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Mounir Amdaoud
César Ducruet
Marc-Antoine Faure

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EconomiX - UMR 7235 Bâtiment Maurice Allais
Université Paris Nanterre 200, Avenue de la République
92001 Nanterre Cedex

Site Web : economix.fr
Contact : secreteriat@economix.fr
Twitter : @EconomixU

cnrs Université Paris Nanterre

Port-city linkages and multi-level hinterlands: the case of France

Mounir Amdaoud, Research Fellow at EconomiX, (CEPN, CNRS, Paris Nord University) – Email: mounir.amdaoud@economix.fr

César Ducruet, Senior Researcher at EconomiX, CNRS – Email: cesar.ducruet@economix.fr

Marc-Antoine Faure, Research Assistant at EconomiX, CNRS – Email: marc-antoine.faure@dauphine.eu

Abstract

The objective of this research is to examine the similarities between port traffic structure and economic structure of French port cities. Such an exercise is challenged by the core-periphery pattern of the French economy favouring transhipment. 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, thus considerably improving the statistical significance and economic meaningfulness of the observed linkages.

Keywords: AIS; hinterland; maritime transport; port city; specialization; supply chain

JEL CODES: O18, L90, R40, R12,

Relations ville-port et arrière-pays multi-niveaux : le cas de la France

Résumé

L'objectif de cette recherche est d'examiner les similitudes entre la structure du trafic portuaire et la structure économique des villes portuaires françaises. Un tel exercice est mis à l'épreuve par le modèle cœur-périphérie de l'économie française favorisant le transbordement. Les données AIS (Automated Identification System) de navigation maritime et celles sur l'emploi permettent des analyses complémentaires de la spécialisation mutuelle entre les ports et les villes. Les principaux résultats montrent que si les grandes villes ont un trafic plus diversifié, la spécialisation croisée est atténuée du fait de la complexité des chaînes d'approvisionnement et des réseaux d'échanges. Nous proposons ensuite une nouvelle méthodologie dans laquelle l'unité spatiale d'analyse est élargie en fonction du type et du volume de trafic portuaire, améliorant ainsi considérablement la signification statistique et l'importance économique des liens observés.

Mots-clés: AIS ; arrière-pays; transport maritime; ville portuaire; spécialisation; chaîne logistique

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 and Mori, 1996), or access maritime trade through nearby outports (Wackermann, 1998). Throughout the wide literature on port-city relationships, research has long been mostly qualitative, focusing on architectural, urbanistic, and social transformations taking place at the port-city interface, where the spatial and functional 'divorce' between port and city had been the most visible (Hoyle, 1989). Following the shift of modern terminals away from the city centre, numerous waterfront redevelopment initiatives reinforced the common belief that ports and cities had ceased to interact.

In turn, quantitative research on port cities has long been restricted to port economic impact studies. Robert Vleugels (1969), then General Manager of the Port of Antwerp, soon observed that such studies differ too much by their sources, methods, and results to allow identifying trends and regularities. 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). Despite such limitations, and as presented in more detail below, a variety of approaches had been proposed on the attractiveness of ports, the socio-economic status of areas surrounding ports, the influence of sea access on regional trade, the centrality of cities in maritime networks, and the regional branching of port activities. The latter analysis has never been applied at the city level, and existing research remains bound to aggregated variables. In addition, there remains a challenge to study port-city linkages in a core-periphery spatial setting. Port cities bear the costs of international trade flows passing through them, while most benefits go to inland regions as spillovers (OECD, 2014; Márquez-Ramos, 2016).

France is a good example of such a core-periphery structure, with an urban system centred upon the capital region. In 2020, Greater Paris concentrated 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 and 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 Péris, 2015). 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 transhipment 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 in economic geography that discusses the ability of places to attract and retain firms and flows in an increasingly spaceless world (see Markusen, 1996). In particular, the last decade witnessed a burgeoning of research about the role of physical, cargo flows in urban and regional development (Hall and 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 and 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. Fujita and Mori (1996) were the first to propose a model of economic geography that studies the role of ports in the development of major cities. Their model makes it possible to go beyond the neoclassical view of port cities, in which it is the initial comparative advantage (i.e. easy and cheap access to the sea) that will allow cities to develop as large port cities. For the authors it is a 'lock-in effect' of certain agglomeration forces that helps to explain why the large port cities of the last century remained prosperous cities despite the disappearance of their initial comparative advantage. Yet, port-related urban growth may occur only when the 'shadow effect' of the core region on the port city is lowered by 'worsening' the transport link between them. This framework is particularly suitable for the analysis of the French port-city system.

