finishes in Basel, connectivity with Italy is achieved by road and rail transport (**Figure 1**).

Nonetheless, IWT is the dominant transport mode in the RALP, with 50% of the share, followed by road (34%) and rail (16%) (European Commission, 2020). By 2020, the corridor transported 138 billion TKM annually by waterways. Even though IWT is one of the most environmentally friendly modes, a large proportion of European cargo transported by waterways are mining products, crude petroleum, and natural gas. Nonetheless, containerized throughput has been the most used indicator to measure port competitiveness (Bu & Nachtmann, 2021) and concerns the cargo type with the highest potential for market uptake (European Commission, 2017).

In this segment, international transport of containers dominated national and transit transport, with over half of the container transport performance in TEUs-km (TUEKM) between 2011 to 2021 (Eurostat, 2023b). Disaggregating by country, the Netherlands, Germany, France, and Belgium contribute almost the total number of loaded TEUKM in Europe. International transport is predominant in Germany and the Netherlands, with 76 and 40.8%, respectively, while national transport was considerably higher in France and Belgium, with 94.1% and 61.9%. The proportion of transit transport was also high in the Netherlands and Germany (18.0 and 20.4%), while less than 1% in the latter two countries (Eurostat, 2023b).

Figure 1. The Rhine-Alpine Corridor

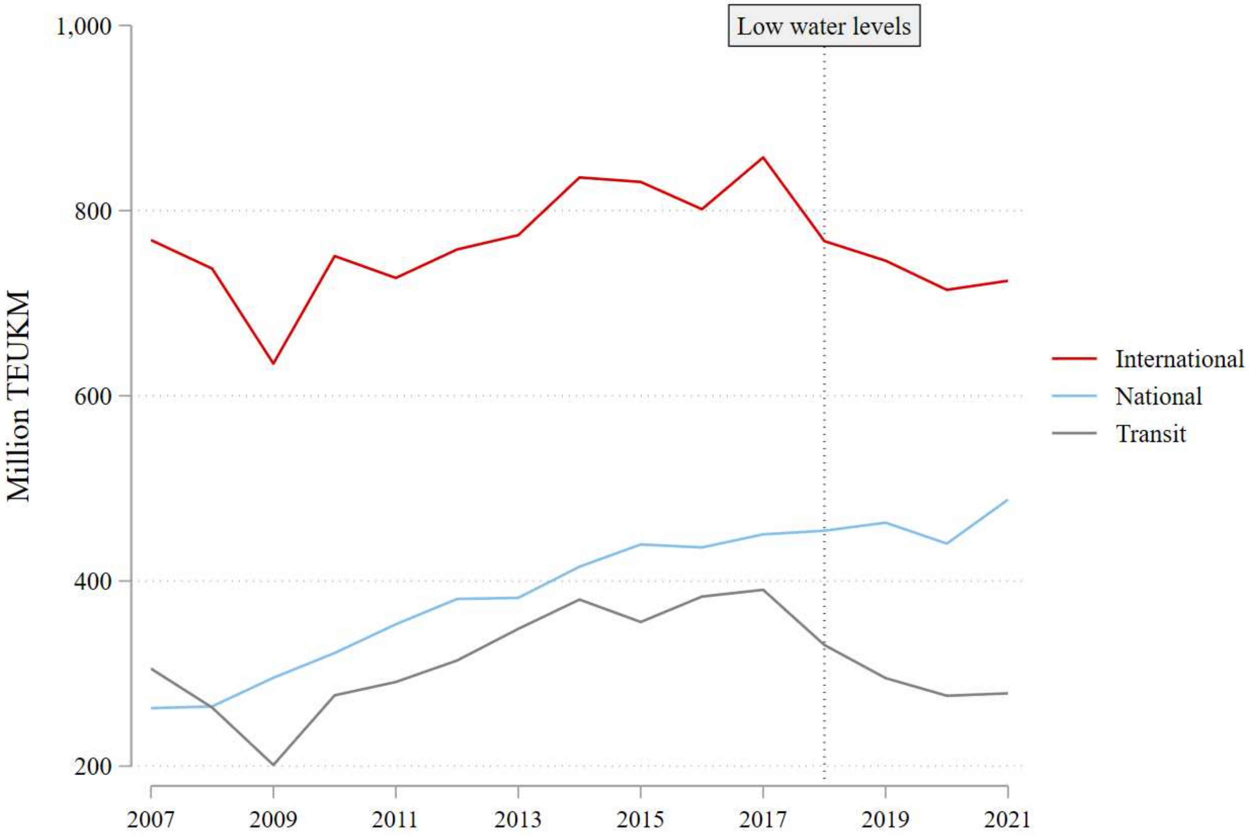


Source: Own elaboration based on European Commission (2017).

The geographical setting of container IWT in the RALP makes plausible the existence of regional spatial dependence. This study hypothesizes that such spatial dependence would be cross-border between ports along the RALP, depending on its role in the container inland corridor. For instance, the spatial cargo patterns between ports in the Netherlands and Germany can behave differently than those on the German-French border. Moreover, it can evolve according to socioeconomic and navigability conditions. The existence of such spatial dynamics would consequently lead to spillover effects from ports of one country to another.

As a study case, we look closer at the break in the time series observed in 2018 due to critically low water levels severely affecting containers' loading factors. It was one most critical disruptions of IWT in decades, causing a decrease in international TEUKM transported of 10.1% compared to 2017, which continued in 2019 (-2.2%), and 2020 (-3.8%). The decrease was also observed in transit and national transport but considerably less in the latter. Longer and more critical droughts are probable to occur due to climate-changing patterns (CCNR, 2023), thus becoming a central topic of policy discussion. The following section describes the data and the methodological approach developed to characterize the spatial dependence and spillover effects of container IWT transport performance in the RALP during the last 15 years.

Figure 2. Container IWT by type of transport, EU, 2007-2021



Source: Adaptation from Eurostat (2023a).
Note: Data for Italy is not available.

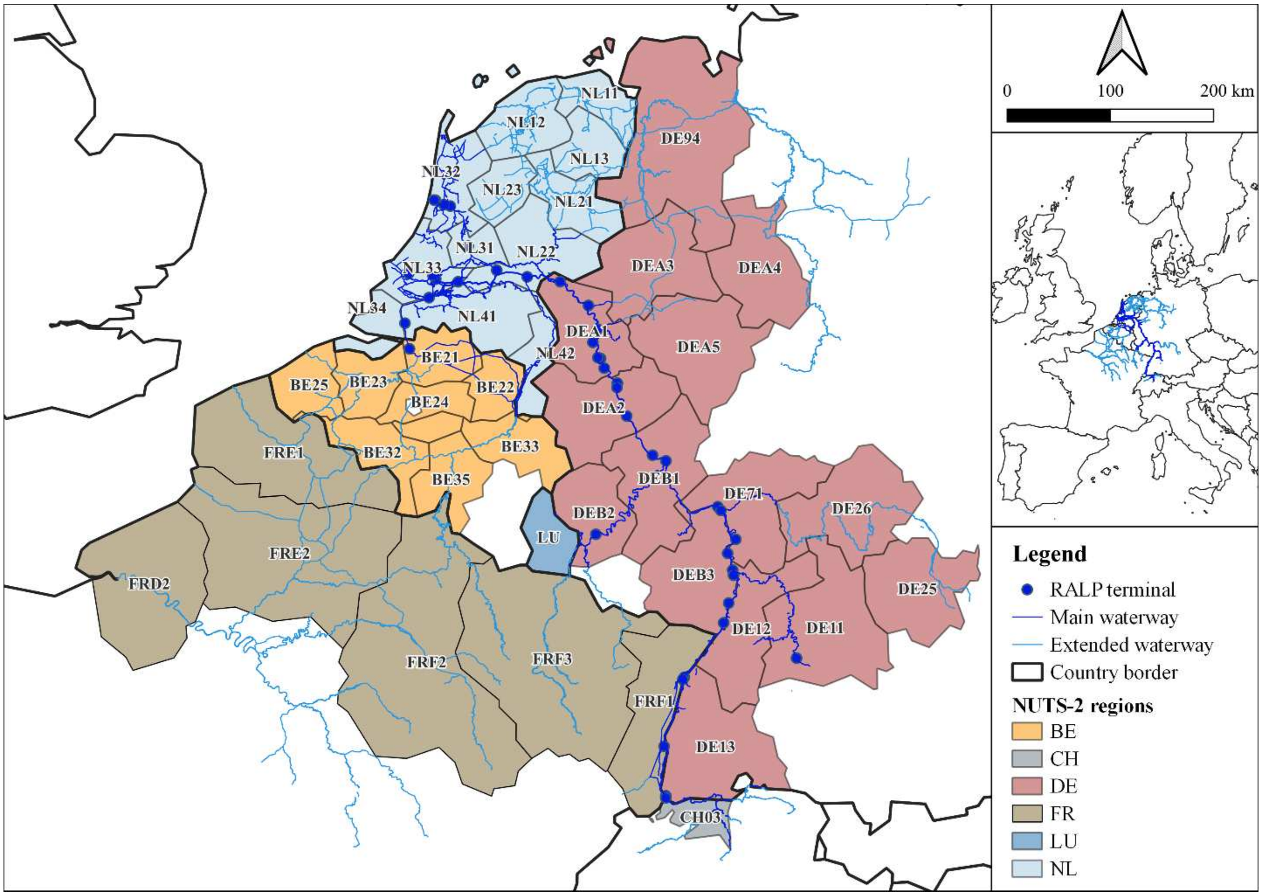
4. Data and Methods

We collected regional container throughput annually between 2007 and 2021 from Eurostat. Throughput is measured as the total TKM and TEUKM transported between all Origin-Destination pair of terminals along the corridor. Regional data is collected at the NUTS 2 level. This geographical disaggregation allows accounting for within and between country variability in economic and social outcomes (European Commission, 2022). We leverage it to conduct the econometric analysis while controlling for time-invariant regional attributes such as the area of the region, the length of the border between countries, and the topological characteristics of the waterways.

