A qualitative and quantitative assessment of port migration patterns in the global port system since the 1950s

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Abstract

In this paper, we undertake an overview of port migration throughout the world from two perspectives, qualitative and quantitative. The qualitative perspective discusses existing models, drivers and impediments of port migration, supported by concrete cases from around the world. . The quantitative approach measures port migration patterns using urban population and vessel traffic data of about 4,000 places from the 1950s to the present, calculating the volume and share of "outer" versus "inner" traffic and analysing/mapping its evolution/distribution. In conclusion, we discuss the universality of port migration and its readable effects on urban growth or decline.

Keywords: *Port cities; port migration; port development; shipping networks; spatio-temporal evolution; world trade patterns*

1. Introduction

Port migration can be defined as the shift of port infrastructure and/or maritime traffic from one location to one or multiple other locations within a given period of time. Such migration processes can involve new port or new terminal development near existing facilities (e.g. a new port area being developed on a greenfield site away from an existing older port area), at medium distances (e.g. a new port at 25km from an existing port zone) or longer distances. In a number of cases, port migration can change the physical and spatial features of the port, e.g. a river port can become an estuary or coastal port, in case of downstream development.

The discussion on port migration is embedded in research on port and port system development, a key theme in the port geography literature (Ng et al., 2014). Modern ports typically developed away from the obsolete facilities near the urban core to less urban locations with ample space, and a better nautical accessibility, as exemplified in the 'Anyport' model of James Bird (1963, 1971). The port migration pattern is very dependent on the nautical and geographical characteristics of the port's location. For example, upstream river ports typically develop downstream to new terminal locations along the river or in dock systems connected to the river or estuary, at coastal or even offshore locations. As remarked by Jackson (1983), the major cause for the decline of ports across history had been technical or physical, i.e. the congestion of channel entrances by sediments due to insufficient dredging . Transport and other economic actors were thus constantly in search of alternative locations to ship their goods and keep trade going on.

Other factors of port migration have appeared, however. Given the enormous global growth in international trade and maritime transport since the end of WW2 and the co-dependent technological developments in ships and cargo handling, it is inevitable that ports have been forced to undergo significant transformations. One facet of the transformations is site expansion, either by accretion or relocation, or a combination of both. The older obsolete port areas are either abandoned and given a new function in the context of waterfront redevelopment schemes (Hoyle, 1989) or might undergo a rehabilitation/conversion phase in view of taking up other port logistics functions focused on specific market segments.

Port migration processes have an impact on cargo concentration patterns in port systems. Barke (1986) pointed to processes of cargo de-concentration in port systems resulting from port activities leaving the urban core for less congested suburban or peripheral port sites. Hayuth (1981) introduced a trend towards de-concentration in port systems as a result of the so-called ‘challenge of the periphery’, a concept which was empirically tested by Notteboom (2005) for Europe, and Slack and Wang (2002) for Asia, the latter insisting more on shipping lines’ strategies than on physical factors. Port migration is recognized in the extant literature as an important structural factor influencing port and port system development. Still, the measurement of the extent of port migration processes is underdeveloped, while also a comprehensive and structured discussion on port migration factors is lacking.

This paper attempts to contribute to filling these two research gaps by focusing on two goals. The first objective is to consider the forces that are shaping port migration, based upon a review of the literature. This exercise will demonstrate that site locations are shaped by seemingly contradictory forces. Some forces incite development on new sites to exploit factors such as land availability and access to deeper water. Others reinforce the attractiveness of urban locations that ensure better access to local and hinterland markets. The literature review provides a discussion of the different forces and examples of their impacts.

The second goal is to provide a global quantitative assessment of port migration. Three large data sets are compiled: the first dataset includes ports of all types since the 1950s based on vessel calls, the second covers ports of all types including vessel tonnage since the 1980s, and the third dataset consists of container ports only also using vessel tonnage. Based on the location of each port or terminal, sites were apportioned between inner and outer locations for measuring respective traffic volume and share. In addition, the use of urban population data along with the migration shift results allows an analysis of the relationships between demographic changes and port migration. The paper also compiles a basic typology of port migration. Migration profiles of representative ports in each class are selected to describe the actual patterns of migration and to describe the most important and most specific shifts.

The paper is structured as follows. Section 2 offers a holistic view on the forces that foster or limit port migration, based on concrete examples but also existing models of port system evolution and port-city evolution. It provides classic and specific examples of port migration through space and time all over the world. The third section is quantitative in nature as it tries to find certain rules by which port migration is more advanced in certain places and not in others. In conclusion, we discuss the difficulty to match perfectly quantitative and qualitative approaches, although they remain complementary, and identify future research avenues.