In the empirical literature, many econometric models seek to assess the impact of port activity on the area directly involved and on neighbouring areas. Applying the augmented Solow model proposed by Mankiw et al. (1992), Park and Seo (2016) show with panel data on seaport regions in South Korea that there is a throughput threshold below which cargo ports obstruct regional economic growth. In a similar vein, Shan et al. (2014) investigate the seaport's economic impact with data from 41 Chinese major port cities using the set of control variables proposed by Mankiw et al. (1992). They provide 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) measured the spillover effects – positive – of port activity using a spatial Durbin model (SDM); they underline the existence of both positive direct effects in the area where the port is located and large and positive spillovers in nearby regions. Conventional spatial interaction models (SIM) are usually applied in two cases (Moura et al. 2019): 1) analysing the trade patterns of port hinterland (Debrie and Guerrero, 2008; Ferrari et al., 2011) and 2) analysing the role of port infrastructure in the international trade orientation of regions (see for e.g. Wilson et al., 2004 on bilateral trade of 75 countries and Bottasso et al., 2018 who focus on Brazilian foreign trade). Marquez-Ramos (2016) and Moura et al. (2019) use a combination of both approaches, leading to the Spatial Econometric Interaction Modelling (SEIM). The former suggests that regional spillovers may play a larger role than port for the growth of Spanish exports while the latter provides results that confirm the fact that "economic size largely explains the intensity of the provincial maritime flows in Spain" (Moura et al., 2019).

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 and 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. Using Generalized Method of Moments (GMM) techniques, Ferrari et al. (2012) used the Blundell and Bond (1998) GMM-SYS estimator to evaluate the impact of port throughput on employment in European port regions. They found a positive impact of total throughput, especially when ignoring liquid bulk. Using Spanish employment data at the regional level, Fageda and Gonzalez-Aregall (2017) examined the impact of transport modes on industrial employment. Through an SDM, they found that port traffic had a positive and statistically significant direct impact on employment on the manufacturing sector. Moreover, their empirical analysis showed that a large port may generate positive effects on neighbouring regions.

Across European ports, it was found that traffic diversity is positively related with traffic size (Ducruet et al., 2010), but also with city size, especially in the case of medium-sized ports remotely located from the European economic core – away from port competition. Multivariate analyses based on traffic and employment data categories were used by Ducruet et al. (2015) and Ducruet and Itoh (2016) to detect interdependencies between port specialisation and regional specialisation across the world. It was found that bulk traffic concentrates in regions specialized in the primary sector, while containers and general cargo concentrated 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). More recently and at the global level, it was found that larger ports are more diversified in terms of commodity structure (Ducruet, 2021). At the same level and using scaling laws, Ducruet (2020) also found that the most valued traffic concentrates at larger cities (i.e. containers and general cargo).

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 and 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 transhipment 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, 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. The specialization in the tertiary sector was found to be closer to energy flows of which solid bulks (e.g. coal) and liquid bulks (e.g. oil products) to feed urban metabolism but also to containers for the consumption of finished goods (Ducruet and Itoh, 2016). 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. Based on the aforementioned literature on port hinterlands and port system evolution, we expect that the linkages between port activities and economic activities shall intensify as the spatial unit of analysis gets larger, whereby catching a more important proportion of the market area of the ports.

3. Main results

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 and 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).

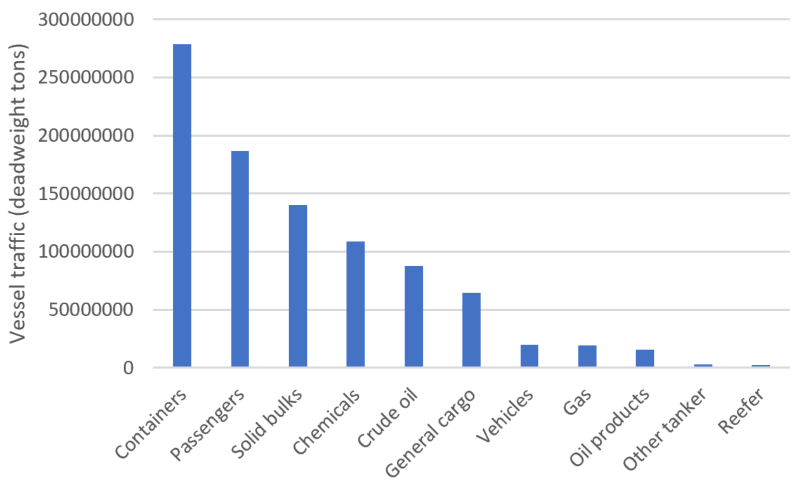

Figure 1. Port traffic distribution per main category, 2016

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 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 areas[1]) 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 activites 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.