The dataset involves 43 regions from Belgium, France, Germany, Luxemburg, Netherlands, and Switzerland, which are connected to the RALP port network and report any handling of containerized freight in the timeframe under study. **Figure 3** illustrates the regions in the study and their main waterways. The terminals along the RALP identify the main inland corridor from Antwerp (Belgium), Rotterdam and Amsterdam (Netherlands) in the North Sea, reaching Duisburg, Manheim, Weil am Rhein (Germany), and Basel (Switzerland). The rest of the regions also contain inland terminals and report container handling, which is influenced by the leading network of terminals.

The regions in the study are listed in **Table 1**, reporting their yearly average TKM and TEUKM. The highest throughput was handled in Ziud Holland (NL33), Rheinhessen Pfalz (DEB3), Nordwestschweiz (CH03), Düsseldorf (DEA1), and Prov. Antwerp (BE21). The main limitation of the study is that not all connected regions reported the value of containerized throughput during the 15 years. For instance, regions in France started to record their container IWT in 2017. The last column of **Table 1** indicates the 29 regions with a strongly balanced panel dataset, i.e., complete reports, between 2007 and 2021. Nonetheless, unavailable values do not compromise the analysis because inland terminals in the strongly balanced dataset capture 99% of the container IWT in the RALP.

Figure 3. Regions in the study



Source: Own elaboration with data from Novimove.

Note: Brussels-Capital (BE10), Prov. Luxemburg (BE34), and Saarland (DEC0), were excluded because of data availability.

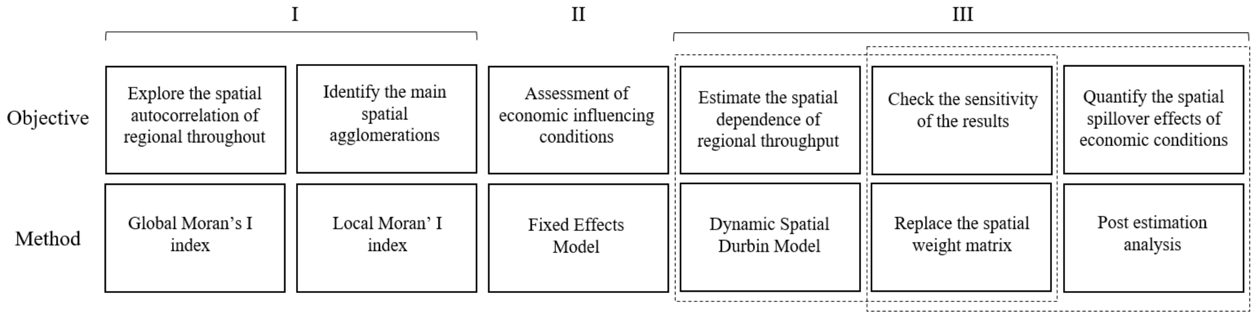
Table 1. List of regions in the study

Region	NUTS2	TKM*	TEUKM*	Records
Prov. Antwerp	BE21	621.4	49.9	15/15
Prov. Limburg (BE)	BE22	72.0	4.9	15/15
Prov. Oost Vlaanderen	BE23	8.9	1.6	15/15
Prov. Vlaams Brabant	BE24	28.5	1.9	15/15
Prov. West Vlaanderen	BE25	65.1	6.5	15/15
Prov. Hainaut	BE32	29.1	2.7	14/15
Prov. Liège	BE33	153.0	8.2	15/15
Prov. Namur	BE35	2.0	0.1	3/15
Nordwestschweiz	CH03	1025.9	106.1	15/15
Stuttgart	DE11	78.0	9.5	15/15
Karlsruhe	DE12	601.0	58.0	15/15
Freiburg	DE13	278.1	29.3	15/15
Mittelfranken	DE25	0.0	0.1	2/15
Unterfranken	DE26	12.0	1.2	15/15
Darmstadt	DE71	322.1	40.3	15/15
Weser Ems	DE94	22.3	1.9	15/15
Düsseldorf	DEA1	706.7	75.1	15/15
Köln	DEA2	282.9	30.5	15/15
Münster	DEA3	0.8	0.1	5/15
Detmold	DEA4	0.7	0.1	6/15
Arnsberg	DEA5	6.1	0.8	9/15
Koblenz	DEB1	246.1	21.0	15/15
Trier	DEB2	26.9	3.1	15/15
Rheinhessen Pfalz	DEB3	1644.9	205.3	15/15
Haute Normandie	FRD2	15.6	1.3	5/15
Nord Pas de Calais	FRE1	12.0	1.7	5/15
Picardie	FRE2	1.6	0.2	5/15
Alsace	FRF1	35.6	3.4	5/15
Champagne Ardenne	FRF2	14.0	1.0	5/15
Lorraine	FRF3	0.8	0.1	4/15
Luxembourg	LU	0.5	0.2	6/15
Groningen	NL11	300.7	32.8	15/15
Friesland (NL)	NL12	127.7	12.3	15/15
Drenthe	NL13	124.9	14.8	15/15
Overijssel	NL21	284.9	32.3	15/15
Gelderland	NL22	156.5	18.3	15/15
Flevoland	NL23	11.0	1.1	12/15
Utrecht	NL31	66.3	7.6	15/15
Noord Holland	NL32	442.9	42.5	15/15
Zuid Holland	NL33	3740.3	421.3	15/15
Zeeland	NL34	137.6	12.5	15/15
Noord Brabant	NL41	378.8	47.0	15/15
Limburg (NL)	NL42	420.9	51.9	15/15

Note: * Yearly average in millions (2007 – 2021).

To characterize the spatial dependence of container IWT and spillover effects of economic influencing conditions in the RALP, we build on the analysis framework offered by Shi et al. (2023). It consists of three parts illustrated in **Figure 4**: I) We explore the spatial autocorrelation of container IWT and the main spatial agglomerations at the regional level. II) An econometric approach is developed to assess the influence of regional economic conditions. III) The model is enhanced to quantify the spatial dependence and disaggregate the total effect of economic conditions between direct and spillover effects. In the last module, we test the sensitivity of each spatial regression to different spatial weights matrices, as illustrated with dashed boxes in **Figure 4**. The following subsections expand each module of the analysis framework.

Figure 4. Analysis framework



Source: Adaptation from Shi et al. (2023).

3.1. Spatial dependence

The global Moran's I statistic is calculated annually to explore the spatial configuration in the study area based on weight matrices representing spatial interactions between regions connected to the RALP. Spatial weights are measured either with a continuity indication where regions share a physical border or based on a distance indication of neighborship. We use a row normalization for the contiguity weight matrix to avoid overestimating spatial dependence (Elhorst, 2013). The inverse distance weighting is calculated using the reciprocal distance to each region's centroid before normalization. As the regional estimates depend on the basic geographical dimensions (MAUP), it is necessary to consider a relativized measure as the case of throughput per kilometer of inland waterways transported, i.e., TKM and TEUKM. Furthermore, we use a monotonous transformation to smooth outliers and avoid undefined values by adding one and applying the natural logarithm (Duschl et al., 2014). The formulation is indicated in Equation (1):

$$I = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}(x_i - \bar{x})(x_j - \bar{x})}{\sum_{i=1}^{n}(x_i - \bar{x})^2} \frac{n}{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}} \tag{1}$$

Where x takes the form of $\ln(TKM + 1)$ or $\ln(TEUKM + 1)$. n refers to the number of regions indexed with i and j, and W_{ij} is the matrix of spatial weights with zeros in the diagonal. The value of Moran's I is generally between -1 and 1, with positive values indicating that regions reporting high or low levels of throughput are overall bordered by others of the same type, i.e., positive spatial dependence. In contrast, a negative value indicates regions are neighbored by others of the opposite kind. In line with Kelejian & Prucha (2001), the statistical significance of the index is tested following that $I \backsim N(0,1)$ and $I^2 \backsim \chi^2(1)$.