2. Drivers of and impediments to port migration

This review of port migration factors is largely inspired by the respective works of Notteboom (2016) and later Merk (2018) who analysed the specific role of container ship size on port relocation processes. Extant literature primarily points to forces promoting port migration. It provides fewer clues on the processes that might favour a further development of ports in urban locations. Therefore, in this section we also discuss forces that help to explain why urban seaports can still have a significant role to play in port systems. We divided this section in two main parts: spatial and technological; economic and operational.

2.1 Spatial and technological factors

Nautical accessibility and scale increases in vessel size

The need for deep water access to accommodate ever larger vessels is one of the prime reasons for port migration. Scale increases in vessel size force ports to look for deep-water locations, typically in an estuary or along a coastline, bay or deep-water inlet. Not only draft conditions are important. A rise in beam and length of vessels requires more manoeuvring room, wider turning circles near terminals and wider port access channels, particularly when considering that two-way traffic on navigational channels is the norm. While also many coastal and estuarine ports are challenged to dredge and widen access channels, investments in the nautical accessibility of upstream seaports located along rivers typically require larger budgets and come with more complex issues revolving around river morphology and ecology, flood protection and the disposal of (contaminated) dredged material.

When elaborating on the link between vessel size and port migration, it is important to consider that vessel size increases across the spectrum of shipping are not uniform. Liquid bulk underwent a very significant increase in scale economies in the 1970s with the emergence of Ultra-Large Crude Carriers (ULCCs), a time when container vessels were below panamax capacities. In a short space of time the ULCCs disappeared because of changed market conditions, but before they did precipitate the establishment of new oil terminal facilities. Dry bulk vessel size growth was slower, first plateauing at the scale of Very Large Crude Carriers (VLCCs) only to grow in the 2010s to Chinamax as a result of Chinese demand for iron ore. Throughout this evolution of scale of bulk vessels there remain important sub-markets such as the grain trade, where smaller handymax vessels are still pre-eminent. This diversity of scales is present also in the container trades, despite the recent upscaling to +20,000 TEU ships. The lesson is that scale economies produce different effects in different markets and on different ports and hence on demand for land in ports.

Still, not all ports are moving downstream. Baltimore is a prime example of an upstream urban port trying to regain an important status by combining nautical accessibility (i.e. 50 feet channel and berths), terminal productivity, and strategic inland location. For instance, Baltimore ranks number one among US ports for container berth productivity according to Journal of Commerce (2015), while its central location in the Washington/Baltimore market of some 6.8 million people makes it the closest Atlantic port to major Midwestern production and consumption centres. Another example is London Gateway, which opened in 2013. Global terminal operator DP World tries to lure customers using the marketing slogan “Ship closer. Save money”, thereby referring to the slightly better proximity to the main markets in the UK compared to rival coastal ports Felixstowe and Southampton.

Diseconomies of scale and land availability issues at established ports

These concerns are echoed in Bird (1971). In the 1950s and 1960s, the fast rise of the chemical industry (for example in view of producing plastics) led many ports in Europe to migrate to locations with ample space for the development of vast Maritime Industrial Development Areas (Vigarié, 1981). In more recent times, discussions also revolved around finding enough space to create new large-scale logistics zones in the framework of port-centric logistics (Mangan et al., 2008; Monios and Wilmsmeier, 2012) and free trade and economic development zones (Tiefenbrun, 2012). In the 1950s and 1960s some large ports in NW-Europe witnessed a massive (downstream) development triggered by the demand of fast-growing petrochemical and chemical companies to have access to large maritime sites for the development of industrial complexes (see Table 1 for a comparative perspective). Examples include Antifer near Le Havre but also Rotterdam and Antwerp. Rotterdam would never have been able to become such a large container port if the Botlek and Europoort industrial port areas would not have been developed prior to containerisation, as these developments opened the path to the development of Maasvlakte 1 in the early 1970s and Maasvlakte 2 in the 2010s. Both Maasvlakte 1 and 2 are giant landmasses reclaimed from the sea making Rotterdam de facto a coastal container port despite its initial development along a river. Rotterdam's container volume (14 million TEU in 2018) is almost entirely handled on the container terminals at Maasvlakte I and II. Thus, there is a clear path dependency in port migration processes. In Antwerp and Rotterdam, a first wave of port migration for industrial purposes opened windows of opportunity for a second wave focusing mainly on containers.

[Table 1]

The above examples demonstrate that port migration processes in response to diseconomies of scale, land availability issues or nautical issues can lead to path dependency and a certain spatial 'lock-in' in future port development. Path dependence implies that ports evolve by building on previous phases and 'memory effects'. Past decisions on port migration might thus stimulate or prevent new waves of port migration. Without the port authorities being aware of it, the port migration that took place paved the way for these ports to position themselves as early adopters of containerisation in the late 1960s early 1970s. Path dependent development patterns of port systems can go back many centuries, and therefore lie the foundation for more recent port migration processes or the lack thereof.

