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The mutual specialization of port and urban functions: the case of France¹

Mounir Amdaoud

EconomiX, (CEPN, CNRS, Paris Nord University) – Email: mounir.amdaoud@economix.fr

César Ducruet

EconomiX, CNRS – Email: cesar.ducruet@economix.fr

Marc-Antoine Faure

EconomiX, CNRS – Email: marc-antoine.faure@dauphine.eu

Abstract

This research examines the similarities between port traffic structure and economic structure of French port cities. Based on the combination of Automated Identification System (AIS) data and employment data, it performs complementary analyses of the mutual specialization between ports and cities. Main results show that while larger cities handle more diversified traffic, the cross-specialization is blurred by the complexity of trade networks and supply chains. We then propose a novel methodology whereby the spatial unit of analysis is enlarged according to the type and volume of port traffic.

KEYWORDS: hinterland; maritime transport; port city; specialization; supply chain

JEL CLASSIFICATION: O18; L90 ; R40; R12

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1 | INTRODUCTION

Maritime industry plays a central role in trade and economic growth at both global and local scales, as seaports handle approximately 80% of world merchandise trade in volume (UNCTAD, 2019). In geography and elsewhere, it has long been recognized that ports are not only transport nodes between sea and land networks; they are also important places for urban and economic development (Banister, 1995). While a substantial share of world urban population resides along the shores (Noin, 2000), many of the world's largest cities are also port cities (Fujita & Mori, 1996), or access maritime trade through nearby outports (Wackermann, 1998).

The wide literature on port-city relationships is mostly qualitative, focusing on the port-city interface (Hayuth, 1982). Port economic impact studies dominate quantitative research, but it was soon observed that they differ too much by their sources, methods, and results to allow identifying trends and regularities (Vleugels, 1969). The absence of a well-defined port city concept also explains such disparities and the lack of a specific methodology (Brocard et al., 1995). Precise and harmonized urban and port indicators often remain lacking, strongly limiting systematic analyses (Rozenblat et al., 2004).

In addition, port cities belong to a “national system of ports and cities” (Kidwai, 1989). In this system and according to Fujita and Mori (1996, p. 96), port cities “are more likely to grow dominantly than nonport cities” thanks to the “extra advantage of transport access”, while “some nonport cities created by historical accidents may continue to dominate the economy (...) due to their self-reinforcing agglomeration”. This core-periphery pattern is found in several economies, where the inland capital city dominates port cities both demographically and economically, as seen in many Latin American (e.g. Chile, Ecuador, Venezuela), African (e.g. Egypt, South Africa, Kenya), European (e.g. Russia, Ukraine, Spain, France), and Asian countries (e.g. Iran, India, South Korea) (Ducruet and Guerrero, 2021). Such a pattern creates a “lock-in effect” by which people and economic activities tend to be attracted by the core (Fujita and Mori, 1996), while ports keep

less-qualified activities and higher unemployment levels (O'Connor, 1989; Grobar, 2008; Hall, 2009).

France is a good example of such a core-periphery structure, with an urban system centred upon the capital region. In 2020, Greater Paris concentrates about 18% of national population, 31% of GDP, and 40% of R&D expenditures (CCI Paris Ile-de-France, 2021). Such a concentration and its consequences on ports is not a new fact. The 1842 law paved the way towards the so-called « Legrand » star-shaped railway system centered upon Paris, connecting the major ports (Marnot, 2005). Relatively low densities over a large territory, however, did not motivate investment towards the “periphery”, so that economic development kept concentrating around the seat of political power (Gravier, 1947). After World War II, factors combined such as central government control over ports, domestic focus, trade protectionism, the centralization of transport networks and tertiary functions by the Paris core region, all contributed to weakening the competitiveness of French port cities (Baudouin & Collin, 1996). The latter authors particularly insisted on the fact that the top-down nature of French port development hindered synergies between port and city as well as the local development of trading and value-added activities, « with catastrophic consequences on employment » (p. 343). The shift of heavy industries towards seaports in the 1960s, through a decentralization policy, is seen to have had little effect on local economic growth (Raoulx, 1996). An empirical study demonstrated the absence of a relationship between the demographic and traffic evolution of French urban areas in the 1970s-1990s (Steck, 1995). The study suggested that while urban population is not a perfect proxy of economic weight, results might be influenced by the distance to Paris and the presence of heavy industrial complexes in port areas. Subsequent studies on France focused mainly on port governance, discussing the 2008 port reform, the new role of the « local » in port affairs, and the intervention of private actors (see Guillaume, 2012), but without exploring port-city linkages in a systematic manner.

Further understanding local port-city linkages is also strategic, as the French maritime sector is responsible for no less than about 300,000 jobs in the country, of which 90,000 for port industries (see P  ris, 2015). The French coastal area grew demographically by 19.4% 1975 and 2005, against 16.1% at the national scale, while its population density is three time higher than average (B  outis et al., 2005). Using untapped data on traffic and employment at the level of labour areas, our research investigates the relationship between port specialization and urban specialization, in order to reveal their interdependencies. We hypothesize that certain traffics are tied to specific industries despite the importance of transshipment to/from other regions. An extension of the analysis to neighbouring areas is proposed to catch such effects. This research contributes to an important stream of literature that emerged about the role of physical, cargo flows in urban and regional development (Hall & Hesse, 2012; Birtchnell et al., 2015). Port-city relationships were seen as “fundamental and delicate” (Hesse, 2013), as ports and cities maintain important synergies (Hall & Jacobs, 2012). Port cities continue to act as prime locations within production networks and commodity chains (Jacobs et al., 2010), despite the growing mobility, complexity, and concentration of maritime networks. It is also a methodological contribution, as port traffic is rarely introduced as an urban indicator on its own.

The remainders of this article are organized as follows. Next section offers a synthesis of theoretical and empirical works on port-city relationships. It is followed by a presentation of our data and methodology. The fourth section presents the results, and the last section concludes about the lessons learned for both research and practice.

2 | THE COMPLEXITY OF PORT-CITY RELATIONSHIPS

2.1 | Ports and local economic development

As argued by Brocard et al. (1995), the literature provides numerous examples of port-city relationships in the form of monographs, but a theoretical framework remains lacking. A longstanding debate exists about the direction of influence between port and city (Boyer et al.,

1982), the historical evolution from port-city synergy to separation (Bird, 1963; Hoyle, 1989; Murphey, 1989), and the variation of this evolution across the world (Lee et al., 2008). Following the seminal work of Hayuth (1982) on the port-city interface, Hoyle (1989) explained the “functional dissociation” by four main factors: 1) the evolution of maritime technology (particularly the development of container terminals), 2) the scale of modern ports (vast lands and water space requirements), 3) the decline in port-related employment within port-cities and 4) the environmental perspectives. His port city evolutionary model was ultimately updated by adding a new “phase” whereby ports and cities came back closer to each other at least functionally.

The relationship between transport and regional development has become an important component of the regional sciences literature since the 1990s with the development of the New Economic Geography (NEG). Krugman’s seminal article (Krugman, 1991) marks a turning point in the consideration of the interactions between economies of scale and transport costs. The combination of low transport costs, strong scale economies, or a high manufacturing share, leads companies to agglomerate in the region that has these characteristics. The aforementioned work of Fujita and Mori (1996) was the first to propose a model of economic geography that studies the role of ports in the development of major cities. Their model proposed to go beyond the neoclassical view of port cities, where the initial comparative advantage (i.e. easy and cheap access to the sea) allowed ports to develop as large cities: “in an economy having a core-periphery dualism, in order to promote the industrial growth in the periphery, it is not always helpful to improve the transport connection between the two regions” (p. 97). However, the empirical literature barely refers to their model, which remained theoretical.

Many econometric models seek to assess the impact of port activity on local economies. For instance, Park and Seo (2016) found that there is a throughput threshold below which cargo ports obstruct regional economic growth. In a similar vein, Shan et al. (2014) provided empirical evidences for the positive impact of a seaport on the economic growth of the host city and for the

positive effect of competition from neighbouring ports, illustrating the concept of *coopetition* – i.e., the fact that port cities in the same region would benefit from mixing competition and cooperation to boost maritime flow of the region. Bottasso et al. (2014) concluded to positive direct effects of port throughput on port regions and large and positive spillovers in nearby regions. Other scholars analysed the trade patterns of port hinterlands (Debie & Guerrero, 2008; Ferrari et al., 2011) and the role of port infrastructure in the international trade orientation of regions (Wilson et al., 2004; Bottasso et al., 2018). In particular, Marquez-Ramos (2016) and Moura et al. (2019) looked at the role of regional spillovers and economic size in explaining the intensity of provincial maritime flows.