The Global Moran's I examines the spatial dependence on the entire area in the study. In addition, we calculate the Local Moran's I to study the spatial dynamics around a specific region i and identify the spatial agglomerations. The formulation is represented by Equation (2). By estimating the Local Moran's I, we classify the regions into four categories. First, the group with a positive spatial autocorrelation includes those regions handling high or low levels of containerized throughput with regional neighbors of the same kind. Conversely, the group with a negative spatial autocorrelation includes regions neighboring others of the opposite type according to its level of container throughput. A cluster map analysis (LISA) was conducted for 2007 and 2021 to identify the spatial agglomerations and their evolution over time. To account for the entire study area are a neighborhood, the Local Moran's I is calculated using the inverse distance weight matrix.

$$I_i = \frac{n\,(x_i - \bar{x})\,\sum_{j=1}^{n} W_{ij}\left(x_j - \bar{x}\right)}{\sum_{i=1}^{n}(x_i - \bar{x})^2} \tag{2}$$

3.2 Assessment of economic influencing conditions

Once the spatial configuration is explored and characterized, we conduct an econometric approach to assess the influence of economic conditions on container IWT before quantifying its spatial spillover effects. Only the strongly balanced panel must be considered, with the regions reporting consistent throughput levels between 2007 and 2021. These regions are indicated in **Table 1**. The Cobb-Douglas production function is used to represent the relationship between economic factors and IWT throughput. The relationship is described by Equation (3), where y represents TKM or TEUKM. A is the technological factor, l represents labor, and k accounts for infrastructure. A increases the efficiency of l and k. If A also has an exponential relationship with the other factors, the log-linear transformation of Equation (3) is represented as in Equation (4).

$$y = A^{\beta_A} l^{\beta_l} k^{\beta_k} \tag{3}$$

$$\log(y) = \beta_A \log(A) + \beta_l \log(l) + \beta_k \log(k) \tag{4}$$

The model is enhanced in four ways, and the final specification is described in Equation (5). First, we leverage the panel data structure to control for the overall temporal trend of IWT throughput and its temporal inertia. It is captured with the annual trend of container TKM and TEUKM (represented by t), and these dependent variables lagged one year (y_{t-1}). Second, we control for changes in demographical patterns per region and year, in addition to the set of economic influencing factors (X_{it}). Third, the orthogonal transformation developed by Lee & Yu (2010) is applied to rule out time-invariant fixed effects, such as the area of the regions, length of waterways, and the number of inland terminals, among others (C_i).

Fourth, we developed a dynamic Spatial Durbin Model (SDM) to account for the spatial dependence of regional throughput ($\sum_{j=1}^{n} W_{ij} y_{it}$) and independent variables ($\sum_{j=1}^{n} W_{ij} X_{it}$) in the model. A set of identification tests were conducted to validate this form of the spatial econometric approach. First, a likelihood ratio (LR) was used to assess the significance of the regional effects after a regular OLS regression. Second, a Lagrange Multiplier test (LM) was implemented to test the existence of spatial lag and error dependence in IWT throughput at the regional level. In this case, rejecting the null hypothesis on a non-spatial model suggest that such effects should be included in the form of a SDM (Elhorst, 2010). Third, multiple Wald tests for spatial terms were conducted with the hypothesis $H_0\colon \theta = 0$, and $H_0\colon \theta + \lambda\rho = 0$. Where λ and ρ are the parameters associated with the spatial lag and error terms, respectively. If both hypotheses are rejected, the SDM is recommended over the Spatial Autoregressive Model (SAR) and the Spatial Error Model (SEM) as the more general formulation (Elhorst, 2010). Finally, we test a set of specifications with spatial interaction terms in dependent and independent variables and identify the best fit of the model.

The quasi-maximum likelihood estimator developed by Lee & Yu (2010) is implemented to estimate the vector of parameters $(\text{i. e.}, \alpha, \gamma, \lambda, \beta, \theta, \ \varphi, \text{and } \rho)$. The estimation results from the SDM depend on how the spatial relation between regions is specified in the model (W and M). Therefore, we check its sensitivity by estimating the model using different spatial interactions. Initially, we consider first vs. second-order contiguity matrices, row normalized, as a local indication of neighborship. Then, we estimate the model using the inverse distance weight matrix, considering the entire study area as a neighborhood based on distances between regional centroids.

$$y_{it} = \alpha + \gamma y_{it-1} + \lambda \sum_{j=1}^{n} W_{ij} y_{it} + \beta X_{it} + \theta \sum_{j=1}^{n} W_{ij} X_{it} + \ \varphi t + C_i + u_{it} \,; \qquad (5)$$

$$u_{it} = \rho \sum_{j=1}^{n} M_{ij} u_i + \ v_{it}$$

Where,

- y_{it} is the log of TKM or TEUKM of region i during year t;
- y_{it-1} accounts for the temporal inertia of throughput over the years;
- X_{it} is a vector with the log of the economic influencing factors and control variables;
- Wy_{it} and WX_{it} captures the spatial dependence of throughput and independent variables between regions connected by the RALP;
- C_i accounts for the regional time-invariant fixed effects, which is ruled out after applying the orthogonal transformation;
- t is a time trend capturing the overall trend of containerized throughput along the RALP between 2007 and 2021;
- u_{it} is the spatially lagged error, and v_{it} is the disturbance term;
- W and M are spatial weighting matrices.

3.4 Disaggregation of spatial spillover effects

In the SDM model, the parameters β and θ cannot be interpreted as the marginal effect of explanatory variables on the dependent variables, i.e., the level of IWT throughput. The reason is the presence of direct and spatial indirect effects involved in the partial derivate (LeSage & Pace, 2009). In this case, the partial derivative includes the initial effect related to a change in an explanatory variable plus the feedback response from neighboring regions impacted by spatial dynamics. We follow the approach of LeSage & Pace (2009) to disaggregate the direct and spatial spillover effects. The latter can be referred to as the separated effect of a change in one explanatory variable on the dependent variable of neighboring regions. Equation (6) can be written in its vector form as follows:

$$Y_t = (I - \lambda W)^{-1}\alpha I_N + (I - \lambda W)^{-1}(X_t\beta + WX_t\theta) + (I - \lambda W)^{-1}\xi \tag{6}$$

Where I is the identity matrix, and I_N is a $n\,x\,1$ vector of ones. ξ includes the error component u, fixed regional effects, and the time trend. The marginal effect of Y with respect to the j_{th} explanatory variable at a given time can be represented as Equation (7). This $n\,x\,n$ matrix includes the effect of a marginal change in the explanatory variable j on all the regions under analysis. β_j and θ_j are the coefficients to be estimated.

$$\delta Y/\delta X_j = (I - \lambda W)^{-1}(\beta_j I + W\theta_j) \tag{7}$$

The log-linear representation depicted in Equation (4) allows the interpretation of the marginal effect as an elasticity. Therefore, Equation (7) represents the effect of a 1% increase in the independent variable j in the throughput level of all the regions in the study. For instance, the marginal effect of a 1% increase in the technological factor A in a given region n can be represented as Equation (8).

$$\delta Y/\delta A_{i=n} = (I - \lambda W)^{-1}(i_n\beta_A + Wi_n\theta_A) \tag{8}$$

Where i_n is a vector taking one in the position of region n. Considering $n = 1$ and ϕ_{ij} as the (i,j) element of $(I - \lambda W)^{-1}$, the effects of a change in A can be written in vector form as represented by Equation (9). The first element of the equation refers to the direct effect of A on the region $i = 1$, and the rest of the vector elements capture the spatial spillover effects associated with the spatial dependence. Consequently, the vector sum is the total effect. Again, we check the sensitivity of the results to contiguity spatial weight matrices of first and second orders and the inverse distance weight matrix.

$$\delta Y/\delta A_{i=1} = \begin{bmatrix} \phi_{11}\beta_A + \sum_{j=1}^{N} \phi_{1j}\, W_{j1}\,\theta_A \\ \sum_{j=1}^{N} \phi_{2j}\, W_{j1}\,\theta_A \\ \vdots \\ \sum_{j=1}^{N} \phi_{Nj}\, W_{j1}\,\theta_A \end{bmatrix} \tag{9}$$

3.6 Empirical specification

In order to account for regional economic conditions that might influence container IWT in the RALP, a database was consolidated at the NUTS-2 level from Eurostat:

- Technological resources (Tech. Res; %): To proxy the technological factor (A), we collect data on human resources in science and technology. This measurement captures all personnel engaged in scientific and technological activities. It comprises two indicators, the ratio of the labor force with tertiary education (HRSTE) and the proportion of the labor force working on science and technology (HRSTO). Only HRSTO is considered in the model as the most accurate measure of technological resources and the R&D workforce (Kumar, 2001; Mahroum, 2007).