Also US East Coast ports all have long histories of development. Ports were the major lifeline for trade and settlers with Great Britain during the colonial period, and even after US independence ports were gateways for US exports of raw materials and imports of European manufactured goods. By the late 19th century they began to serve as focal points of industrialisation, a trend that became even more important through much of the Twentieth with the establishment of new industries such as chemicals and oil refining. By the late 1950s the container revolution began on the US East Coast and continued its expansion until the present day. The fact that the region has such a long history of commercial shipping explains in part the apparent stability of port development indicated later in this study. Changes that are reshaping port development in some other markets have already taken place here. It parallels comparable results for some of the ports in North West Europe which too has a long heritage of port-industrial activity.

Vancouver represents an almost 'text book' example of port migration. In the early 1970s two container terminals were developed from converted sites adjacent to the city's downtown on Burrard Inlet. Although both Centerm and Vanterm terminals possess rail connectivity and provide deepwater accessibility, their sites are constrained by close urban proximity, which limits any physical expansion. In addition, much of the adjacent shoreline is occupied by other bulk cargo terminals which accounted for much of the port's overall business. Indeed, it was the absent of suitable sites on Burrard Inlet that led to the construction of an entirely new coal export terminal 35km from Vancouver at Roberts Bank. It is located at the end of a long causeway extending out of from the mainland into deep water. By the 1990's site constraints at the container terminals led to the decision to expand Roberts Bank and add a new container facility, Deltaport. The new terminal was opened in 1997 and has been expanded since. As with Rotterdam, port migration was initiated out by a bulk trade. One difference with Rotterdam is that Centerm and Vanterm remain very active inner-city container terminals.

Urban density and hierarchies

The urban fabric and networks can exert forces towards port migration. In an urban setting, strong tensions between port development and urban/city development can result in a move away from urban locations. The matrix on port-city relations as presented by Ducruet and Lee (2006) provides a framework to assess the risk of incurring increasing tensions between city and port. Wiegmans and Louw (2011) present a model that adds to the Anyport-model of Bird by referring to zones where conflicts between the existing land use as a port and proposed city land uses takes place. Such city-port tensions can eventually result in port migration. In their network analysis of world's cities connected by shipping flows, Ducruet et al. (2018) observed that the declining relationship between vessel traffic and urban population occurred most frequently in the context of upstream ports and port cities. Despite demonstrating that larger cities keep dominating the global shipping network today, it was acknowledged that maritime hub ports such as Rotterdam and Singapore, which are not very large cities, have maintained their dominance. In Asia, port migration started to emerge in the 1980s and 1990s, such as in Singapore with the reclamation of industrial islands such as Tuas and Jurong, Japan, and in the 2000s, in major Chinese industrial ports such as Shanghai and Ningbo-Zhoushan, etc. Singapore is a key example with the development of the large-scale Tuas container terminal project (Yap and Lam, 2013) and the decommissioning of three terminals close to the city center to make room for urban expansion on prime land.

Dynamics in shipping networks and urban hierarchies do not necessarily result in port migration and a decline of urban ports. Market players typically value some of the supply chain related characteristics of urban ports, such as a closer proximity and better connectivity to inland markets, high cluster and scale effects in cargo generation and savings in environmental costs of land transport. The competitiveness of a seaport is not only determined by its location and the available port infrastructure and superstructure. It is also increasingly being determined by the port's effective integration in these supply chains and logistics pathways (Robinson, 2002; Mangan et al., 2008). From a generalized transport cost approach (also incorporating transit times and service quality elements), urban ports can thus be competitive in a supply chain perspective. The cases of upstream seaports Antwerp and Hamburg are a good illustration. Despite challenges in terms of nautical accessibility, land availability, congestion and the environment, both ports have been able to remain competitive vis-à-vis existing (e.g. Rotterdam) and new (e.g. Wilhelmshaven) container ports in more coastal locations. They have managed to do so by developing strong adaptive capacities to deal with nautical and other challenges, by developing strong supply chain integration strategies linked to the existing logistics cluster, by focusing on a high maritime and land connectivity and by nurturing preferential attachment processes at the level of the market players (Notteboom, 2016).

In fact, the imperatives of modern global supply chains can weaken the push for port/terminal migration to less urban locations. However, the link between port migration and the characteristics of supply chains largely depends on cargo types for which port migration makes more or less sense, certainly when smaller ships are being used and availability of (dock) labour is key to competing in such a cargo segment. In other words, port migration forces might be different depending on the cargo segment under consideration. Port migration forces might be particularly strong for deep-sea container trades and major liquid bulk activities. Also, in some containerised commodity supply chains, such as tobacco and coffee, there are very strong forces towards centralisation of flows in only few ports. Such elevated levels of cargo centralisation might result in a demand for large terminals and warehousing facilities. This could trigger port migration. Other activities, such as shortsea operations, might benefit from a more decentralised approach with many ports and smaller terminal facilities being served. Also other segments in shipping might prefer more urban locations. While this paper does not focus on passenger traffic, it is worthwhile mentioning that many cruise terminals have been developed near urban centres, often on old port sites. There is pressure from the cruise industry to establish terminals closer to the old city centres, rather than in some derelict facilities miles from anywhere.