2.2 | The role of specialization and geographic scale

Tabuchi and Thisse (2002), combining a model of economic geography with a discrete choice model of migration, showed that there is a commodity-specific dimension of agglomeration and dispersion forces influencing the spatial distribution of goods flows. This result is particularly relevant in the case of port studies since we suppose that different cargo types follow different spatial patterns. It can be hypothesized that this occurs in relation with the economic specialization of the port area and its hinterland (Haefner et al., 1980; Marti, 1985). This dimension was explored by Guerrero (2014) who built a spatial interaction model to analyse the hinterlands of different types of cargo across French “départements” (NUTS-3 regions). He demonstrated that main cargo flows, mostly bulky commodities, are tied to local regions, while containers, which concentrated at fewer ports, experienced less spatial friction. Drawing on Guerrero’s approach, Wang et al. (2018) showed that distance remains a key factor in the distribution of cargo flows between ports and hinterlands. They also underlined the fact that large ports are characterized by decentralization (i.e., cargo tends to be distributed across larger distances in the hinterland when throughput increases) even if local and adjacent provinces remain the main outlets for cargo traffic. These results imply that *size* of the port and *distance* – or hinterland area – do matter and that a multi-level approach is

highly justified to analyse port-city and port-hinterland relationships. As such and according to Hesse (2013), the internationalisation of the maritime network and the evolution of port hubs make port and city part of ever larger associations, while increased transport and logistics costs raise the question of possible dispersion effects (see also Beyers & Fowler, 2012). This spatial scale effect is confirmed by the work of Ducruet et al. (2018), showing a declining traffic/population correlation at the level of port cities, but a growing correlation at the level of port city-regions. This was interpreted as a proof of the physical disconnection between ports and cities locally, but also of a maintained and increasing functional interdependency regionally, due to the transformation of landward transport systems and the rise of trucking.

Other works have underlined the role of specific traffic or sectors basing the port-city or port-region relationship. Ferrari et al. (2012) found a positive impact of port throughput on regional employment in Europe, especially when ignoring liquid bulk. Fageda and Gonzalez-Aregall (2017) found that port traffic had a positive and statistically significant direct impact on employment in the manufacturing sector, and that a large port may generate positive effects on neighbouring regions. Across European ports, while traffic diversity is positively related with traffic size, medium-sized ports can also be very diversified when located in large cities and/or remotely from the European economic core – away from port competition (Ducruet et al., 2010). Ducruet et al. (2015) and Ducruet and Itoh (2016) detected interdependencies between port specialisation and regional specialisation, such as the concentration of bulk traffic in regions specialized in the primary sector, containers and general cargo in dense urban regions, richer than average, and specialized in the tertiary sector.

The work of Peris (2015) on French regions (*départements*) stands out by the numerous lessons learned about the relationship between port specialization and regional economic specialization. Customs data allowed calculating the share of port regions in total port traffic, concluding that low value flows travel less than other flows. This work also differentiated port regions according to the

coherence between the respective evolution of traffic and employment, such as metals products and steelworks (Boulogne, Dunkirk), agricultural products and agriculture (Bordeaux, Rouen, Sète, La Rochelle, Bretagne), construction materials and mining (Languedoc, Basque country), oil products and refinery (Nantes, Marseilles-Fos), solid combustibles and energy production (Le Havre). Nevertheless, what remains missing is an analysis at the thinner level of the city, using a wider set of traffic and employment variables, which we propose in the following sections.

2.3 | Main hypotheses

Port traffic includes a wide range of products, which depend on different economic logics, technologies, and markets. As such, ports are more or less specialized and serve a hinterland which geographic extent may vary in time and space (Guerrero, 2014). As remarked by Hoare (1986) already, the rapid evolution of maritime and land-based transport networks eroded the geographical constraints that made port hinterlands relatively captive, i.e. within the range of the city-region or province. According to port system evolutionary models, the phase of port regionalization accentuated the inland penetration of port and logistics activities beyond the traditional borders of the port city and its immediate hinterland (Notteboom & Rodrigue, 2005). In such models, which encompass both developing and developed economies at different time periods, port traffic growth is often occurring in parallel with hinterland expansion (Brocard, 2009). Shippers and wholesalers may not even use the local port for their activity (McCalla et al. 2001). Nevertheless, it is important for local authorities to understand the linkages at stake between their host industries and the port, despite the importance of transit trade and transshipment to/from other areas.

Several hypotheses must be tackled to assess the relationship between commodity flows and local economies:

H1: there is a relationship between size and specialization

H2: traffic specialization and economic specialization are mutually linked

H3: the branching between traffic and industries is a matter of scale

The first hypothesis (H1) questions the relationship between hierarchy and specialization. This step of the analysis is crucial as it constitutes the first attempt to check the effect of port city size on the structure of port city traffic in France. It also constitutes an important phase of data quality validation. Local economies might not always use the local port and the latter might serve distant locations of which inland, especially in a core-periphery context like in France. This hypothesis can be tested at port level, to check the coherence of the port system itself (i.e. are larger ports more diversified?), and in a comparative manner, to check whether larger cities handle more diversified traffic (cf. Ducruet et al., 2010; Ducruet, 2020a), and whether larger traffic occurs in more diversified economies.

The second hypothesis (H2) is the most challenging part of our analysis, as it assumes that specific traffics relate with specific economic activities at the local, port city level. This hypothesis rests on two combined issues, sectoral and directional. The sectoral issue means that traffic is not a priori bound to a specific industry, but this depends on the level of aggregation. For instance, the primary sector may handle agricultural products (solid bulks) such as grain but also fertilizers (liquid bulks) as well as ores, minerals, construction materials (mining), while the industrial sector consumes raw materials (solid and liquid bulks) and produce semi-finished or finished goods that can be more or less containerized. In the work of Ducruet and Itoh (2016), energy flows of which solid bulks (e.g. coal) and liquid bulks (e.g. oil products) concentrated in regions specialized in the tertiary sector (urban regions), as well as containers for the consumption of finished goods. The directional issue relates with the sectoral issue in a sense that the relationship between a given sector

and a given traffic will make sense depending if the commodity is imported or exported. As a result, one same traffic may relate to different activities. The best example is container, which can be – at the same time or not – imported for consumption (wholesale and retail), exported from production (manufacturing), and in all cases transported over land but more or less stored and opened (transport and logistics, warehousing). Unfortunately, available data does not specify the exact destination, origin, and use of cargo flows.

This complexity leads us to test a third hypothesis (H3) where the spatial unit in relation to port traffic is extended to a more or less distant neighbourhood. It assumes that the local economy might be served by a neighbouring port and that economic activities situated outside the port city might better explain port traffic structure, as the clients of the port can be situated further in the hinterland. We expect that the linkages between port activities and economic activities shall intensify as the spatial unit of analysis gets larger, especially for large ports and depending on the type of products handled, which travel more or less far to/from the port (Guerrero, 2014).

3 | DATA AND METHODOLOGY

3.1 | Data presentation and preparation

Port activities are defined in our research by the amount and type of maritime traffic realized by vessels calling at 120 metropolitan French ports in 2016. Obtained from *MarineTraffic.com*, this data is the result of an Automated Identification System (AIS) whereby ship positions are recorded on a regular basis along their voyage (Artikis & Zissis, 2021). The choice of this source is motivated by the limitations of the French Ministry of Ecological Transition in charge of Transport, which only provides data for the main five ports of the country. Although France hosts about 500 seaports and river ports in total, their activity in terms of traffic is not recorded systematically, as many of them are under the control of local administrations or chambers of commerce. While Eurostat

covers a much wider sample with 62 French ports, traffic data per ship type is only available for 22 of them.

Raw traffic data was attributed to ports on vessels' in-port positions, making it possible to calculate the product between call frequency and vessel capacity throughout the year, resulting in total port traffic measured in deadweight tons. Figure 1 shows the breakdown of main traffic categories, after merging the original 11 ones into 6, with containers being the heaviest traffic and general cargo the lightest. To allow a joint analysis of port activities and local economic activities, it was decided to assign ports to their respective travel-to-work area, resulting in a total of 54 labour areas. As seen in Figure 2 and as expected, the labour areas of Le Havre and Istres-Marseilles rank way ahead of other places, as they host the largest container and oil ports of the country. The sample also includes inland river ports of which Paris and Lyon, although their activity is more local (Paffoni, 2013)². River ports are mainly involved in the handling of construction materials, urban and industrial waste, and containers for urban logistics, compared with seaports having a maritime 'foreland'.