- Employment (thousand): We account for labor (l) with the aggregated number of employees in the region between 15 and 64 years old. Previous literature has reported mixed effects from employment. More workers captured by IWT are expected to influence port competitiveness (Satta et al., 2019). However, higher employment does not necessarily imply more people working on freight transport in Europe due to changing market trends and the dematerialization of economies (Alises & Vassallo, 2015; Meersman & Van de Voorde, 2013)

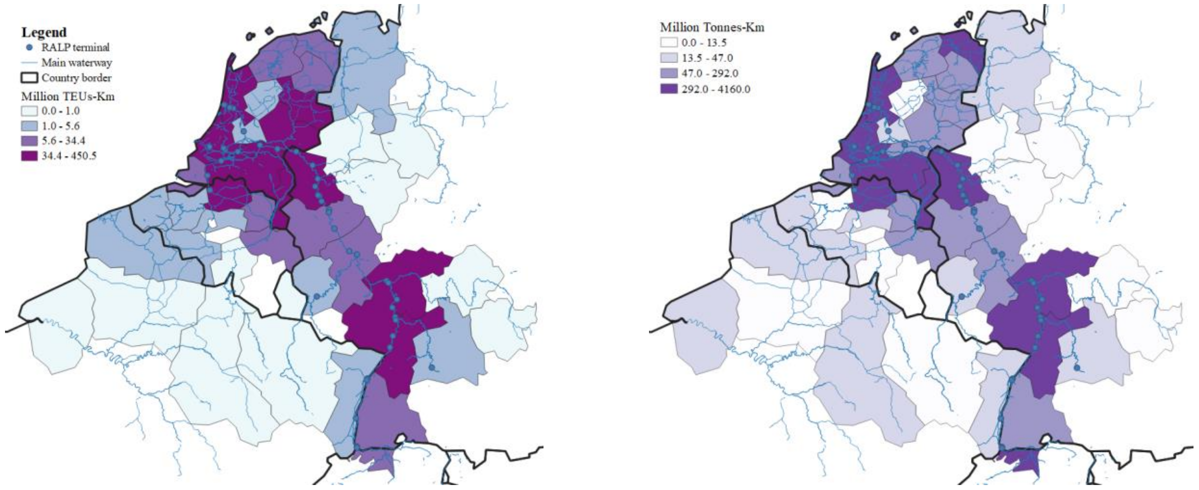
- Population density (People/Km^2): As employment accounts for a specific population segment, it does not capture demographical changes in time. We control for population density to include such variations primarily associated with urbanization patterns (Michaels et al., 2012). This variable is most associated with freight transport demand in the hinterland (OCDE, 2019). In relative terms of the area, the population is highly correlated with employment per Km^2 (coefficient of 0.99 in our sample). Therefore, including only the population per Km^2 allows avoiding multicollinearity concerns in the econometric approach.

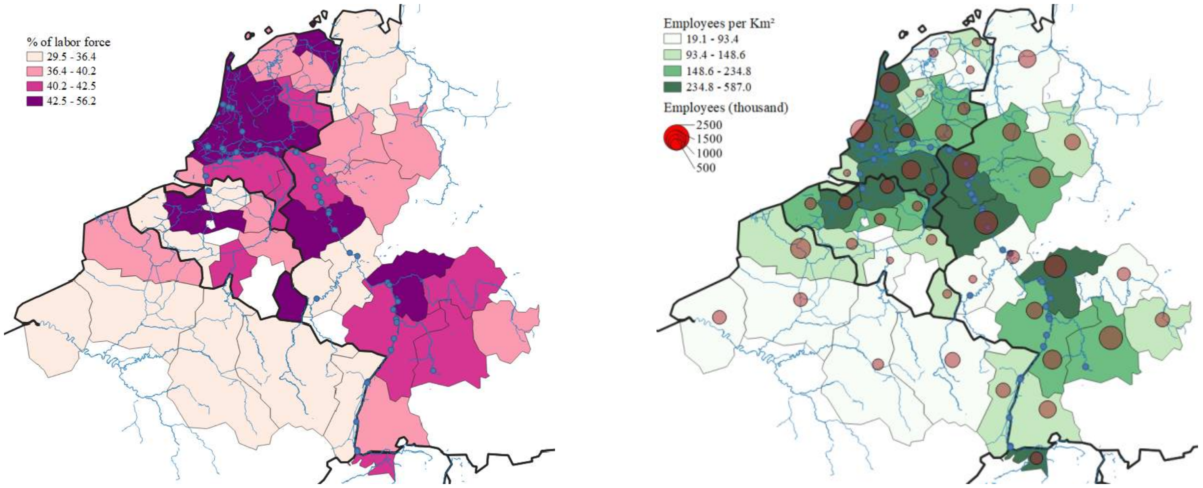
- Motorway (Km/ thousand Km^2): The extent in km of road coverage per thousand Km^2 has been used to capture transport infrastructure availability in the region (Wu & Lee, 2022). It also measures public capital stock (Chen et al., 2021). Urban centers in the region can benefit from better highway connectivity to the ports (Bottasso et al., 2013; Zhang et al., 2020). Therefore, the contribution of ports to regional development depends on the entire transport network (Ducruet, 2009).

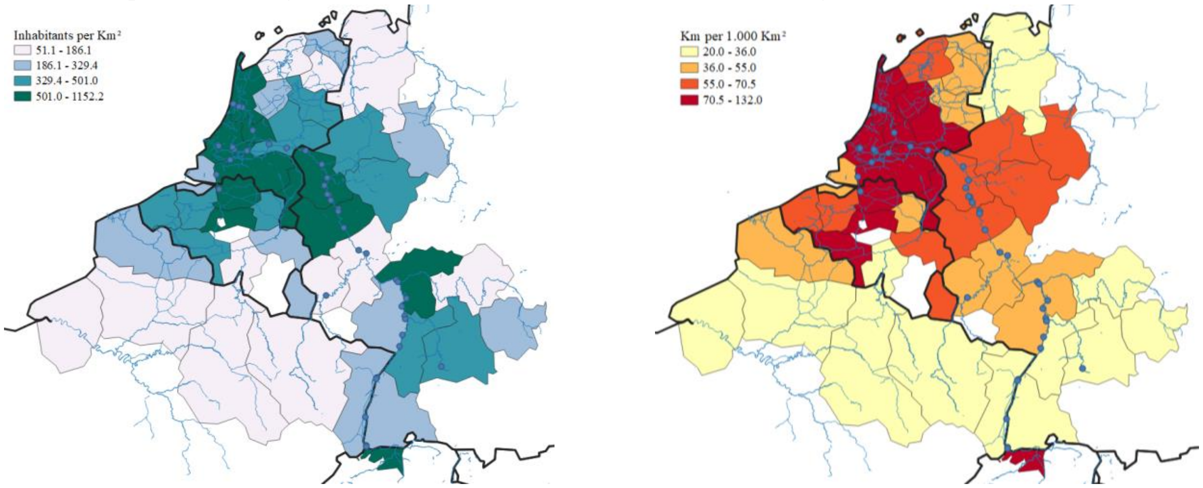
The descriptive statistics between 2007 and 2021 are summarized in **Table 2**. On average, the regions handled 9.2 tonnes per TEU, and there were years of no throughput. High variation is presented between years and regions along the corridor, which is explained by differences in the number of inland terminals and their relevance in the transport network. On average, the NUTS-2 regions have less than a million employees, and 35.6% of the labor force is dedicated to science and technology. Moreover, there is 57.7 Km of motorway per Km^2, and high population density variability with a coefficient variation of 64%.

Intuitively, the geographical distribution in 2021 indicates that TEUKM and TKM are higher in regions more connected by the RALP terminals, especially where inland terminals interrelate with deep-sea ports (**Figure 5**). Regarding independent variables, technological resources appear highly concentrated in the Netherlands, Germany, Luxemburg, and Switzerland. Employment is more available in Germany, some coastal regions of the Netherlands, and others on the border with Belgium and Germany, where the main RALP terminals are positioned. In France, higher employment is at the border with Belgium, Germany, and Switzerland. According to the area dimension, the patterns of employment and population density are very similar in the Netherlands. Concentration is higher in the central regions of Belgium and bordering regions of Germany and Switzerland. Finally, Higher motorway density is observed in Switzerland, Belgium, and most of the regions in the Netherlands containing one of the main RALP terminals.

Figure 5. Geographical distribution in 2021


(a) TEUKM (b) TKM


(c) Tech. Res. (d) Employment


(e) Population density (f) Motorways*

Source: The remaining figures in the study are authors' elaborations with data from Novimove and Eurostat.

Notes: * Data of motorways available up to 2020 and Luxemburg 2019. Germany at the NUTS-1 level.