2.2 Economic and operational

Maritime networks

The need for locations that offer a better 'intermediacy' in shipping networks (Fleming and Hayuth, 1994) can lead to port migration away from urban centers, to estuarine and coastal locations, or even offshore. In the container market, the growing sea-sea transhipment market has led to the emergence of almost pure transhipment hubs (Rodrigue and Notteboom, 2010) with a range of common characteristics in terms of an easy nautical access, a close proximity to main shipping lanes (i.e. low diversion distance from the trunk routes), short vessel turnaround times, and specific ownership structures dominated by carriers or international terminal operators (see e.g. Lirn et al., 2004; Baird, 2006). Strategic passageways in the global shipping network such as the Straits of Gibraltar, the Suez Canal, the Panama Canal and the Malacca Straits act as magnets on the development of transhipment hubs (Ashar, 2002; De Monie, 1997). However, literature demonstrates that the position of container transhipment hubs in shipping networks is more vulnerable than the positions of gateway ports or ports with a mixed cargo base (Robinson, 2008; Ducruet and Notteboom, 2012; Wilmsmeier and Notteboom, 2011) and that the container throughput volatility in transhipment ports is statistically significantly higher than in other ports (Notteboom et al., 2019). In other words, maritime networks are dynamic in nature and the position of intermediate hubs in these networks can be subject to a (sudden) change upwards or downwards. Tthe dynamics in these networks and the relationships with port migration are under-researched.

However, not all port systems around the world feature a presence of significant transhipment activity. One major difference of US ports with the rest of the world is the absence of transhipment. The amount of coastal container trade in the US is negligible because of the high cost of domestic shipping, the result of restrictive domestic shipping regulations (i.e. the Jones Act) that insist on US-built, manned and operated vessels (Slattery et al 2014). US container ports are therefore focused on landward connections. North American ports thus developed other options to keep their activity going on despite the absence of transhipment, such as short sea shipping operation between Newfoundland and Montreal, environmental innovation in Vancouver and LA/Long Beach (Hall et al., 2013) triggered by the pressures on environmental performance as exerted by leader firms, local communities and organizations, and governments.

As observed by Ducruet (2013), container flows are the most overlapped with other maritime flows such as bulks etc. Containerisation made it possible for such heavy industrial complexes to adopt a new function, i.e. the aforementioned intermediacy through hub functions which largely focus on sea-sea transhipment activities also exist in other markets such as the liquid bulk market (e.g. crude oil terminals in the northern part of the UK that tranship North Sea oil) or the automotive market. For instance, the Belgian coastal port of Zeebrugge handled 2.8 new vehicles in 2018 of which a significant part related to sea-sea transhipment activities between north and south Europe and between the British Isles and mainland Europe.

Cost differentials and environmental restrictions

The availability and cost of production factors capital, labour and land play a role in port location decisions. High factor costs at more urban locations can drive port developers and market players to look for new less urban locations. However, there might be a shortage of workers in these more remote locations and commuting times for urban dwellers might be too high. In his seminal paper on port-city separation, Hoyle (1989) used the case of Fos-sur-Mer as an outport of Marseilles. This can be solved by stimulating the further development of existing villages to attract (young) families and port workers or by creating new towns/cities near the new port areas.

Like elsewhere but perhaps under a stricter regulatory environment, national and European regulations, such as the EU Bird and Habitat Directive and the EU Water Directive, combined with an increased stakeholder involvement in the decision-making process, seriously limit the possibility to develop greenfield port projects in ecologically sensitive areas.

Development in the coastal zone requires an approval process that is lengthy and costly. Port development has become particularly difficult because of local opposition that is able to intervene in the evaluation process. Even in case some development can take place, the decision process can easily take 5 to 10 years and initial plans often undergo major changes throughout the entire process to meet demands of the regulators and stakeholders (environmental groups, community groups, etc.). Thus, every greenfield development plan goes hand in hand with lengthy and complex processes without any guarantee of being successful in the end. This knowledge increasingly pushes port developers to consider optimizing and extending existing port areas through intra-port renovation/conversion projects, co-location and co-siting, thereby limiting the pressure for port migration.

However, ports located in urban areas also face specific environmental issues. This can trigger a search for other terminal locations. Given the proximity of urban cores and the associated local communities, issues of noise, air quality, energy consumption, waste management and dredging are typically scrutinized much more than in remote offshore or coastal port sites. Yet, Hall and Jacobs (2012) show that the proximity to urban areas provides urban ports with both dynamic tangible and less tangible advantages which cannot be found in non-urban environments, e.g. superior infrastructure, knowledge, innovation and decision-making capacities. While congestion and environmental challenges negatively affect more urban ports, they can be a major source of innovative power with positive impacts on competitiveness.