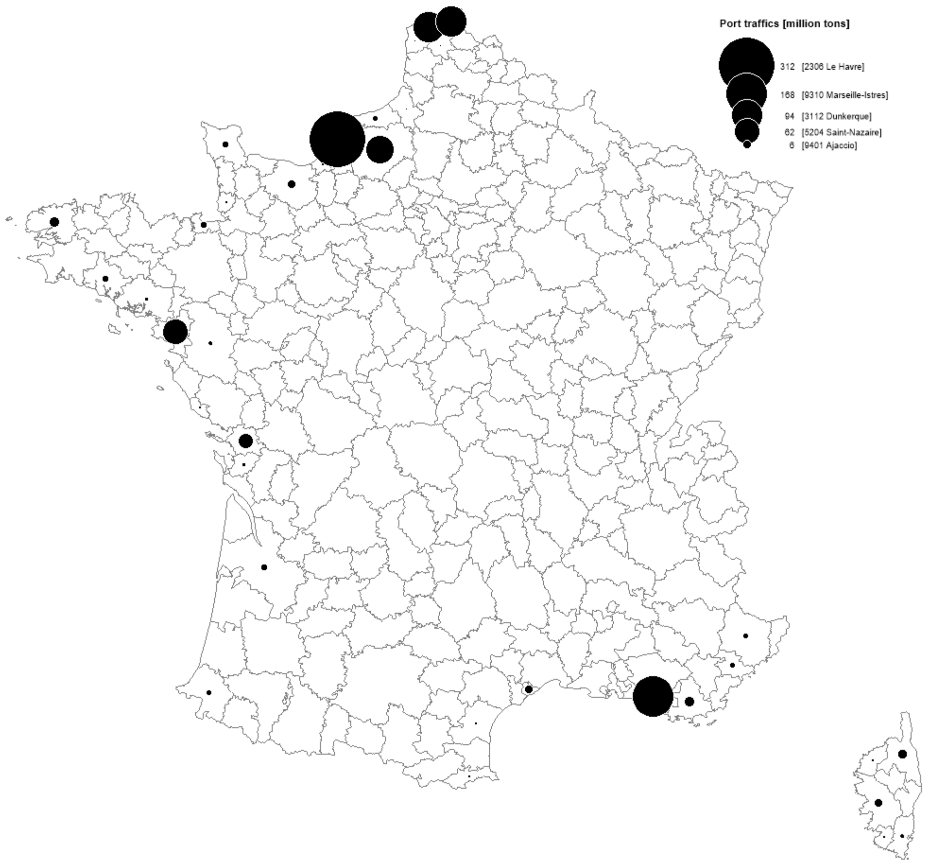

Figure 2. Traffic volume of French port cities, 2016

[1] 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.

3.2. 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[2] (Figure 3, right), in line with a global-level analysis using a different data source (Ducruet, 2021). The latter work also highlighted the opposition here on F2 between liquid bulk traffic (negative) and more valued traffic (positive).