Table 2. Descriptive statistics of variables, 2007 - 2021

Variable	Unit	Mean	SD	Min	Max
TKM	Million	358.3	683.8	0.0	4357.0
TEUKM	Million	39.0	77.8	0.0	488.2
Tech. Res.	Percentage	35.6	5.2	22.9	56.2
Employment	Thousand	867.7	557.6	177.1	2434.8
Pop. Den.	Pop/Km^2	364.0	234.5	51.1	1157.9
Motorways	Km/Km^2	57.7	26.4	20.0	132.0

Source: Own elaboration with data from Eurostat.

5. Results

To explore the spatial configuration of container IWT in the regions connected by the RALP, **Figure 6** presents the Global Moran's I index between 2007 and 2021 for TKM and TEUKM using a first-order weight matrix. The index is more stable for TEUKM in the time frame, likely because cargo volume within one container can vary without modifying the number of containers transported, especially at a regional scale. Each year the global spatial autocorrelation of throughput in the corridor is positive, and the indicator increased considerably after 2018. From this year, the positive spatial correlation of the RALP is statistically significant at the 5% level. A similar trend is observed with other spatial weight matrices, but the index is less significant.

We hypothesize that spatial dynamics are cross-border and evolve according to socioeconomic and navigability conditions. Specifically, the index increased remarkably in the last years, from 0.15 on average before 2016 to 0.25 after 2018. Two reasons may explain the change in trend. First, in 2017 the regions in France started to record their container IWT, enhancing the calculation accuracy of the Global Moran's I by increasing the geographical coverage. This result would suggest that not only the regions covered by the main waterways are involved in the spatial configuration of container throughput, but spatial correlation also exists between inland terminals geographically apart but connected through extended waterways.

To identify the main spatial agglomerations of transport performance, **Figure 7** presents the cluster map of TKM after calculating the Local Moran's I in 2021. The analysis uses an inverse distance weight matrix to consider the entire study area as a neighborhood. There are three principal spatial agglomerations of container throughput. The first cluster is located where inland terminals interrelate with deep sea ports. It includes most spatial units in the Netherlands but also two regions in Belgium (Prov. Antwerp, BE21; and Limburg, NL42) and one in Germany containing Duisburg, the biggest inland port city in Europe (Düsseldorf, DEA1). Most spatial units report high relative throughput and are surrounded by others of the same kind. In this cluster, the only statistically significant region reporting a relatively low throughput is Utrecht (NL31).

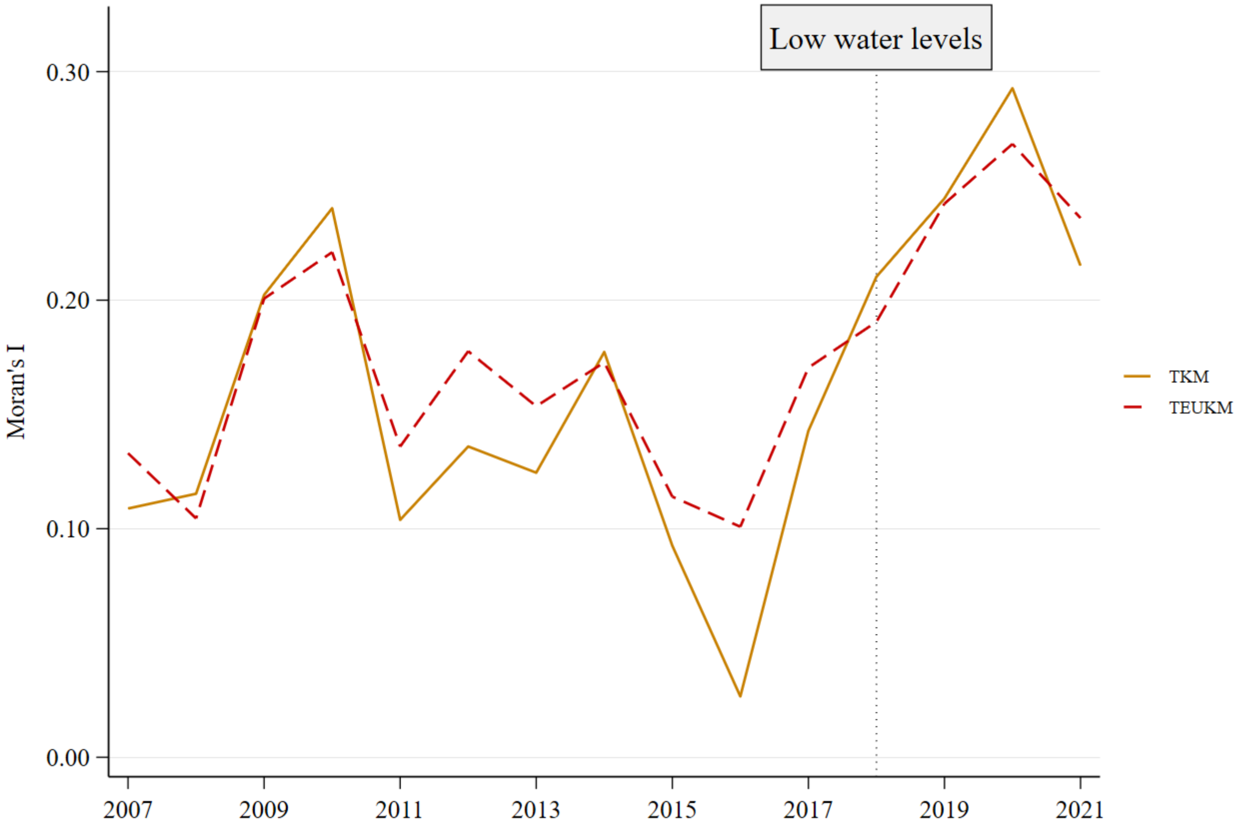
The second cluster is located at the end of the corridor, bordering France, Germany, and Switzerland. This cluster is characterized by four regions reporting relatively high levels of throughput neighboring others of the same type. These are Darstadt, Rheinhessen-Plfalz, Karlsruhe, and Freiburg (DE), which contain eight main RALP terminals. Alsace (FRF1) is the only region in this agglomeration with low throughput levels, as most of the throughput is handled by the terminals in Freiburg (DE13). Separately, Luxemburg operates low TKM and is surrounded by regions reporting high throughput levels. This pattern can be explained since

Luxemburg is linked to the RALP via the Moselle River, with longer sailing times and fewer and smaller vessels transporting cargo.

Finally, the third cluster is formed by the spatial units in France handling low throughput levels as these do not contain any main terminals. These regions are connected to the RALP but are not part of the primary corridor. Between 2007 and 2021, the structure of the principal spatial agglomerations remained consistent with specific changes in the periphery. Specifically, Zeeland (NL34) and Koblenz (DEB1) became statistically insignificant in the first and second cluster, respectively.

The second reason that could explain the trend break of the Global Moran's I after 2018 relates to navigability conditions. Water levels dropped significantly in the last semester of 2018, which affected the entire corridor and possibly led to variations in the spatial correlation of container throughput between regions. On the one hand, as low water levels decreased cargo transported via IWT, the difference between terminals reporting the highest throughput and terminals in adjacent regions could be reduced on average, inducing a higher positive spatial correlation. On the other, it could result from a higher concentration of throughput retreated to the main terminals. To illustrate concentration patterns, **Figure 8** shows throughput levels one year before and after the disruption comparing the distribution quartiles, and **Table 3** summarizes the changes per country. Overall, we confirm higher concentration patterns in the main spatial agglomerations between 2017 and 2019.