2.3. Institutional and governance factors

Administrative borders

Institutional and governance factors and the interplay among stakeholders often have a large impact on port migration decisions. A good example is the role of administrative borders in ‘limiting’ port migration processes in space. Port migration might not go far in case this would imply that the port needs to be developed across borders to other provinces or countries. Several examples underline that port migration typically is spatially constrained to the own territorial borders (county, province, state, country). Physical (country/state) borders also often lead to ‘mental’ borders at the level of public entities, market players and other stakeholders involved in port development processes.

The development of the Antwerp port is another good example of how borders can affect port migration patterns. Until the 1970s, Antwerp saw a strong downstream development on the right bank of the river Scheldt to the north away from the urban core. Rural sparsely populated areas were turned into dock systems connected to the river by sea locks. However, a large part of the navigable section of the river Scheldt flows through the southern part of the Netherlands before reaching the North Sea. This meant that a further downstream development of the port (as portrayed in Bird’s Anyport model) would have implied crossing the Belgian/Dutch border. Therefore, further port development processes shifted to the left bank of the river in the 1970s. Even at present, the main port expansion projects are all focused on the left bank area, e.g. the Deurganckdock (opened in 2005) and the planned Saeftinghedock, making the left bank almost as important as the right bank in cargo volume terms.

Market players often capitalize on the existence of borders and the associated rivalry among nations and regions. For example, in the early 2000s, the container terminal operator APM Terminals benefited from the rivalry between Singapore and Malaysia to push for the development of a large new port in Tanjung Pelepas in Malaysia (just across the border with Singapore) after sister company Maersk Line was denied the development of a dedicated terminal in Singapore.

Collective action and the role of politics

On the other side of the coin, power, politics and collective action by the port community have a role to play in port development and migration. Some actors or stakeholders will use their power and sense for joint action in order to constrain or enable the development of an urban seaport. Jacobs (2007) and Jacobs and Notteboom (2011) demonstrated how strategic or collective action can affect the development path of ports. Also, politics can play a major role. For instance, Ng and Pallis (2007) noted that variations of political traditions and culture could result in the embeddedness of strategies within the institutional frameworks concerned. This governance setting leads to some local rationality in terms of assessing port development opportunities and the port's economic impact. As a result, terminal expansion in other neighbouring ports is often not supported with the argument that a lack of investments in (nautical) accessibility and terminals of the proper port will lead to a vicious cycle towards decline of the port and a decrease of its effects on the (local) economy. Hamburg in Germany provides a good example. The early 2000s brought a discussion in Germany on the development of a new deep-water port in the northern part of the country. A proposed project in Cuxhaven at the mouth of the Elbe River was shelved. In the end, Wilhelmshaven was chosen as the best location. The Jade Weser Port terminal opened in 2012 with a capacity of 2.7 million TEUs. The city and the port of Hamburg have never been strong supporters of the development of the new port as they believe that the port of Hamburg has a much stronger market proposition than any newcomer, but also partly because Wilhelmshaven is located in another German state (Bundesland Niedersachsen) and therefore not under the jurisdiction of the city state of Hamburg (Freie und Hansestadt Hamburg).

*Port ownership structure and (regional) port integration*The institutional arrangements at the level of port and terminal ownership can play a role in port development and migration. Even though the ports operate as public entities there exist large numbers of privately owned and operated facilities. Typically, these are terminals that serve an industrial function that is located alongside, receiving coal for a thermal power station, or receiving crude oil and shipping out refined products. The activity is controlled by the corporation with no public input. They tend to be fixed in their use for long periods of time, and thus contribute to the spatial stability of port infrastructure. In contrast publicly-owned sites may undergo periodic reappraisal and may be leased to other users for a different function.

Governance issues are paramount also for many US ports with the role of private terminals (Fawcett, 2007). US ports are under State jurisdiction, like most East Coast States, unlike the West Coast where port jurisdiction has been devolved to municipalities. The absence of transhipment (cf. the Jones Act) makes that all US container ports are gateway ports focusing on import/export flows. This undoubtedly shapes port areas and location decisions in terms of port extension. At the same time, over the last 60 years, the US has developed an increasingly restrictive set of regulations relating to coastal zone management. The time and cost considerations have resulted in very limited greenfield port development in the US, where conversion of existing sites has been a very common approach to new facility provision (Hirshman et al., 1999).