[Figure 1 here]

In our study, we use data on employment collected by French National Institute of Statistics and Economics Studies (henceforth the INSEE). This information is gathered in a data set called DADS ("Déclarations Annuelles de Données Sociales"). This latter consists of a large collection of matched employer-employee data derived from the mandatory employer reports of the earnings of each worker to tax agencies. Each observation in the data set corresponds to a unique employee-firm-year combination. In terms of content, we have detailed information on the employee like the

² In addition, the measurement of their shipping activity via AIS antennas located inland and subject to signal fuzziness is not as concise as for seaports, thus carrying the risk of underestimating traffic.

sex, age, place of birth, total earnings during the year, occupation category and part or full-time of jobs, as well as the location and industry of the employer's establishment.

To undertake our investigations, employment data were aggregated by location (304 employment areas³) and industry (38 categories). To consider data availability; we limit this research to the year 2016. Geographical breakdown to labour market area is particularly relevant for local economic studies since it is free from administrative divisions, makes easier the detection of local agglomeration forces and the study of spillover effects. OECD (2002) refers to them as “functional regions”. As for industrial categories, we use the Statistical classification of economic activities in the European Community (NACE Rev. 2) in 38 sectors more appropriate to stress links between port traffic and port-city or hinterland area activities. The year 2016 was the most recent one at which maritime and employment data were available. Unfortunately, data on transport infrastructure, urban Gross Domestic Product, and import/export flows with true origins and destinations were not available at the city (labour area) level.

[Figure 2 here]

3.2 | Analytical framework

In order to examine the relationship between size and specialization (H1), the diversity index (DI) (see Duranton and Puga, 2000) is calculated for each labour area as the sum of the absolute differences between the share of traffic (or employment) j ($j=1,..,J$) in labour area i ($i=1,.., I$) and the share of the corresponding traffic (or employment) j at the national level as follows:

³ Employment area or zone is a cluster of municipalities within which most of the labour force lives and works. They are defined periodically by INSEE. We use in this study the zoning of 2010.

$$DI = 1 / \sum_j |S_{ij} - S_j|$$

Where S is the share of traffic (or employment).

A number of methodological choices have been made to test the second hypothesis (H2) and facilitate the discovery of hidden information, mainly consisting in reducing the number of variables. Certain port traffic variables were merged due to their high mutual correlation, such as passengers/vehicles, general cargo/reefer, and crude oil/gas/oil products/other tanker (liquid bulks), resulting in a total of six traffic variables including also containers, chemicals, and solid bulks. Numerous employment variables were omitted due to their absence of correlation with port variables, mainly in the tertiary sector (e.g. public administration, financial services, electricity and water, construction, etc.). The six retained variables are as follows:

- Agriculture and mining (primary)
- Trade, entertainment, and accommodation (tourism)
- Refineries and chemicals (transformation)
- Transport and warehousing (logistics)
- Food, textile, and paper pulp (production)
- Metals, machines, and equipment (manufacturing)

Based on a total of 12 variables expressed as a percentage or in terms of relative share (the descriptive statistics are shown in Table A1 in the appendix), we investigate the linkages at stake between traffic and activities through a Principal Components Analysis (PCA). This method was chosen as it reveals proximities among variables and among port cities⁴. The main applications of

⁴The idea is to summarize a set of p measured variables on n individuals by a small set q of derived variables ($q < p$). These are called principal components; they are linear combinations of the p original variables. These new components or axes are uncorrelated, and are ordered so that the first few retain most of the variation present in all of the original variables. The technique has proved useful in other statistical methods, such as linear regression, linear discriminant

PCA are descriptive and exploratory, rather than inferential. PCA is a very adaptive method because it doesn't require any distributional assumptions about data.

The diversity index and the dummy for river city were added as illustrative variables.

Geospatial methods were used to test the third hypothesis (H3) about the varying spatial extent of the local study area (see Figure A2 in Appendix for a graphical illustration). While the first PCA is applied to strictly labour areas containing ports, the ulterior ones extend the spatial unit in three different and consecutive ways. We defined labour areas' neighbours by applying a spatial weight matrix based on binary physical contiguity (i.e., when areas share a common border of non-zero length.)⁵. The second PCA is based on first-order contiguity, thereby considering the employment and traffic structure of the new spatial unit composed of the initial labour area and its closest neighbours. The third PCA is based on the assumption that larger ports distribute goods over wider hinterlands, so that the geographic area in which employment is counted has been adjusted to traffic levels, contrary to previous empirical works using a fixed spatial unit. Based on three percentiles of weighted traffic⁶, small ports are attributed to the belonged labour area, medium-sized ports to the second-order contiguity area, and large ports to the third-order contiguity area. It was decided to perform the latter analysis without river port cities, since seaport cities are much

analysis, etc. It is also a very adaptable tool that allows analysis of datasets that may include, for instance, missing values, multicollinearity, categorical data, etc. However, one significant limitation of this statistical method is that the new variables defined are generally linear functions of a p -dimensional dataset (for more details see Jolliffe and Cadima, 2016).

⁵ Operationally, the elements of binary contiguity matrix W are non-zero when the spatial units i and j are neighbours (and zero otherwise). Higher order contiguity weights are constructed in the same way as the first order but with a specification of a threshold. This latter refers to a lower order neighbour. Thus, with these different specifications, it can be possible to check for the sensitiveness of the results to the neighbourhood matrix chosen. The first weight matrix assumes that hinterland is bounded by areas within the considered threshold of geographic proximity, while the others assume that hinterland expands to more distant regions.

⁶ Traffic was weighted according to the method of Charlier (1994), which applies a reduction coefficient to different traffic types to get total traffic closer to its monetary value and to its local employment generation power. Crude oil is divided by 12, other liquid bulks by 9, solid bulks by 6, containers and ro-ro (including passenger transport) by 3, and general cargo remains unchanged. Another reason to use this method is that a noticeable proportion of liquid bulks reach the hinterland through pipelines. It also has the effect of adjusting traffic to its level of spatial friction, as containers and general cargo travel over longer distances (Guerrero, 2014, Wang et al., 2018).

more concerned by hinterland penetration and economies of scale. The last PCA is the same analysis but starting with small ports attributed to second-order spatial units.

4 | MAIN RESULTS

4.1 | Diversity increases with size

One first step of the analysis has been to test the relationship between size and specialization using disaggregated data, at the port level and with 11 traffic categories. The four main components concentrate no less than 78.3% of total variance. The distribution of variables along the first two components is meaningful, thereby confirming the accuracy of the data (Figure 3, left). Total traffic, measured in logarithm to lower the size effect of extreme values, is the best represented variable, while others are also projected on positive values on F1, indicating that “size” predominates over specialization: larger ports are more diversified. This tendency is somewhat reflected by the correlation between total traffic and traffic diversity (Figure 3, right), in line with a global-level analysis using a different data source (Ducruet, 2020b). The latter work also highlighted the opposition here on F2 between liquid bulk traffic (negative) and more valued traffic (positive).

[Figure 3 here]

Results show that for all cities, port traffic diversity is very sensitive to the size of the local economy, as traffic diversity increases with employment volume. This is truer for coastal cities, for which the largest ones reach a diversity of 1.05 compared with 0.89 for all cities and 0.68 for river cities. The lower traffic diversity of river cities is explained by a more local activity, bound to a limited number of functions such as the handling of urban waste, construction materials,

combustibles, and some container shipping, while coastal ports are less spatially constrained and connect international trade networks. Yet, medium-sized ports like Brest, Lorient, and Bordeaux are among the most diversified, having a score comparable with Dunkirk, Marseilles, and Le Havre (cf. Figure A1 in Appendix). Such a phenomenon was observed across Europe by Ducruet et al. (2010), whereby port cities situated in the periphery handle multiple flows to serve a relatively captive hinterland. Conversely, the large port of Rouen is more specialized than Caen that is ten times smaller, mainly because Rouen handles enormous volumes of dry cargo, as Europe's largest port for grain and other agricultural products.