Figure 6. Moran's I in the RALP

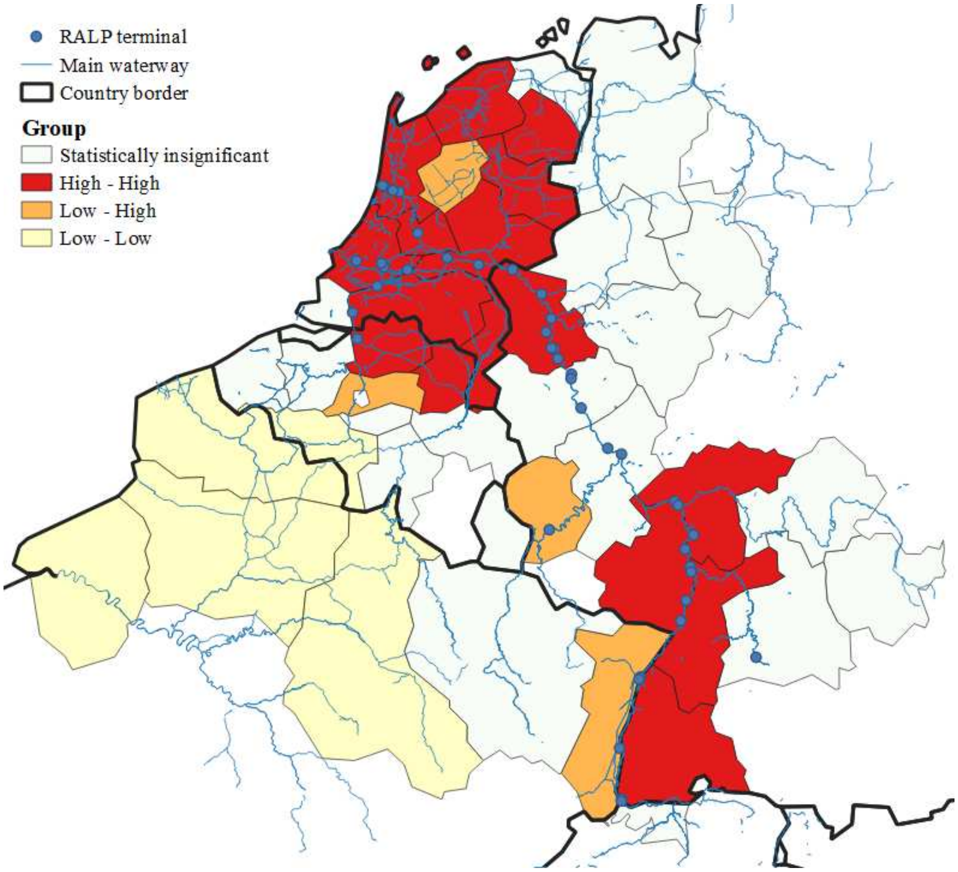


Notes: The calculation uses a first-order weight matrix.
Statistically significant at the 5% level after 2018.

Table 3. Changes in distribution quartiles, 2017 vs. 2019

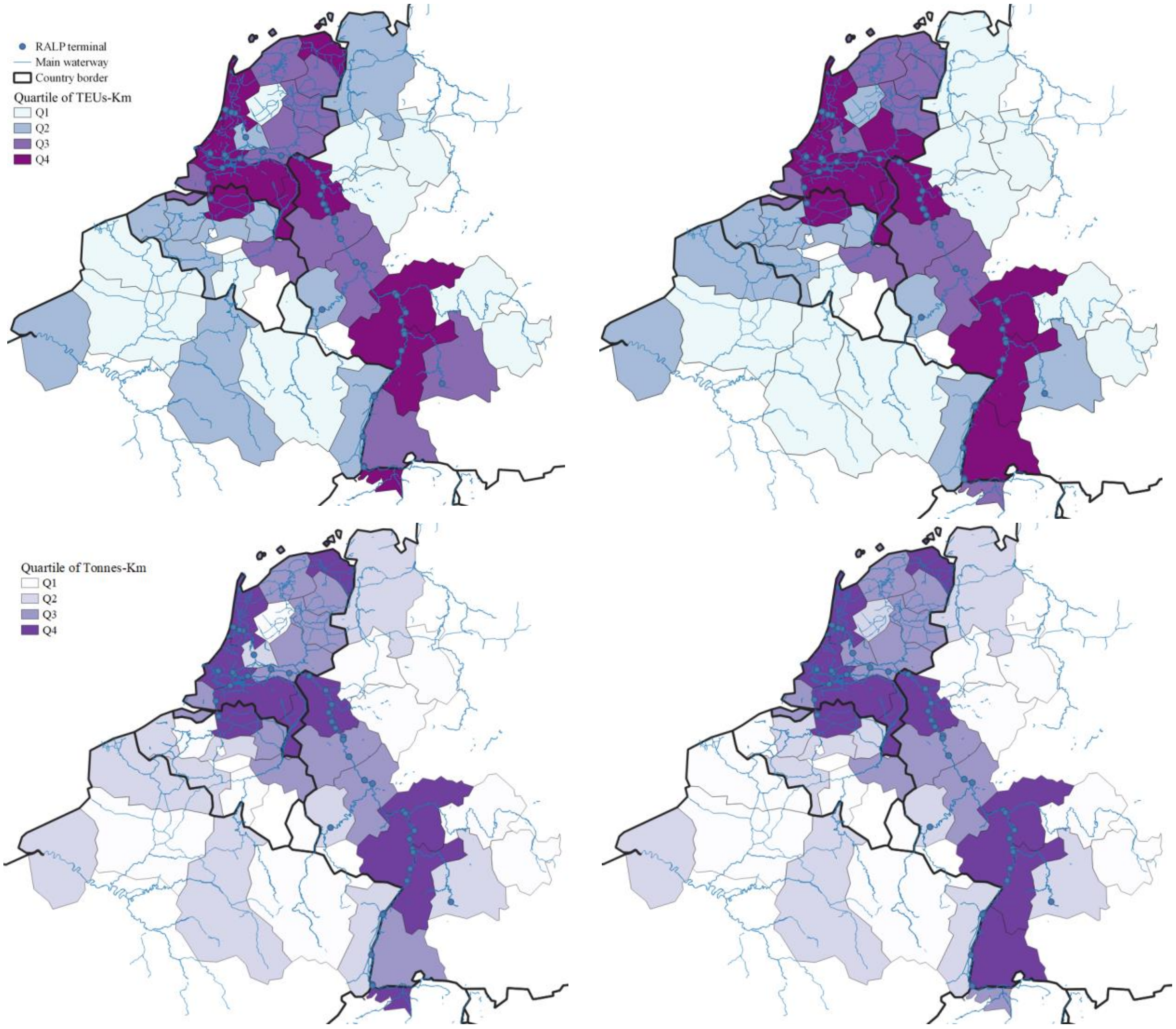
Country	TEUKM	TKM
Belgium	Unaltered	Downgrade in Prov. Oost-Vlaanderen (BE25).
France	Downgrade in Champagne-Ardenne (FRF2) and upgrade in Nord-Pas de Calais (FRE1).	Downgrade in Nord-Pas de Calais (FRE1).
Germany	Downgrade in Stuttgart (DE11) and upgrade in Freiburg (DE13).	Upgrade in Freiburg (DE13).
Netherlands	Downgrade in Groningen (NL11) and upgrade in Gelderland (NL22).	Upgrade in Utrecht (NL31) and Flevoland (NL23).
Luxemburg	Unaltered	Unaltered
Switzerland	Downgrade in Nordwestschweiz (CH03).	Downgrade in Nordwestschweiz (CH03).

Figure 7. Cluster map in 2021



Notes: The calculation uses an inverse distance weight matrix.
Clusters have been virtually unchanged since 2007.

Figure 8. Geographical distribution of TEUKM and TKM in 2017 vs. 2019


(a) 2017

(b) 2019

For the econometric approach, the battery of specification tests is conducted with the first-order contiguity weight matrix, following the result from the Global Moran's I index calculation (**Table 4**). The Hausman test results suggest developing a Fixed Effects model instead of a Random Effects model in all cases. Regarding spatial dependence, the LM and LR tests reject the null hypothesis that it is statistically irrelevant in the dependent variables (i.e., TKM and TEUKM), and the same result is obtained for the disturbance term of the regressions. Meanwhile, the robust LM suggested contrary evidence, but the Wald test provides resolving evidence to suggest accounting for both spatial terms. Therefore, a SDM is more recommended than SAR or SEM because it is the general case (Elhorst, 2010).

The overall results from the regular Fixed Effects model and the SDM are presented in **Table 5**. The estimation only considers the strongly balanced panel with regions that consistently report TKM and TEUKM data in the analysis timeframe, leaving out all incomplete regions. The parameters estimated with the regular Fixed Effects model indicate that technological resources and population density are associated with favorable changes in TKM and TEUKM. In theory, the Cobb-Douglass production function indicates that the technological factor can increase the efficiency of labor and infrastructure. In the RALP context, technological resources could contribute to developing innovative improvements that cope with the constraints of IWT, such as low water levels. Consequently, its competitiveness can be enhanced while reducing operational and economic costs.

Furthermore, higher population density can make IWT container throughput more competitive as it can respond to freight transport demand with higher economies of scale than other modes. That would be the case if more population is concentrated in the hinterland and not scattered in towns or villages across the region. In contrast, employment and motorways are found to be linked to adverse effects on container IWT. This result can be explained by the market update that road transportation has achieved in Europe during the last years, capturing most of the employment and freight transport demand. We also noticed a strong positive correlation between employment and GDP (0.97), and the link between economic activity and freight transport has evolved according to decoupling patterns (Alises & Vassallo, 2015; Meersman & Van de Voorde, 2013). Considering the same scenario, higher demand for transport from towns and villages scattered across the regions would require higher transport flexibility and decrease the relative attractiveness of IWT.

According to the SDM, the results of the λ parameter suggest that spatial dependence exists in the RALP at the first level of contiguity but not at higher orders. In the case of TKM, the parameter is 0.58 and is significant at the 1% confidence level. Therefore, an increase in the volume of regional containerized throughput is associated with favorable variations in the TKM of terminals in neighbor regions. This result indicates that the volume of container transport exceeds regional borders. In other words, when more tonnes are loaded (unloaded) in one specific region, the same pattern will likely be observed in neighboring regions during the same year.