Finally, port system development in China, and associated processes of port migration and outer development have been and still are heavily affect by institutional arrangements and governance issues, given the strong role of government and state-owned enterprises in economic life in China. Cullinane and Wang (2007) and Notteboom and Yang (2017) examined the distinctive phases in port governance reform in China. The strong growth of the economy meant that port capacity was developed on a massive scale, thereby enhancing outer development and large-scale port migration in established and new ports. In more recent years, the central government's policy encourages port co-operation and integration schemes at the regional/provincial level to fight overcapacity, duplication of facilities and excessive competition among regional ports. Wang et al. (2015) analysed the nature of port integration in China, including associated temporal pathways, spatial patterns and dynamics. Huo et al. (2018) concluded that China's domestic port cooperation has resulted in the formation of provincial port groups (such as Zhejiang Port Group) through investment holding or acquisition and strategic alliance. Next to the envisaged synergies and advantages of such port integration schemes, we expect that this trend will also affect the regional cargo distribution patterns among ports and investment decisions on new port expansions. More specifically, regional port integration brings port development discussions from the local to the regional/provincial level, thereby opening more possibilities for increased specialisation of ports and the further development of hub facilities, particularly in outer locations. Such a specialisation might be needed to prepare the regional port system for increased inter-regional port competition and strongly reduced levels of intra-regional competition.

3. A world geography of port migration

3.1 Defining and measuring port migration from an urban perspective

Given the range of drivers shaping port migration described in Section 2, it remains challenging to attempt a quantitative assessment on a global scale. After many attempts it was decided to adopt an urban perspective. Port migration is defined here as the traffic performed at terminals and ports outside a port city and which bear another name than the (principal) port of this city. This allows to catch a good part of the port migration phenomenon as explained below in more detail, allowing us to distinguish amongst inner and outer port activity.

Thus, our definition does not fit for all cases the same, depending on local conditions and specificities. For instance, Maasvlakte 2 in Rotterdam is at about 45km from the urban area, but since it is still the port of Rotterdam and part of the Rotterdam metropolitan area, it is seen as “Rotterdam” and so as an inner development. The same applies to Antwerp, of which the most northern part of the port is located on the right bank of the river Scheldt some 15km from the urban area, but still on the territory of the city of Antwerp and part of the Antwerp port. The left bank, where the massive Deurganckdock is located is even closer to the city of Antwerp, but although it is located on the territory of another city/municipality/province but administered by the same port authority, it is also considered as inner port activity. Contrarily, Antifer oil terminal is about 25km from Le Havre, but since it is not located in the urban area of Le Havre, and has a different name, it is classified as an outer port activity.

In other words, port migration in our paper always involves a port development which is spatially/physically disconnected from the existing port area and not just a continuous expansion of an existing port. In some cases, the definition of outer port activity had been difficult, such as in the case of London Gateway, Thamesport, and Felixstowe being considered outer ports given their location outside the urban area. In the same vein, Wilhelmshaven is considered, like Bremerhaven, an outer port of Bremen, just like Zeebrugge in Belgium is considered as an outer port of Brugge. In Asia, Tanjung Pelepas is one of the (inner) ports of Johor Bahru urban area.

Our methodological approach is thus a specific view of port migration, due to the limits of quantitative possibilities. First, measuring port migration would require micro-level data such as vessel traffic or tonnage figures per terminal, which, unfortunately, does not exist[1]. We thus opted for a more “macro-level” perspective with the city, or urban area, as the unit of analysis. Dealing with the urban dimension of port migration was inspired by numerous works about gateway cities (Burghardt, 1970; Bird, 1973) and settlement patterns (Vance, 1970; Brocard, 1988) in the post-colonial and post-industrial world, backed by a countless literature about port-city relationships (see Ng et al., 2014 for a review). The urban area is larger than the municipality as it includes adjacent localities, based on a more functional or morphological definition of the city (**Figure 1**).

[Figure1]

Ports were then attributed to urban areas depending on their location inside or outside this area, thereby defining them as “inner” or “outer” ports. One urban area may host one or more ports. Outer traffic is thus operated at external terminals or ports that are still within the region but at some distance from the city. Each port and city was treated case by case manually looking at the map (physical distance, elevation, road network connectivity, urban morphology and regional urban network patterns) and consulting numerous websites giving

[1] Sources such as Containerisation International Yearbooks and Lloyd’s Ports of the World do contain terminal-level information but mainly a physical description and barely no traffic data.

more detailed information on trucking flows for instance and historical elements. In Figure 1, the A, B, and C configurations are variants of the same process of port migration, depending on the site and situation of ports and cities, coastal morphology, etc. Type D is a special case where we attributed coastal ports to a nearby, inland, and non-port urban area based on the same criteria mentioned earlier. In fact, the only difference between types A and D is the absence, in the latter case, of a river access.