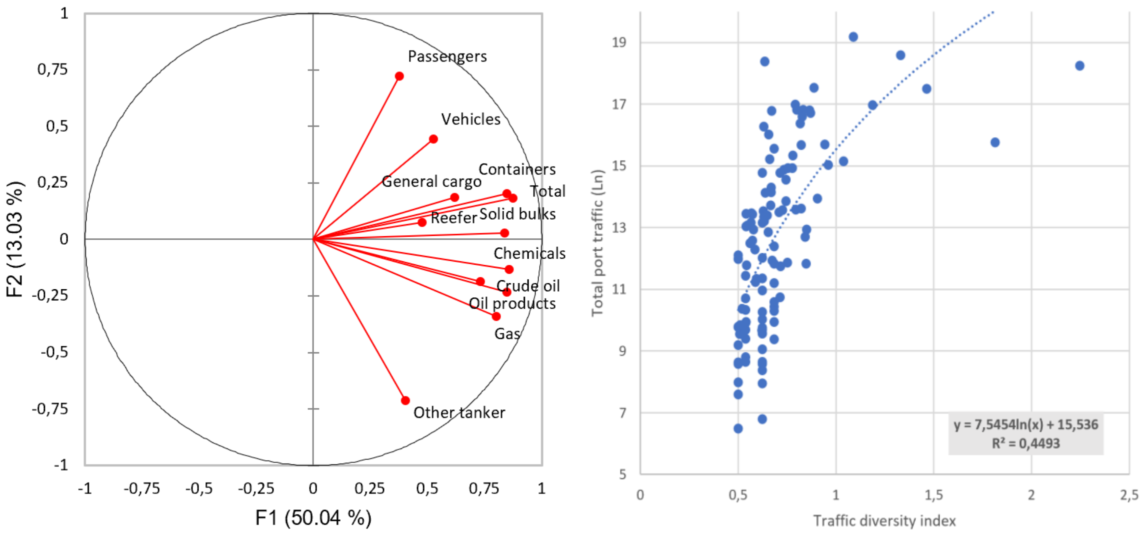

Figure 3. Principal components analysis of French port traffic

The next step is to examine the relationship between size and specialization based on the employment volume of cities hosting ports (Table 1). The diversity index (DI) 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:

$$DI = 1 \Big/ \sum_{j} \left| S_{ij} - S_j \right|$$

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

Results show that for all cities, port traffic diversity[3] is very sensitive to the size of the local economy, as traffic diversity increases with employment volume. This is truer for coastal cities,

[2] The diversity index is calculated following the methodology of Duranton and Puga (2000).
[3] The map provided in figure A1 in Appendix illustrates the different regional patterns of port traffic diversity in France.

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.

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

Table 1. Average port traffic diversity by city size and location type

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 ($R^2=-0.25$).

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

Table 2. Average employment diversity by traffic size and location type

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.

3.3. Traffic specialization relates with local economic specialization

A number of methodological choices have been made to test the second hypothesis 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 (shares), we investigate the linkages at stake between traffic and activities through a Principal Components Analysis (PCA) in the following Figure 4. The diversity index and the dummy for river city were added as illustrative variables. Results are significant, 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, as the largest and most diversified ports, handling large amounts of containers and liquid bulks, followed by Dunkirk and Rouen.

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.

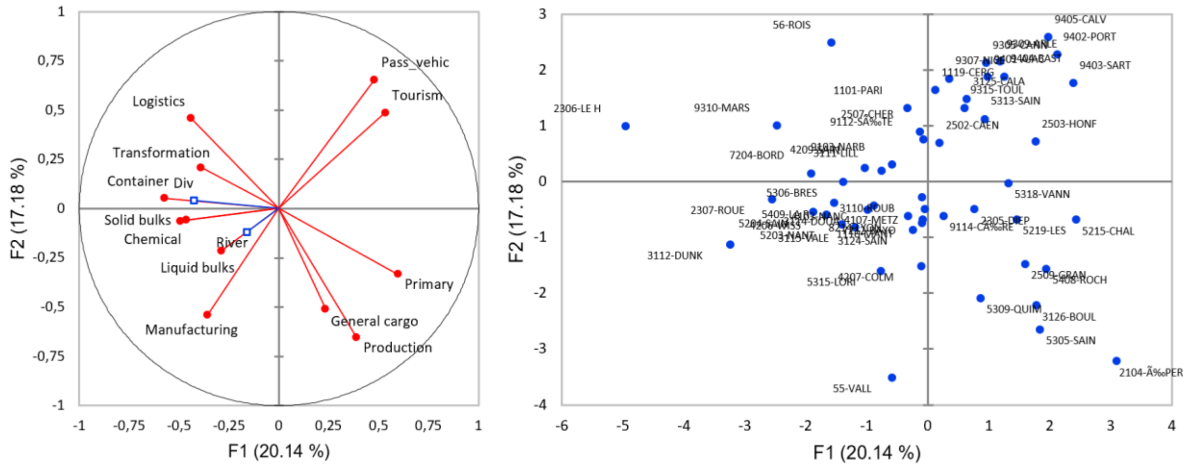

Figure 4. Principal components analysis of traffic and employment at port city level

3.4. 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 slight improvement validates our hypothesis that 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 Péris (2015), the Gironde *département* 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 Péris (2015) at the regional level.