[Table 1 here]

Conversely, the diversity of employment (based on 38 categories) has been tested in relation with traffic size. While the relationship is not as straightforward as in the previous analysis, we observe that cities handling the largest traffic are the most diversified economically (quintiles 4 and 5 for coastal cities). River cities are, on average, more diversified than coastal cities given their role as central places in the land-based transport system. The correlation coefficient (Pearson) between traffic diversity and employment diversity is not significant, should it be for all cities ($R^2=0.12$), coastal cities ($R^2=0.20$), and river cities ($R^2=-0.25$).

[Table 2 here]

Despite the absence of a linear relationship between size and specialization, such evidence confirms our first hypothesis on the link between size and specialization. Larger cities handle more diversified traffic, and larger ports are located in more diversified cities. This interaction offers a fertile ground to go further and test its nature, in terms of cross-specialization between port and other economic activities.

4.3 | Traffic specialization relates with local economic specialization

Results are significant (Figure 4), since 71.34% of total variance is captured by the 5 first components with respective eigenvalue > 1 . The first two components F1 and F2 illustrate the main trends, by which passenger and vehicle traffic is close to “tourism”, an association which could not be captured by previous works as passenger traffic was overlooked. This association is meaningful and particularly applies to port cities in the Mediterranean (Corsica, Nice, Toulon, Arles, Cannes) and along the Channel (Caen, Honfleur, Calais). General cargo and reefer traffic are close to “primary” and “production”, which is plausible as this type of traffic may include very diverse goods such as timber, paper, fertilizer, fruit, chemicals, building materials and structures. It is interesting to note that “manufacturing” also is close to general cargo and reefer on F2 (negative values), as general cargo also includes metal products in diverse forms (bars, tubes, scrap). Related port cities include Boulogne-sur-Mer (steelworks), Rochefort (fertilizers, wood, scrap metal, grain, corn, sand, cement), and Granville (construction materials, gravels, scrap, seafood), thereby confirming the adequation between ports and local economies.

Variables projected negatively on F1 also share commonalities, such as transport / logistics activities and container traffic, “transformation” and chemicals, liquid bulks. As confirmed by the plot of F3 and F4, the river dummy is associated with liquid bulks and the diversity index with container traffic. Le Havre and Marseilles are exemplary of such associations, being the largest ports and the second and third most diversified ones, handling large amounts of containers and liquid bulks, a category which also includes Dunkirk and Rouen, although the latter is less diversified.

Based on these results, it is possible to validate our second hypothesis H2 about the mutual specialization between port traffic and local economy. However, certain variables such as solid bulks are difficult to interpret in the current PCA, as one could have expected to see this traffic closer to the primary sector for instance. In addition, chemicals traffic and “transformation”

(including chemical industries) are opposed on F2 although they share a similar nature. While such a state of affairs may relate to the aforementioned sectoral and/or directional bias, it can be expected that this mutual specialization gets more significant when enlarging the unit of analysis, thus leading us to investigate the next hypothesis.

[Figure 4 here]

4.4 | **The mutual specialization is stronger in the neighbourhood**

The unit of analysis has been enlarged from the port city itself to the adjacent labour areas of the port city (Figure 5, top). Results are significant, since 75.68% of total variance is captured by the 5 first components with respective eigenvalue > 1 . This higher significance than in the previous analysis validates our hypothesis: the relationship between traffic and employment is more significant when extending hinterland coverage. Not only has the overall relationship improved, but cross-specializations had become more meaningful, except for the stable closeness between “tourism” and passenger/vehicle traffic, with a strong Mediterranean base. The former opposition between solid bulk and the primary sector is now an association on F2, with Bordeaux as an exemplary case. As noted by P  ris (2015), the Gironde *d  partement* is strongly specialized in agriculture (of which wine production), while Bordeaux port is specialized in agricultural products, food products, and fertilizers. This association is also meaningful for ports such as Bayonne (construction materials, ores, mining), La Rochelle (agricultural products, food products, agriculture), Brest and Lorient (food products, fertilizers, agri-food business). In the upper-left quadrant, solid bulk traffic (and general cargo traffic to a lesser extent) is also associated with “production” (of which food industries and paper pulp), thereby strengthening the logic of the observed trend. Lastly, the former opposition between liquid bulk traffic and “transformation” had become an association, in the bottom-left quadrant, which includes the emblematic case of Marseilles-Fos. This mutual specialization was also underlined by P  ris (2015) at the regional level.

The next PCA (Figure 5, middle) further validates our hypothesis (H3), as 80.34% of total variance is contained in the 5 first components with eigenvalue > 1 , while the first two components alone concentrate nearly half (46.20%), a much higher significance than previous analyses (Figure 5, middle). The mutual specialization between port traffic and local economic structure also gained in clarity and meaningfulness. Negative values on F1 group passenger and ro-ro traffic with “tourism”. This trend particularly well applies to Corsican and Mediterranean port cities, and to a lesser extent to Calais and Cherbourg. Another relevant trend (bottom-left quadrant) is the association between the primary sector, “production” (food, textile, paper pulp), and general cargo/reefer traffic. Fresh products can be produced by the agricultural sector, while general cargo ships may carry intermediate inputs for such industries. This is particularly true for Brittany port cities such as Saint-Brieuc, Quimper, Lorient, and Brest, but also numerous Atlantic ports including Les Sables d’Olonne, Challans, Rochefort, Bordeaux, Bayonne, and Granville in Normandy, the latter being France’s largest port for sea shells. The association between “manufacturing” (metals, machines and equipment), “logistics” (transport and warehousing), “transformation” (refineries and chemicals), and container traffic had become more evident as such variables are positively projected on F2. This trend, if we exclude the Dieppe outlier, is best represented by the three major ports of Rouen, Le Havre, and Marseille. The last noticeable trend is formed by the closeness between manufacturing, solid bulk, chemical, and liquid bulk (and to a lesser extent container) that applies to the nearby ports of Nantes and Saint-Nazaire, which form an important petrochemical complex as well as an agri-food cluster.

[Figure 5 here]

Lastly, we tested the PCA starting from the close neighbourhood for smaller traffic ports (Figure 5, bottom)⁷. Results slightly improved, with 81.40% of total variance contained in the 5

⁷ The neighbourhood structure constructed using different contiguity matrix is as follows: to the class of small traffic we attributed the first order neighbours, then the second order neighbours to the medium-sized traffic class and finally the third order neighbours to the largest traffic class.

first components with eigenvalue > 1 , and 48.14% for the first two components alone. The position of variables in the scatter plot of F1 and F2 did not change much, however (Figure 5, bottom). More evident is the emergence of a strong geographic logic behind the position of places along the two first components. A majority of southern ports is grouped on F1 negative values (tourism, passengers and vehicles), while Corsican ones form a distinct subgroup on the bottom-left. Ports of Normandy occupy the upper-right quadrant (Dieppe, Le Havre, Rouen, Honfleur, Caen) together with Dunkirk, marked by a specialization in containers, refineries/chemicals and manufacturing, but also transport and warehousing (F2 positive values). The bottom-right quadrant groups a majority of Atlantic coast ports, with a specialization in “production” (food, textile, paper pulp) and general cargo as well as the primary sector (negative values on F2). Such a spatial distribution corresponds to the economic geography of French coastal regions, which was less evident in the previous analyses.

4.5 | Towards a typology

Based on the latest PCA, we ran a hierarchical clustering to classify ports and their host territory, and to verify the effect of mutual specialization in each obtained cluster. Table 3 displays the average employment and traffic share for each of the four clusters.

[Table 3 here]

Cluster 1 is made of individuals in the Channel (mainly Picardy and Normandy) and in the Mediterranean. They share high values in 1) coking and chemistry, 2) passenger transport and 3) transport and warehousing (i.e., logistics) while they are also characterized by low values for the primary sector. Although values are low for chemical traffic and transformation, they are higher than in other clusters and underline a logical mutual specialization.

The second cluster (2) comprises the largest ports of which all the Grands Ports Maritimes managed by the State. They have in common not to score the highest in any employment sector, but rank second for values in production and transformation. As large logistics hubs and petrochemicals complexes, they score the highest for shares in solid bulk, chemical, container, and liquid bulk. These large ports are also characterized by the most diversified traffic. Such places are not very specialized in the tourism industry, even if tourism is an important component of the economy of cities such as Nantes or La Rochelle. They share industrial strengths, with Le Havre and its neighbourhood focusing on automobile manufacturing and petrochemical industries, and the Nantes metropolis which is the leader in the agri-food industry at the national level and also has the second largest wholesale food market in France after Rungis, but which also a top-area in the aeronautic industry. Saint-Nazaire is France's largest shipyard, but also a center for aeronautical and mechanical engineering. Its port has an intense activity in the transport of refrigerated and food products and in shipbuilding and repair. Areas such as La Rochelle (aeronautics, naval, chemicals) or Saint-Brieuc (metallurgy, food processing, chemicals) also help explain the importance of industrial sectors in this cluster.