We measured traffic at such ports using *Lloyd's List Intelligence* (LLI) data, the world's leading maritime insurance company, over the period 1950-2016. Vessel traffic volume per city was averaged every 5 years to keep the maximum number of places, as some of them did not always handle cargo every year; also to eliminate the "noise" caused by fluctuations within yearly time-series. Three datasets were selected for the sake of comparing different periods, traffic types, and units: (1) total vessel tonnage 1980-2010, corresponding to vessel capacity in deadweight tons (DWTs); (2) container vessel tonnage 1980-2015 (using the same method); and number of vessel calls 1950-2010 (i.e. without taking into account ship size). We then calculated the relative amount (%) of inner versus outer port traffic for each urban area and traffic type.

London provides a fertile ground to test our methodology (**Figure 2**). It is known to have undergone drastic port migration: outer traffic grew from about 30% in the 1980s to nearly 70% in the 2010s. We included in this calculation Thames River terminals and distant seaports. The right part of the figure uses the 5-year traffic average as a reference, for the case of containerships only, showing a similar evolution. Yet, we observe a revival of inner port traffic in the late period, probably due to Dubai Ports World (DPW)'s investment Greater London through the London Gateway project; similar reinvestments were observed in other large cities such as Taipei, Jakarta, Osaka, and Tokyo (El Hosni, 2017). This shows that port migration can be counterbalanced by other forces than pure logistical and supply chain matters, such as socio-economic determinants (Ducruet and Itoh, 2016).

[Figure 2]

3.2 The urban influence on port migration

We first calculated the correlation between traffic volume and demographic size[2] (**Table 2**). Our results indicate a moderate significance of population as a determinant of total traffic. Yet, urban areas always exhibit more significant correlations than port cities due to their

[2] Our population database is the outcome of the merger and harmonization of four different world urban population databases (see Ducruet et al., 2018 for more information): Populstat (1950-2005), World Gazetteer (2010), Citypopulation.de (1980-2015), and Geopolis (1950-1990).

wider spatial extent, although in many cases there has been a somewhat haphazard relocation of "satellite" terminals (Slack, 1999), an inland shift of port activities through port regionalization (Notteboom and Rodrigue, 2005), and planning policies more or less in favour of port-city separation or reconnection (Hall and Clark, 2010).

Vessel calls (1950-2010) provide the most significant correlation with urban population, i.e. more than two times higher than total and container tonnage respectively (1980-2010). It is only in 1965 that urban areas, beyond the sole port city, started to be more significantly correlated with traffic, way before containerization took off and/or spread globally, meaning that the port migration was not caused, but reinforced by, containerization. Previous phases of port development saw the coastal shift of heavy industrial complexes using deep-water terminals to import and export their products. This important distinction helps us to question the impact of technological evolution on the distribution of modern supply chains.

[Table 2]

A complementary analysis of the interplay between cities and ports is proposed in **Figure 3** where we show, for three different traffic types and two basic indicators, urban population and vessel traffic, the distribution of average outer traffic per quantiles of identical sample size. Strikingly, there is a very close relationship between the amount of outer traffic, the size of vessel traffic, and city size. Urban areas are magnets and producers of finished, higher-valued goods so that they increasingly concentrate such traffic in their vicinity (Ducruet et al., 2015). Yet for container traffic tonnage, this interdependence is not so obvious, at least before the 2000s, when ports and cities exhibited a random share of outer traffic, due to the uneven distribution of container flows at the early stages of containerisation, led by other factors such as port selection and intermodalism (Slack, 1985). Overall, this analysis confirms that larger places are more likely to undergo port migration due to congestion and lack of space, should it be due to the intensity of cargo flows and/or to the density of urbanized areas. Yet, this especially applies to urban factors, given that the average share of outer traffic among the largest cities (urban areas) always surpasses the one among the largest ports, from 5 to 10 points and with an increasing gap overtime.

[Figure 3]

3.3 A global typology of port migration trajectories

We then performed a clustering of urban areas depending on their type of migration trajectory overtime (e.g. stability, decline, growth). Factor loadings using a Principal Component Analysis (PCA) based on time-series are the base of the complementary cartography of such clusters across the world[3]. Total tonnage (1980-2010) provided two factors condensing no less than 74.1% of total variance. Three main trajectories are revealed: stagnation (cluster 1), inner city concentration (cluster 2), and migration (cluster 3). The majority of cities fall into the broad category of stagnation as no clear or strong variation was observed. In comparison, clusters 2 and 3 only concern a minority of cases but their trajectory is clearer (Figure 3a).

[Figure 3]

When it comes to container traffic only, the variance contained in the two loading factors remains smaller so that results are less significant and straightforward (56.8%). However, we obtain a similar typology: stagnation (cluster 1), abrupt change but low migration (cluster 3), and growing migration (cluster 2). Container shipping being still a spreading innovation in the early 1980s (Guerrero and Rodrigue, 2014), its effects on port migration are less clear than total traffic, despite those three main trajectories. In terms of vessel calls over a longer time period (Figure 3c), our results follow the previous trends. The total variance captured by the two main principal components is even higher than for container traffic alone, i.e. 60.5%. But some differences with other traffic types are worthy of investigation. The three clusters exhibit declining outport traffic (cluster 1), early growth and stagnation (cluster 2), and late but steady growth (cluster 3).