Based on the assumption that larger ports distribute goods over wider hinterlands, the reference area in which employment is counted has been adjusted to traffic levels. It is the first time such a method is employed, as previous empirical works analysed port activities in relation with a fixed spatial unit, namely the urban areas or the subnational region. First, cities were distributed in equal numbers into three groups based on their total amount of port traffic. Traffic was weighted using the method proposed by Charlier (1994), to reduce the proportion of bulks, which represent disproportionately high volumes despite a relatively lower value. Another reason 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). The class of small traffic was attributed to the labour area; adjacent labour areas were added to the second class (medium-sized weighted traffic), forming a new spatial unit; and the labour areas adjacent to this new unit were added for port cities of the third class (largest traffic)[4]. In addition, it was decided to perform this analysis excluding river port cities, since seaport cities are much more concerned by hinterland penetration and economies of scale.

The PCA based on such variables validates our hypothesis, 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 project on F2. This trend, if we exclude the Dieppe outlier, is best represented by the three major ports of Rouen, Le Havre, and Marseilles. 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.

[4] The most common approach to define neighbours is to apply a spatial weight matrix based on physical contiguity (i.e., when areas share a common border of non-zero length.). In order to consider both the closest neighbours and more distant regions, the analysis is based on binary weight matrix with three classes: contiguity first order, contiguity second order and contiguity third order. 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. The contiguity third order matrix is not used in PCA II.