The third cluster (3) is composed of only five places but stands high for production, manufacturing, and general cargo. It confirms the association between general cargo and these activities as seen above. This is logical in the case of Granville (seafood as reefer traffic, wood with food and paper pulp) and Sables-d'Olonne, but also Boulogne-sur-Mer and Saint-Brieuc (metals, machinery), and Rochefort for the aeronautics industry (spare parts) and yachting shipyards.

Cluster 4, composed of Corsican ports, is characterized by high values in tourism, passenger, and the primary sector. As Corsica is characterized by an extremely important weight of tourism in its economy, which represents about one third of the GDP (Insee, 2015), this cluster can be described as a "tourism cluster". Moreover, the individuals of this cluster share low values for 1) Metals, machines, and equipment, 2) Food, textile, and paper pulp, 3) Coking and chemistry and

4) General reefer. The heavy reliance on tourism is therefore accompanied by a rather low level of industry. Corsica falls into the category of "small island tourism economies" (SITEs, see Shareef & McAleer, 2005; McElroy, 2006; Peterson & DiPietro, 2021): the region is not very industrialised and is small in size, but has natural amenities (landscapes, warm sea, beaches, mountains, etc.) which make it very attractive for tourists. The island character of such ports is a common limitation in terms of hinterland coverage and maritime connectivity is vital to palliate isolation (Zwier et al., 1994). Yet, unlike other island ports of the Mediterranean (e.g. Sardinia, Malta, Cyprus), Corsica has not developed container transshipment functions due to its higher deviation distance from the main trunk lines (Zohil & Prijon, 1999).

5 | CONCLUSION

The aim of this study is to investigate linkages between port traffic and local economic structure in France. While most of academic contributions focus on the economic relevance of port infrastructure to regional development, the studies addressing the local embedding of material or commodity flows are still scarce, especially in the context of France. This paper contributes to filling this gap, by applying a set of quantitative techniques to a sample of ports and their 54 corresponding local economies in 2016. The latter correspond to labour areas, which have the advantage to be functional spatial units comparatively to administrative units. Specifically, we investigate the cross-specialization of ports - proxied by maritime flows - and local economic structures - proxied by employment.

Our findings disclose statistical evidence on the interwoven relationship between ports and local (city port) or regional economies, but with some notable differences depending on the type, amount of port traffic, and the spatial extent of the hinterland. Three main outcomes were obtained.

First, the results confirm the correlation between size and specialization (hypothesis 1) even though the relationship is not linear. Overall, we find that larger cities tend to score higher on the traffic variety index. This recalls the findings of Ducruet et al. (2010) about European ports.

Second, our outcome supports that traffic specialization and economic specialization are mutually linked (hypothesis 2). Some of the interdependencies between port traffic and regional characteristics are more obvious than others. For instance, passenger and vehicle traffics are concentrated in areas specialized in the tourism industry, such as port cities of the Mediterranean (Arles, Cannes, Toulon, Nice, Corsica) and along the Channel (Caen, Honfleur, Calais). We find also two other affinities between, on the one hand, general and reefer traffics and primary and production sectors, and, on the other hand, the “manufacturing” sector and general cargo traffic. Nonetheless, certain expected associations such as solid bulks and primary sector, or between chemicals traffic and the “transformation” sector that encompasses chemical industries, need more investigation.

Third, we find evidence that the relationship between port traffic and local economy is more evident in the neighbourhood (hypothesis 3). The interconnection between weighted port traffic and employment is more significant when we extend the unit of analysis. This relation remains stable when river port cities are excluded from the sample. Seaport cities are much more concerned by hinterland penetration and economies of scale. This last analysis is accompanied by a typology that highlights the logistical and economic functions of seaport regions. The multi-level analysis thus confirms that despite the core-periphery pattern of the French economy, port activities are linked to their belonged local territories.

This research has important implications for port policy and management, and wider strategies in terms of urban, regional, and national planning and economic development. Results suggest that despite a widely acknowledged physical and functional ‘divorce’ between ports and local economies, which is mainly seen at the micro-level of the port-city interface, maritime flows remain

tightly linked to the outlying territory, should it be the port city itself or the wider region. This can motivate local actors to further attract port-related industries, in a context of possible reindustrialisation and nearshoring (van Hassel et al., 2021). It also shall motivate certain port authorities to reconquer their hinterland, as seen with the explicit will of Bordeaux Port to ship Bordeaux wine exports (of which 85% for Asia) instead of letting them reach Le Havre by road transport (Richard, 2019). Meanwhile, many areas of Le Havre's hinterland, such as Greater Paris, remain contested by Antwerp in Belgium, resulting in huge road traffic flows across the border. This research thus raises not only economic but also environmental (road transport pollution) and social (loss of employment) issues, which need to be addressed such as by the foreseen launch of a new "ecotax" by French regions, including Nouvelle-Aquitaine

In methodological terms, this research underlines that port traffic data can be seen as crucial territorial indicators that capture urban and regional dynamics. Port activities are rarely introduced in studies of cities and territorial development, which dominantly focus on people's mobility rather than freight (i.e. airports and high-speed rail) when assessing accessibility and attractiveness. Thus, our results motivate the inclusion of port variables besides other local indicators to balance analyses looking primarily at virtual rather than physical flows (cf. telecommunications, firms' networks) when dealing with local economic development. Theoretically, it nuances the model of Fujita and Mori (1996), mainly based on developing economies at the time (e.g. Seoul, Bangkok), by showing that French port activities remain tied with the 'local'. France is a former colonial power and an old industrial country, where numerous port cities have developed despite the centralization of Greater Paris.

Our analysis comes with three limitations. First of all, our maritime data are based on vessels' in-port positions, thus for each port Marine Traffic allocates its total traffic. However, no information is given on the direction (incoming or outgoing) of traffic flows, about the true amount of cargo handled at the docks, and for which precise origins and destinations. For that reason, our

findings must be handled with care. Secondly, our investigation offers a static picture of the association between port specialisation and local economic specialisation. It says nothing about the stability of these links over time or the direction of the causal effect. This amounts to question, if ports drive the development of the area in which they are located and in their hinterland, or, conversely, whether regional development generates a positive effect on port activities. Thirdly, our proposed approach needs to control for other modes of transportation, such as air traffic, railways and motorways⁸. This is particularly relevant for extended hinterland coverage where port-hinterland relationships can suffer from a cumulative effect of the presence of various modes of transportation. This is the case, for instance, for tourism port-region linkages where hinterland can have a good rail connection and/or an important air traffic density.

There are several other areas of possible improvement that could be addressed in future research. First, other metrics than traffic that can be used to characterize port activities, such as outbound and inbound flows, the value of foreign trade, and a more detailed classification of traffic types that would unravel the precise products and commodities carried as containers and solid bulks for instance. The same comment applies for regional economic development, which could be further detailed through more performance proxies such as value added, productivity, income, employment rate, etc.

Second, environmental indicators could be integrated into this analysis, such as air quality levels but also urban congestion levels, which relate to both port and city, and would have important implications in terms of related health risks for local populations. Specific port traffic and economic activities foster specific pollutions, while port-related freight movements (i.e. heavy-duty vehicles) are mixed with daily commuting along urban road arteries. Most of these negative impacts concern pollution (air, water and soil), noise and dust.

⁸ Data on connectivity of a location or accessibility (e.g., motorways and railways networks) are only available in France at NUTS-3 level.

Third, issue relates to the nature of relations between ports and the localities situated in their close hinterland, in terms of the spillovers that port throughputs bring to an area. The studies on the benefits of port activity stress that the positive effects can sprawl beyond the port city (see, e.g., Bottasso et al. 2014). This spillover effect to nearby regions raises a number of questions: should these regions take part in the governance of the ports? Should they co-finance port infrastructure? How should ports compensate such localities for the negative externalities generated by their activity through hinterland distribution? Further research on these questions shall inevitably bridge quantitative and qualitative perspectives, considering dynamics and practices taking place not only in France but also in Europe and the rest of the world.