In contrast, the ρ parameter indicates the existence of other regional features not captured explicitly by the model that negatively influence the neighbors' level of throughput. The coefficient is -0.68. Consider, for instance, the impact of low water levels in the RALP during 2018, as explored earlier in **Figure 8**. The phenomena decreased containers' loading factors across regions, and groups of adjacent regions were likely to be more or less affected according to the impact on its waterways' navigability (CCNR, 2019).

The findings for the case of TEUKM indicate a negative sign for λ (-0.69) and a positive for ρ (0.57). A higher number of containers loaded (unloaded) is associated with fewer containers loaded (unloaded) in neighboring regions. For instance, if terminals of different regions can serve to reach the hinterland, the terminal choice would decrease the number of containers loaded (unloaded) in other terminals of a neighboring region. **Figure 8** showed that concentration patterns in TEUKM were more predominant than TKM. The model results suggest that such patterns are associated directly with the terminal choice between regions. In this case, other factors impact the total number of containers transported across regions. For example, differentiated effects of low water levels would decrease the number of TEUs between terminals of adjacent regions.

Table 4. Specification tests

	TKM	**TEUKM**
Hausman	74.51	67.51
	(0.00)	(0.00)
SAR		
LM	3.71	4.86
	(0.05)	(0.03)
RLM	0.46	0.35
	(0.50)	(0.56)
LR	88.96	105.73
	(0.00)	(0.00)
Wald	25.78	15.28
	(0.00)	(0.02)
SEM		
LM	6.16	7.40
	(0.01)	(0.01)
RLM	2.92	2.88
	(0.08)	(0.09)
LR	72.86	90.80
	(0.00)	(0.00)
Wald	9.13	15.25
	(0.00)	(0.02)

Notes: Calculations with a first-order spatial weight matrix.
Value of chi-squared distribution outside the parenthesis. P-value inside parenthesis.
LR (Likelihood Ratio), LM (Lagrange Multiplier), and RLM (Robust Lagrange Multiplier).

As mentioned in the methodological section, the parameters reported in **Table 5** should not be interpreted as marginal effects because they combine direct and feedback dynamics with other regions. The disaggregated elasticity between direct and spatial spillover effects is reported in **Table 6** for each independent variable and spatial weight matrix. In the case of TKM, a one percent increase in technological resources reports a direct regional effect ranging from 1.07 to 1.66%. Furthermore, the spatial spillover effect to contiguous regions is considerably higher, from 3.26 to 4.03%.

The direct effect of population density ranges from 5.05 to 5.77%, and there are no statistically significant spillover effects. In contrast, higher regional employment is associated with a negative direct elasticity ranging from -2.59 to -3.62%, while the spatial spillover effect to contiguous regions is estimated between -4.10 to -5.41%. The direct effect of motorways is -0.39%, but it is not statistically relevant when considering spatial dependence.

Concerning TEUKM, the direct effect of technological resources is estimated between 0.87 and 1.15%. In this case, it is the only influencing factor reporting the existence of spatial spillover effect at the first-order contiguity, with a coefficient of 1.16%. The local effect of population density ranges from 2.27 to 2.81%. Grouping the adverse effects, the direct effect of employment ranges from -1.91 to -2.08%, and motorways from -0.27 to -0.36%.

Table 5. General results

	TKM				TEUKM			
	I	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**
Tech. Res.	1.66***	0.71	1.52**	1.53**	1.15***	0.82**	0.87**	1.00***
	(0.59)	(0.69)	(0.64)	(0.62)	(0.41)	(0.35)	(0.38)	(0.36)
Employment	-3.62***	-2.48**	-3.15***	-2.76***	-1.93***	-2.00***	-2.05***	-1.93***
	(0.88)	(1.09)	(1.02)	(1.02)	(0.52)	(0.57)	(0.61)	(0.61)
Motorways	-0.39**	-0.37	-0.23	-0.24	-0.31**	-0.41***	-0.27*	-0.28*
	(0.17)	(0.24)	(0.25)	(0.24)	(0.12)	(0.14)	(0.15)	(0.15)
Pop. Den	5.77**	5.23**	5.25***	4.94***	2.78**	2.80***	2.72**	2.67**
	(2.76)	(2.10)	(1.79)	(1.76)	(1.23)	(1.09)	(1.07)	(1.06)
		W1	**W2**	**Wid**		**W1**	**W2**	**Wid**
Tech. Res.		1.12	4.63*	6.96		2.03***	1.21	3.44
		(0.96)	(2.60)	(4.51)		(0.73)	(1.04)	(2.55)
Employment		-0.48	-6.82*	-9.75**		-0.99	-0.44	-2.18
		(1.36)	(3.53)	(4.91)		(1.06)	(1.35)	(2.40)
Motorways		0.21	0.43	1.04		-0.51	0.38	0.05
		(0.38)	(0.76)	(1.66)		(0.35)	(0.41)	(1.04)
Pop. Den		-2.18	0.97	-2.49		4.63**	-2.87	-3.24
		(2.91)	(6.44)	(10.68)		(2.01)	(2.65)	(6.36)
λ		0.58***	-0.23	-0.56		-0.69***	0.04	-0.71
		(0.08)	(0.48)	(0.55)		(0.10)	(0.35)	(0.55)
ρ		-0.68***	0.34	0.57***		0.57***	0.05	0.54**
		(0.11)	(0.34)	(0.21)		(0.08)	(0.35)	(0.22)
Log-likelihood	-136.65	-119.65	-119.38	-120.44	59.70	62.16	56.53	55.90
R2 (Pseudo)	0.52	0.18	0.16	0.30	0.62	0.29	0.50	0.54

Notes: Estimates in column I comes from a regular Fixed Effects model. Columns II to IV indicate the Spatial Durbin Model (SDM) estimates. The specification includes the dependent variables lagged one year, fixed effects, and a general temporal trend. Standard errors in parenthesis. * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

Table 6. Disaggregation of spatial spillover effects

	TKM				TEUKM			
	FE	**W1**	**W2**	**Wid**	**FE**	**W1**	**W2**	**Wid**
				Direct				
Tech. Res.	1.66***	1.07*	1.42**	1.40**	1.15***	0.53	0.87**	0.93 **
	(0.59)	(0.63)	(0.62)	(0.62)	(0.41)	(0.40)	(0.37)	(0.37)
Employment	-3.62***	-2.94**	-3.00***	-2.59**	-1.93***	-2.08***	-2.05***	-1.91***
	(0.88)	(1.00)	(0.99)	(1.05)	(0.52)	(0.61)	(0.61)	(0.64)
Motorway	-0.39**	-0.38	-0.24	-0.26	-0.31**	-0.36**	-0.27*	-0.29*
	(0.17)	(0.23)*	(0.24)	(0.24)	(0.12)	(0.14)	(0.15)	(0.14)
Pop. Den	5.77**	5.42**	5.25**	5.05***	2.78**	2.27*	2.71**	2.81**
	(2.76)	(1.89)	(1.79)	(1.80)	(1.23)	(1.19)	(1.06)	(1.10)
				Indirect				
Tech. Res.		3.26**	3.58**	4.03*		1.16**	1.28	1.67
		(1.46)	(1.46)	(2.17)		(0.56)	(0.83)	(1.17)
Employment		-4.10**	-5.10***	-5.41*		0.31	-0.53	-0.49
		(1.90)	(1.96)	2.96		(0.79)	(1.07)	(1.55)
Motorway		-0.01	0.41	0.77		-0.18	0.39	0.16
		(0.68)	(0.63)	1.09		(0.25)	(0.43)	(0.61)
Pop. Den		1.79	-0.20	-3.49		2.13	-2.86	-3.14
		(4.23)	(4.27)	6.94		(1.52)	(2.71)	(3.93)
				Total				
Tech. Res.	1.66***	4.34**	4.50**	5.43**	1.15***	1.69***	2.12***	2.59**
	(0.59)	(1.42)	(1.47)	(2.12)	(0.41)	(0.52)	(0.81)	(1.11)
Employment	-3.62***	-7.03**	-8.10***	-8.00**	-1.93***	-1.77**	-2.58**	-2.40
	(0.88)	(1.86)	(1.97)	(2.76)	(0.52)	(0.80)	(1.01)	(1.36)
Motorway	-0.39**	-0.39	0.17	0.51	-0.31**	-0.54**	0.11	-0.13
	(0.17)	(0.73)	(0.72)	(1.11)	(0.12)	(0.24)	(0.48)	(0.62)
Pop. Den	5.77**	7.22*	5.05	1.56	2.78**	4.40***	-0.15	-0.33
	(2.76)	(3.99)	(4.54)	(6.69)	(1.23)	(1.43)	(2.76)	(3.77)

Notes: Postestimation of the SDM. The specification includes the dependent variables lagged one year, fixed effects, and a general temporal trend. Standard errors in parenthesis. * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

6. Discussion and policy implications

The European Union is implementing more than 400 infrastructure projects along the RALP to improve the performance of freight transport by eliminating existing and potential bottlenecks. 60% of these projects are expected to be completed by 2025 and 87% by 2030. As a result, freight transport is projected to increase by 25%, generating over € 500 billion in GDP for involved countries and more than 1.7 million jobs between 2017 to 2030. It is also anticipated that efficiency gains and a modal shift from road transport will lead to a reduction of around 14% of CO2 emissions by 2030 (European Commission, 2020).