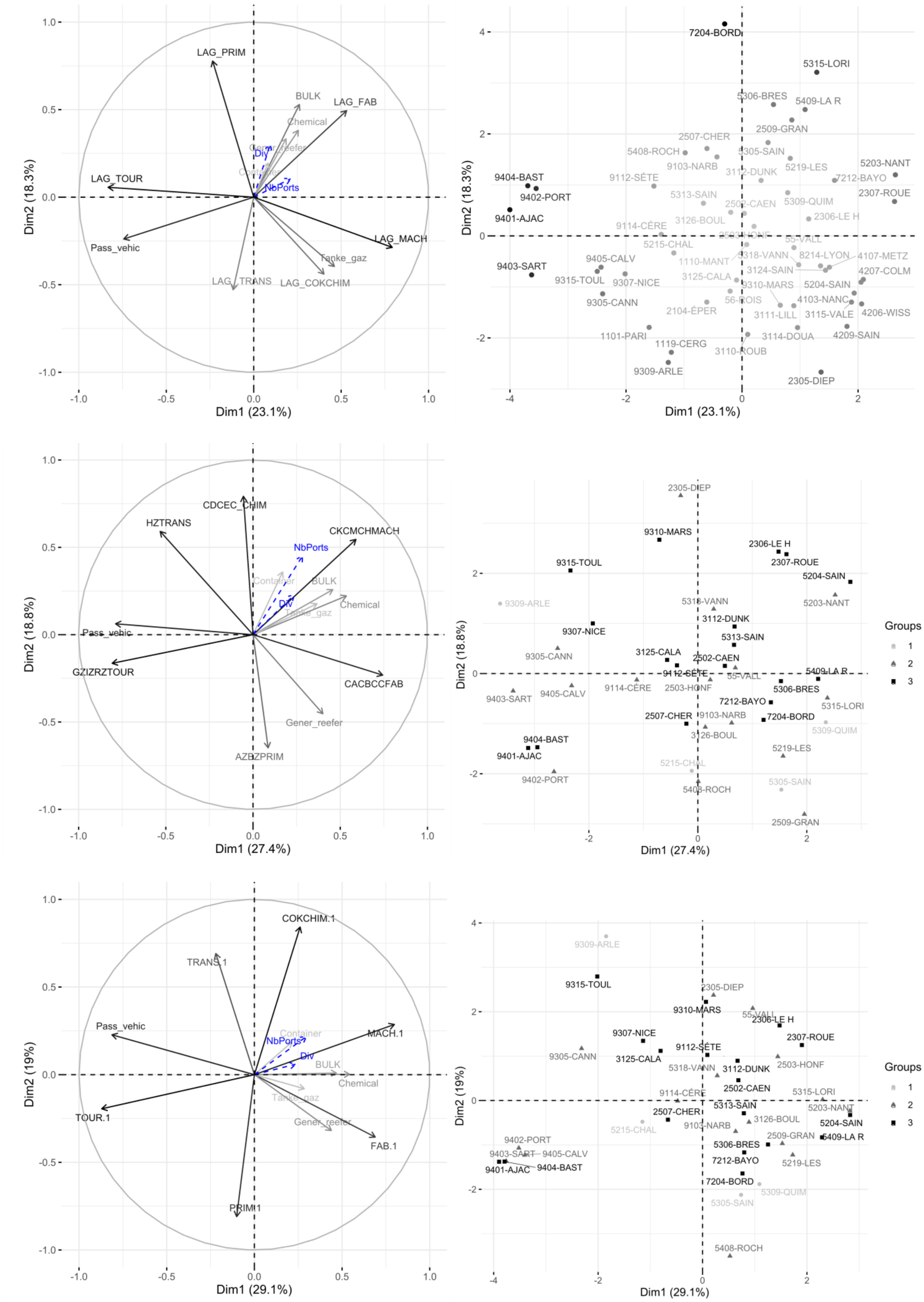

Figure 5. Principal components analysis of traffic and employment at various geographic scales

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

3.5. 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.

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**

Table 3. Average employment and traffic shares of port clusters

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.

[5] 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.

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 and McAleer, 2005; McElroy, 2006; Peterson and 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 transhipment functions due to its higher deviation distance from the main trunk lines (Zohil and Prijon, 1999).

4. 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 has important implications for port policy and management, and wider strategies in terms of urban, regional, and national planning and economic development. In methodological terms, this research underlines that port traffic data can be seen as crucial territorial indicators that capture urban and regional dynamics.

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 be fine-turned further, as it doesn't control for other modes of transportation, such as air traffic, railways and motorways[6]. 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.

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

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.

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.

Appendix

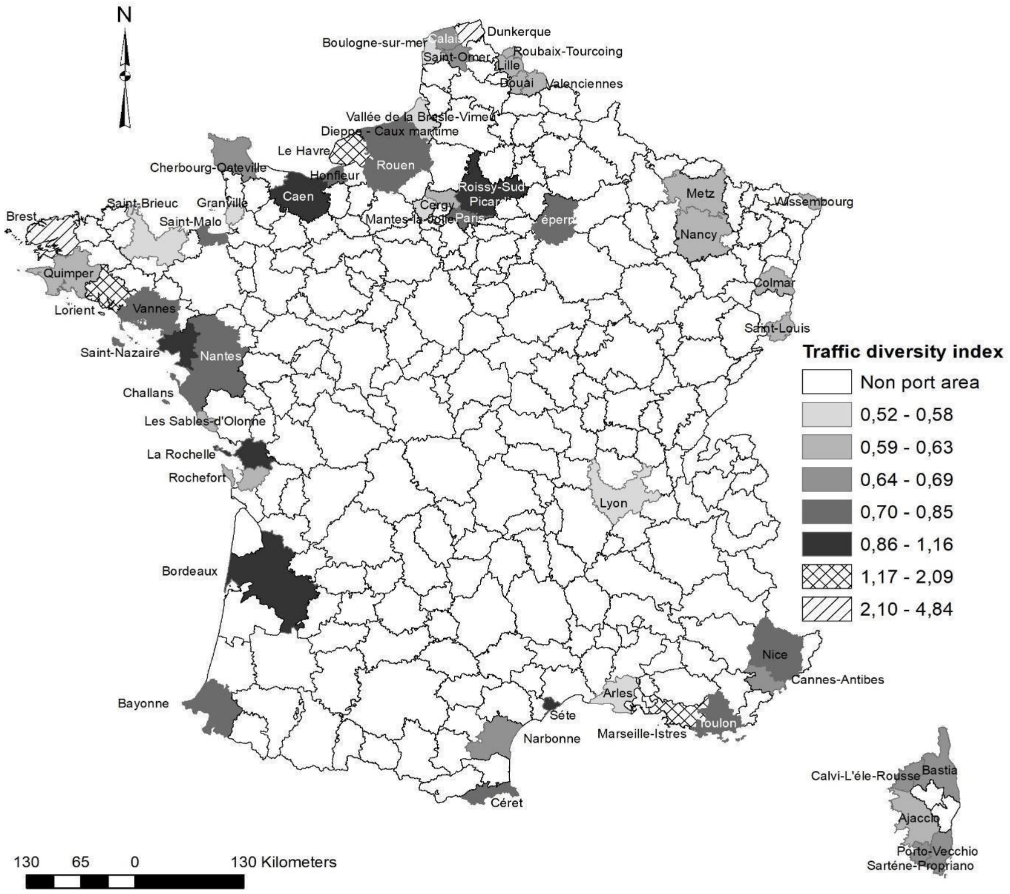

Figure A1. Traffic diversity level of French port cities, 2016

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