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TABLE 1 Average port traffic diversity by city size and location type

Employment volume (quintiles)	All cities	Coastal cities	River cities
1 (small)	0.68	0.69	0.58
2	0.65	0.68	0.62
3	0.91	0.99	0.58
4	1.12	1.42	0.60
5 (large)	0.89	1.05	0.68
All	0.85	0.95	0.63

Note: We use the Kruskal–Wallis test, as the underlying assumptions for the F tests in ANOVA are violated. The test is not significant for all the port areas. For the other categories, we do not have enough observations to run the test.

The values in the table are the means by quintile class.

TABLE 2 Average employment diversity by traffic size and location type

Traffic volume (quintiles)	All cities	Coastal cities	River cities
1 (small)	2.88	2.55	2.96
2	2.80	1.93	3.12
3	2.26	2.26	-
4	3.25	3.25	-
5 (large)	3.15	3.15	-
All	2.88	2.82	3.04

Note: The Kruskal–Wallis test is significant at 5% for all the port areas.

The values in the table are the means by quintile class.

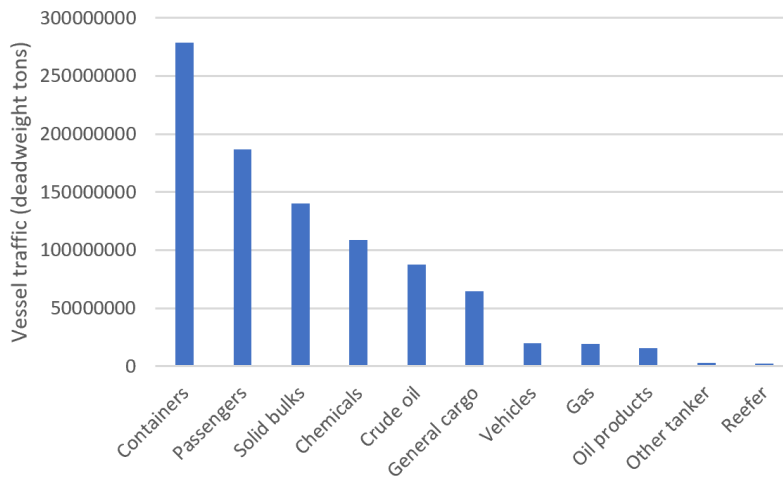
TABLE 3 Average employment and traffic shares of port clusters

Employment	Primary	Production	Transformation	Manufacturing	Logistics	Tourism
Cluster 1	0.72	5.24	1.10	3.90	5.22	17.13
Cluster 2	1.06	5.93	0.78	3.60	4.79	17.31
Cluster 3	1.51	7.18	0.37	3.96	4.48	16.55
Cluster 4	1.73	2.67	0.02	0.80	5.04	23.60
Traffic	Solid bulk	Chemical	Container	Liquid bulk	General cargo	Passenger & vehicle
Cluster 1	2.47	1.29	1.09	0.41	20.72	74.01
Cluster 2	20.92	15.87	15.07	12.30	26.95	8.90
Cluster 3	0.00	0.91	2.98	0.00	95.42	0.69
Cluster 4	2.20	0.00	0.00	0.00	0.15	97.65

Note: The optimal cluster solution in four groups is achieved by using hierarchical cluster analysis. The latter was performed on the five most significant principal components of PCA 4.

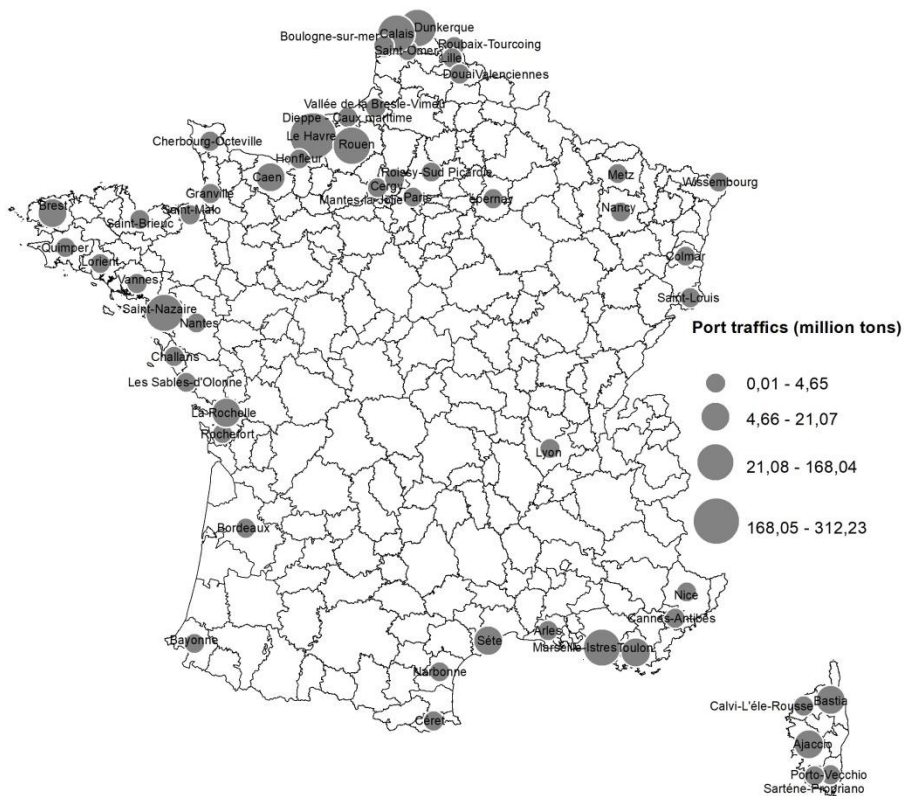
TABLE A1 Descriptive statistics of variables

Variables	No. Obs.	Mean	Std. Dev.	Min.	Max.
ALL (seaports & river ports)					
Agriculture and mining (primary)	54	0,01	0,01	0,00	0,03
Food, textile, and paper pulp (production)	54	0,04	0,03	0,01	0,15
Refineries and chemicals (transformation)	54	0,01	0,01	0,00	0,05
Metals, machines, and equipment (manufacturing)	54	0,03	0,03	0,01	0,15
Transport and warehousing (logistics)	54	0,05	0,02	0,02	0,18
Trade, entertainment, and accommodation (tourism)	54	0,19	0,04	0,12	0,33
Solid bulks	54	0,07	0,13	0,00	0,51
Chemicals	54	0,06	0,09	0,00	0,39
Containers	54	0,05	0,11	0,00	0,54
Liquid bulks	54	0,20	0,37	0,00	1,00
General cargo/reefer	54	0,28	0,36	0,00	1,00
Passengers/vehicles	54	0,35	0,41	0,00	1,00
Seaports					
Agriculture and mining (primary)	38	0,01	0,01	0,00	0,03
Food, textile, and paper pulp (production)	38	0,04	0,02	0,01	0,09
Refineries and chemicals (transformation)	38	0,01	0,01	0,00	0,05
Metals, machines, and equipment (manufacturing)	38	0,03	0,03	0,01	0,15
Transport and warehousing (logistics)	38	0,05	0,02	0,02	0,11
Trade, entertainment, and accommodation (tourism)	38	0,19	0,05	0,13	0,33
Solid bulks	38	0,09	0,15	0,00	0,51
Chemicals	38	0,07	0,10	0,00	0,39
Containers	38	0,07	0,13	0,00	0,54
Liquid bulks	38	0,05	0,14	0,00	0,71
General cargo/reefer	38	0,30	0,35	0,00	1,00
Passengers/vehicles	38	0,42	0,42	0,00	1,00
River ports					
Agriculture and mining (primary)	16	0,00	0,01	0,00	0,03
Food, textile, and paper pulp (production)	16	0,04	0,03	0,01	0,15
Refineries and chemicals (transformation)	16	0,01	0,01	0,00	0,04
Metals, machines, and equipment (manufacturing)	16	0,04	0,02	0,01	0,07
Transport and warehousing (logistics)	16	0,06	0,03	0,03	0,18
Trade, entertainment, and accommodation (tourism)	16	0,17	0,02	0,12	0,21
Solid bulks	16	0,00	0,00	0,00	0,00
Chemicals	16	0,03	0,07	0,00	0,24
Containers	16	0,00	0,01	0,00	0,03
Liquid bulks	16	0,56	0,50	0,00	1,00
General cargo/reefer	16	0,23	0,38	0,00	1,00
Passengers/vehicles	16	0,17	0,33	0,00	1,00



Note: The traffic categories are based on vessel types, as identified by AIS.