With IWT remaining the dominant transport mode in the RALP, comprehensive assessments of its development contribute to successfully implementing planned and ongoing projects. Nonetheless, country-aggregated and port-level evaluations ignore the diversity of regional geographical and economic conditions. Consequently, traditional assessments disregard spatial spillover leading to limited policy on land-driven development strategies from the Inside-Out perspective. It is especially relevant for IWT since developing navigable inland waterways as transport corridors depends highly on geography. Recent studies provided evidence of spatial spillovers from IWT on economic outcomes within China, but the results are not generalizable to other geographical contexts. In the RALP, it involves multiple countries and stakeholders.

This paper contributes to the literature by quantifying the spatial dependence and spillover effects of container throughput performance in Europe. The results add to the finding of Notteboom et al. (2020) on market concentration patterns in the inland port system between 1975 and 2015. We report that the configuration of inland terminals in navigable waterways from Antwerp (Belgium) to Basel (Switzerland) also led to a positive spatial concentration of container cargo between 2007 and 2021, mainly in two spatial agglomerations. Furthermore, spatial concentration increased considerably after water levels dropped in 2018.

The results also offer consensus regarding the recent mixed evidence from the studies of Wu & Lee (2022) and Shi et al. (2023). We show that the conclusions are relative to the measure adopted for inland container transport performance, i.e., tonne-km vs. TEUs-km. Aligned with Wu & Lee (2022), we report a positive spatial dependence on the volume of containerized transport in the RALP; however, it is negative regarding TEUs, as shown by Shi et al. (2023). Therefore, both measures should be considered to reach more accurate conclusions on the spatial dynamic of container IWT. The econometric approach allowed us to quantify the spatial dependence, indicating that the throughput performance of container inland terminals in one region depends on the development of terminals in the first-order adjacent regions.

We discuss the policy implications of our study following the framework proposed by van Hassel (2023) on the main current challenges of IWT in Europe. First, the impact of climate change. Low water levels in 2018q3 vs. 2017q3 were followed by a 35% decrease of TKM in Switzerland, followed by Germany (26%), Luxemburg (21%), Belgium (13%), and the Netherlands (7%) (CCNR, 2019). Consequently, less reliability on IWT upon droughts and disruptions in navigability has contributed to the modal switch from IWT towards road transport. From 2007 to 2021, the modal share of IWT decreased from 6.5 to 5.6 while economic activity continued to grow, except for 2018 and 2020 (Eurostat, 2023c). This trend should be reversed to progress towards a sustainable transition of freight transport in Europe. To do so, higher resiliency of IWT upon critical water levels is essential, as more extreme and prolonged episodes of low water levels are likely to occur in the following years (CCNR, 2023).

The results of the present study uncover the spatial patterns to assist in designing better land-driven strategies to prevent a permanent modal shift from IWT. Specifically, we inform on higher geographical concentration within two regional agglomerations as container throughput performance retreated to the main terminals after 2018. It implies that IWT in regions outside these agglomerations is less resilient to critical water levels than terminals. These less resilient regions are also along the extended waterways from the traditional Rhine, which are usually overlooked. Therefore, policies intended to prevent a permanent modal shift can be more effective by implementing contingency measures distinguishing more vulnerable regions, i.e., outside the spatial agglomerations.

There are different response levels to improve the resiliency of IWT in the RALP upon future water level disruptions, including enhancing available IWT infrastructure, designing and building new vessels, and developing better weather forecasting tools (CCNR, 2023). While these responses will benefit the entire corridor, spatial targeting can benefit the effectiveness of such developments. Better inclusion of multimodality remains a feasible improvement for regions outside the spatial agglomerations while innovational initiatives are deployed. Under IWT disruptions, a temporary shift to other modes may be an option for particular containerized goods to prevent long-term modal shifts in those regions.

The second challenge in the framework of van Hassel (2023) is workforce decline. From 2011 to 2020, the number of persons employed on freight IWT in Europe decreased by more than 5% due to socioeconomic conditions, mainly low wages, aging, and lack of technical competencies (CCNR, 2021; Eurostat, 2023a). The results in this study confirm a negative association with regional employment, involving spillover effects on neighboring regions. However, we found that it can be coped with a higher proportion of the labor force dedicated to science and technology. Aligned with the Naiades II Implementation Expert Group, the sector requires creating attractive workplaces with high social, qualification, safety, and security standards, especially for young generations. To achieve a sustainable transition of freight transport, IWT will need smart and sustainable jobs to complement infrastructure and fleets better integrated with other transport modes (Naiades II, 2019).

Our results indicate that technological jobs have been associated with higher container throughput performance, including considerable spillover effects compared to the local impact. It is especially relevant within spatial agglomerations where innovational improvements will likely influence the most. For instance, optimizing the loading factors of containers transported from coastal regions in the first spatial agglomeration and improving unloading operations in the terminals of the second agglomeration. More technological resources are also determinant for enhancing IWT resiliency to climate change, which affects both agglomerations differently. Solutions include designing resilient infrastructure and vessels to disruptions on water levels, progressing on digitalization to improve navigation, and improving weather forecasting, among others (CCNR, 2023).

The third main challenge is the need for new business models, which are required to attract stakeholders willing to cover the costs of the innovational developments (van Hassel, 2023). The results of our study suggest that IWT gets more attractive with higher population density. Between 2012 and 2018, around 25% of European cities moved towards densification, most notably in Germany and the Netherlands (Cortinovis et al., 2022). With already high pressure on roads, transporting cargo by trucks will likely increase delays and generate further externalities in urban environments, such as congestion, noise, and air pollution. New business models can be developed to reach densely populated areas with greater participation of IWT. The CCNR (2022) highlighted new markets for IWT, including urban and freight transport by inland vessels and increasing cargo flows stimulated by circular economy strategies. The results in this study confirm that population density is associated with higher demand for container IWT at a regional level and can play a determinant response role under the current demographical trends.

In Europe, the development of innovational initiatives and business models will inevitably require cooperation between crucial actors and member countries. The existence of spatial dependence and spillovers found in this study suggest that improvements (downgrades) in container throughput performance in one region affect neighboring regions. It is especially relevant as each identified spatial agglomeration involves regions for multiple countries. Therefore, the results also highlight the need to develop aligned visions for IWT development and growth.

The quantitative approach developed in this study reveals both the limitations and opportunities for conducting further research concerning land-side development strategies of IWT in Europe. Firstly, more exhaustive spatial analysis can be achieved with the complete historical records of regions. We acknowledge the limitations it brings to disentangle the causal mechanisms behind the findings. With higher spatial and temporal data disaggregation, future research can progress in understanding the link between IWT and overall regional economic performance.

Secondly, better data on regional infrastructure disaggregated by IWT, road, and rail would benefit the quality of the analysis aiming for policy advice toward a sustainable intermodal transition of freight transport. Thirdly, the study ignores other spillover effects of IWT that are not necessarily dependent on the spatial relationship, such as network externalities related to connectivity agglomerations. Finally, while containerized throughput is a reliable indicator to measure the competitiveness of deep sea and inland ports, other key performance indicators are needed for more comprehensive assessments, such as the costs per TEU transported, the load factor of containers, lead times at terminals, and levels of emissions.

7. Conclusions

Inland waterways will continue to play a crucial role in enhancing port-hinterland connectivity and fostering sustainable freight transport. However, comprehensive assessments of transport development are required to enhance its competitiveness as a transport corridor for container cargo. This study focused on spatial dynamics and informs on land-driven development strategies. We found a positive spatial autocorrelation between 2007 and 2021. After water levels dropped in 2018, concentration patterns intensified, and cargo moved toward spatial agglomerations. With more prolonged droughts likely to occur, spatially oriented policies can be leveraged to prevent permanent modal shifts.

In the RALP, container IWT performance has been characterized by positive spatial dependence in tonne-km and negative dependence in TEU-km. Furthermore, this spatial dependence facilitates the spillover of technological resources and employment to neighboring regions. Given the negative trend in IWT employment, technological resources stand out as an alternative to improving the overall navigability conditions. To offset the costs, population density patterns bring new market opportunities to increase the participation of container IWT. However, achieving this will require cross-border collaboration among member countries and stakeholders.

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