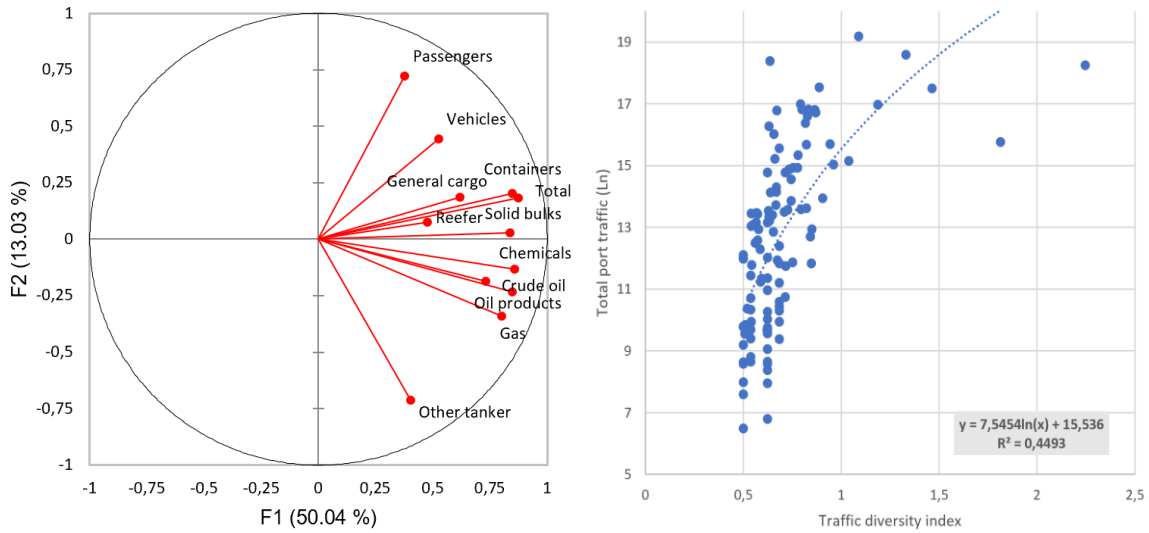
FIGURE 1 Port traffic distribution per main category, 2016



Note: The highest level of maritime traffic is recorded in the port area of Le Havre (312 million tons) while the lowest is recorded in the area of Valenciennes (616 tons).

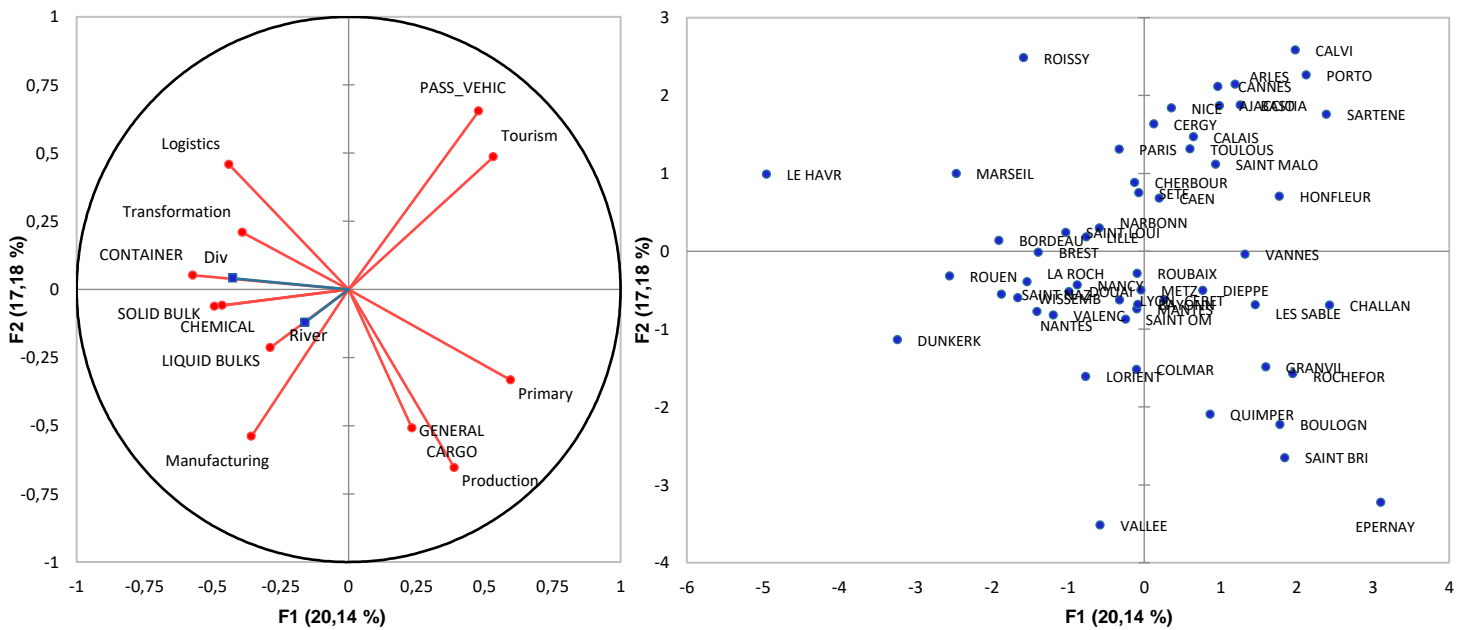
Scope: 304 employment areas in metropolitan France.

FIGURE 2 Traffic volume of French port cities, 2016



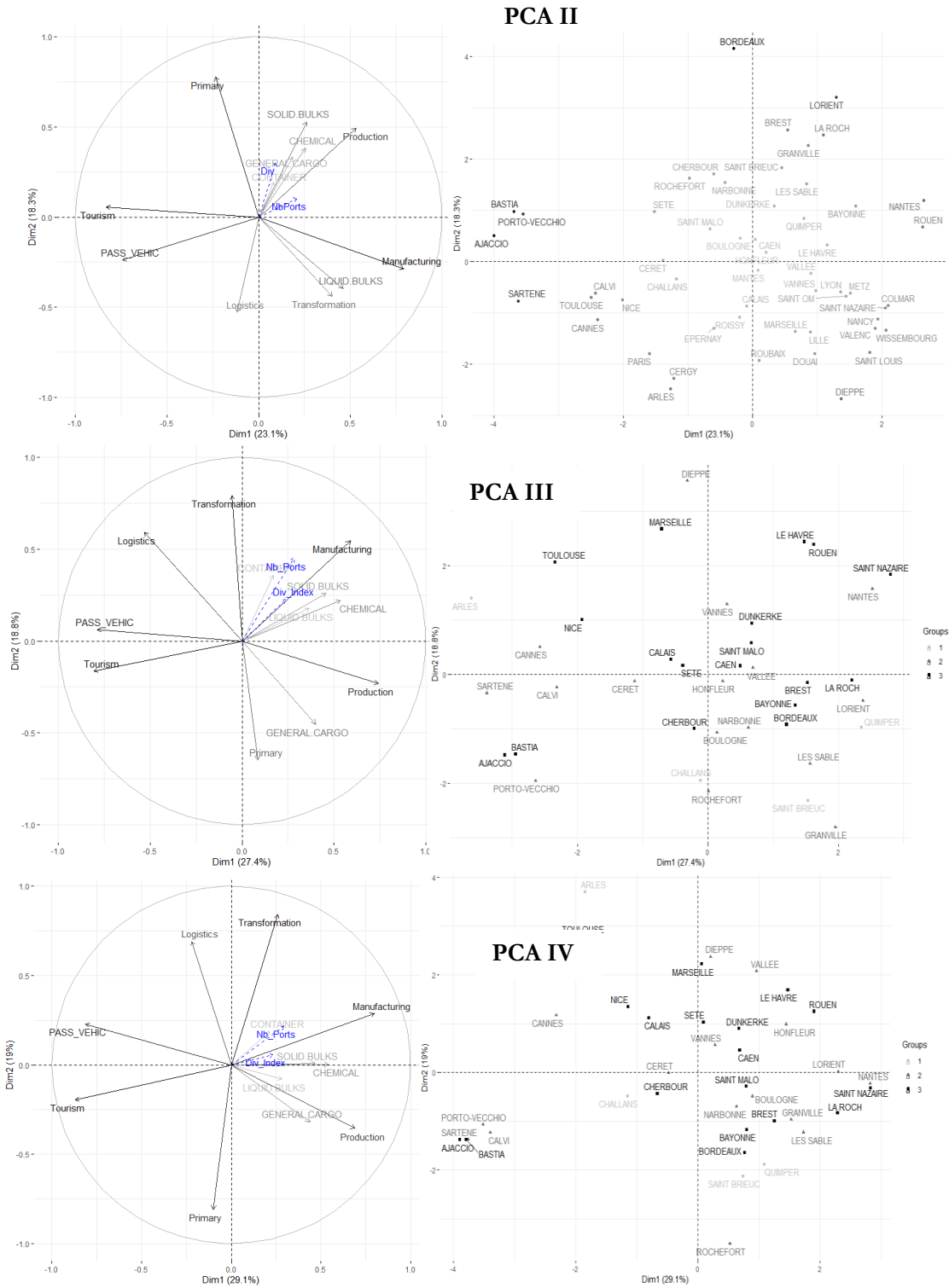
Note: The figure on the right plots the first two components loading vectors and shows the location of the variables in the multivariate space.

FIGURE 3 Principal components analysis of French port traffic



Note: The figure plots the first two components score vectors of PCA 1. On the left-hand side we have the location of the variables in the multivariate space, and on the right-hand side we find the location of the 54 individuals.

FIGURE 4 Principal components analysis of traffic and employment at port city level

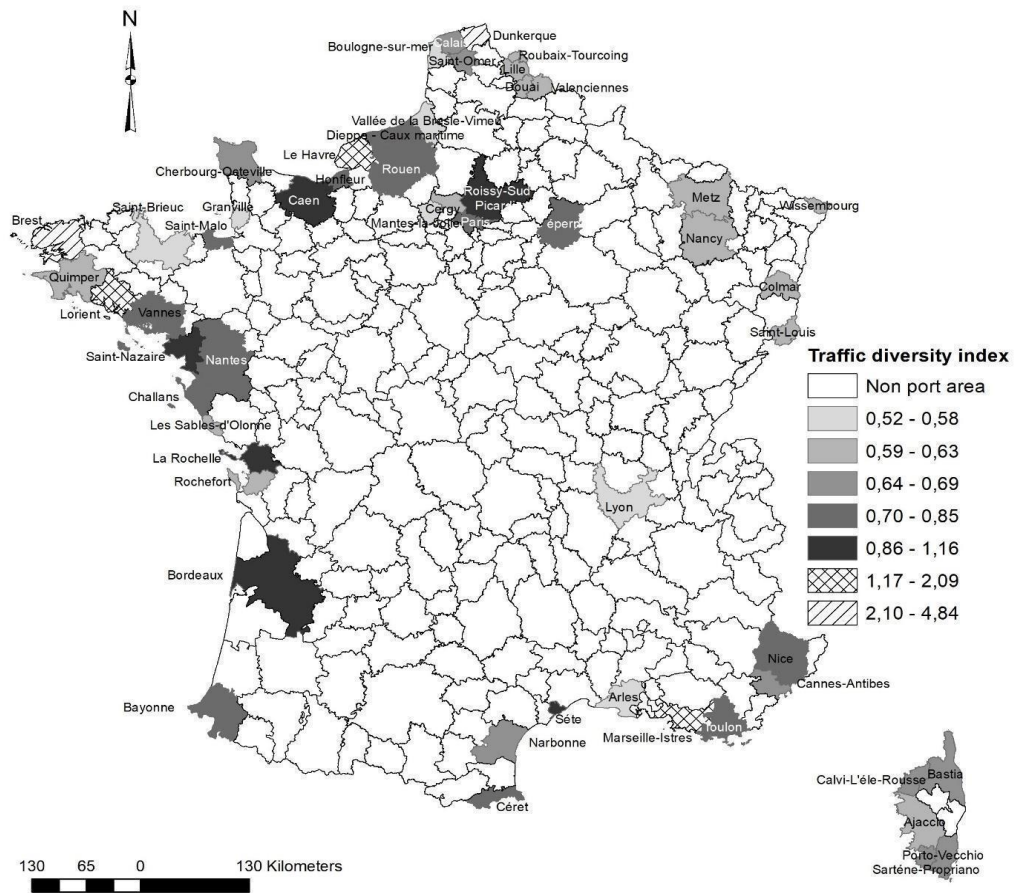


The correlation circle map on the left shows the projection of the original variables in the factors space. When two variables are far from the origin, then, if they are close to each other, they are positively correlated; if they are orthogonal, they are not correlated; if they are on the opposite side of the center, then they are negatively correlated. When the variables are close to the centre of gravity of the scatterplot, some information is carried on other axes. On the right, we have a plot of the position of the individuals in a two-dimensional principal subspace which allows detecting possible trends and clustering.

Groups 1 to 3 in the figure refer to port cities classes according to their total port traffic.

FIGURE 5 Principal components analysis of traffic and employment at various geographic scales (*Erratum: Toulon instead of Toulouse*)

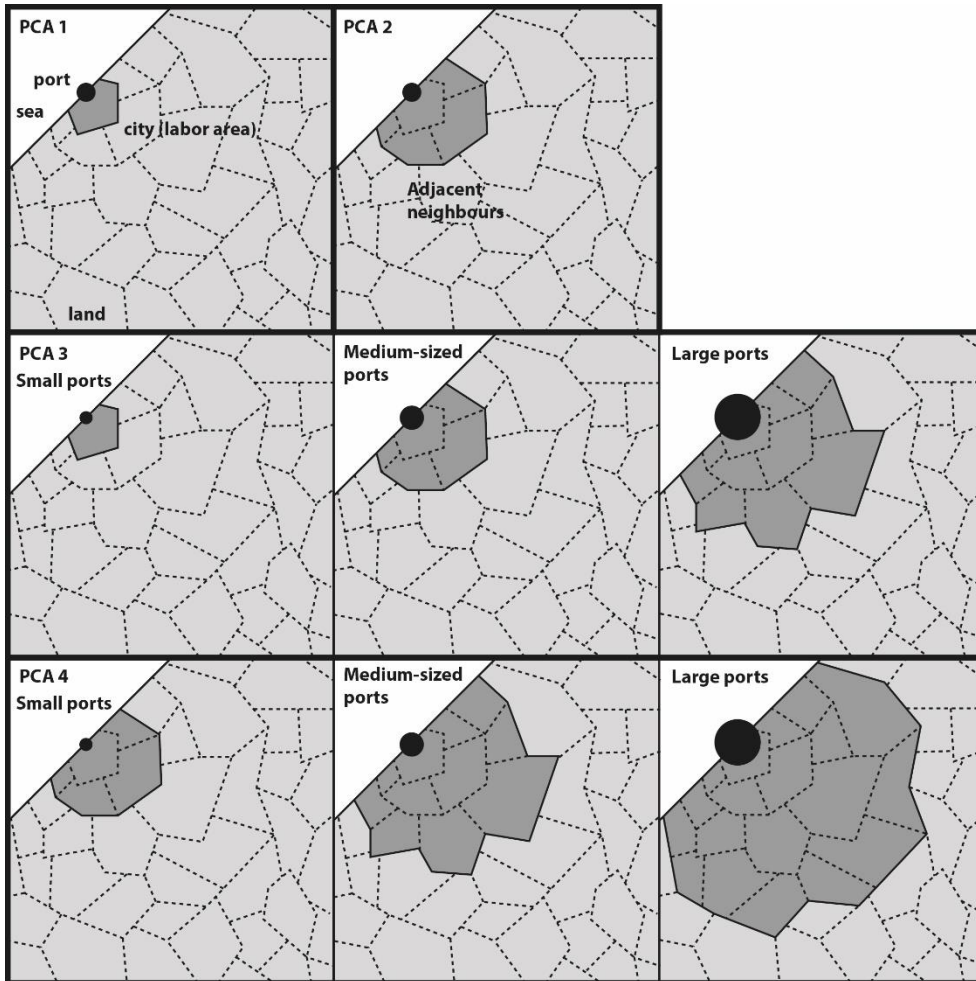
APPENDIX



Note: The traffic diversity index varies from 4.84 for the most diversified port city (Brest) to 0.51 for the least diversified (Arles).

Scope: 304 employment areas in metropolitan France.

FIGURE A1 Traffic diversity level of French port cities, 2016



Note: This methodology is applied in the principal component analysis reported in Figure 4 for PCA 1 and in Figure 5 for PCA 2 to PCA4.

FIGURE A2 The multi-level hinterlands approach