We map the results per city to observe how they are geographically distributed (**Figure 4**). This is based on the hypothesis that certain trends may be linked to a regional logic, as (port) cities of the world went through different trajectories, such as between Europe and Asia (Lee et al., 2008). The map based on total tonnage (1980-2010, Figure 4a) is dominated by cities having a relatively stable outer traffic share, including London and Buenos Aires. Port migration is mainly observable in the North Atlantic region, with Chicago, Los Angeles in the U.S., St. Petersburg in Europe, but also northeastern Brazil, Shanghai and Bangkok in Asia, among the largest cities. Reverse migration (inner traffic growth) can be observed at Luanda in Africa but also Istanbul, Vancouver, Boston, and Chittagong in other parts of the world.

[Figure 4a]

The specific case of container traffic (**Figure 4b**) is dominated by two main types, stable migration and late migration. The concerned cities are more or less the same than in the previous map, but this time it includes Sydney, Buenos Aires, Casablanca, Alexandria, Izmir, on top of the aforementioned cities based on total traffic. The last map based on vessel calls (**Figure 4c**) is more diverse geographically speaking, with many demographically large cities

[3] We used TRAJPOP software developed by Cura (2013) to obtain clusters: http://trajpop.parisgeo.cnrs.fr/

encompassing early port migration (e.g. Rio de Janeiro, Manila, Sydney, Montreal, Toronto, Karachi, Jeddah, Casablanca, Rome, and several West European cities). The late but steady port migration is not specifically bound to certain regions of the world, but include many port cities of the emerging countries (East Asia, Latin America) as well as cities located in old industrial countries (e.g. North America) and in the vicinity of Europe (Turkey, Egypt, Russia). Inner traffic growth (reverse port migration) is mainly observed in the Northern hemisphere (e.g. Japan, USA) but also in Europe and West Africa.

4. Conclusion

This paper demonstrates that there is no simple and unambiguous answer to the questions concerning the dominant tendency shaping port migration. Earlier empirical evidence is derived from a small number of cases, the results of which tended to be contradictory, thereby justifying the particular arguments of each proponent. By undertaking a quantitative analysis of a global set of ports it was hoped that greater clarity would be possible. The results reveal that migration of port activities has taken place in the large majority of cases, but that the traffic proportions between the older 'inner' facilities and the newer 'outer' terminals have remained relatively stable over time. In a smaller number of cases the 'outports' have been the engines of traffic growth. Part of the reason for the diversity of results is that different metrics are used in the quantitative analysis: vessel tonnage, vessel calls, and container vessel calls. It is suggested also that the methodology in defining inner and outer could be refined by a more rigorous classification based on field work.

Part 2 of the paper examines the main drivers of port migration. A large number of factors are presented, that while demonstrating their relevance, does not suggest any prioritisation. This engenders uncertainty as to how all the drivers are to be applied to question of port migration. It is evident, however there are important interdependencies between the main drivers that we summarise as spatial/physical economic/governance. For example, environmental legislation may set the conditions for port expansion that may shape future port functions and traffic. In turn the present effects of the three main drivers are shaped by the history and stage of life cycle of the port.

The results of the quantitative analysis in Part 3 indicate some divergence in the patterns of migration depending on the metric employed. Tonnage data indicated very limited inner city growth, spatially extensive changes categorized as stable and average port migration, and with outer traffic increases restricted to a small set of regional cases. Based on vessel calls inner city growth exhibits a slightly more extensive distribution pattern, while ports with stable and average port migration are less numerous than the same class based on tonnage data. Ports classed as displaying late and steady port migration are significantly more extensive, especially in North and South America, the Eastern Mediterranean and along the main east-west shipping lanes to East Asia. Container traffic provides only two classes: stable and average port migration, late and steady port migration

Why are there differences? Vessel tonnage data gives a better indication for bulk shipments, since most movements are end to end. It will inflate container traffic because vessels are engaged in multiport itineraries so the same size vessel making multiple calls will count the same. Ship numbers will inflate cargo activity (vessels of different sizes) but are superior for a wider range of ports because that determines berth capacity requirements.

Further research should revisit the question of how to measure outer ports. Here, a city-region approach was adopted in order to obtain a broad spatial perspective on migration. It led to questions about the definition of specific sites as 'outer' in particular. Moreover, our urban approach and the lack of precision of the traffic data both confirmed and infirmed established cases where port migration was known to have happened but could not be properly measured and then compared. One way forward is to better categorize locations in a harmonious way, so as to better bridge qualitative and quantitative, field observation and macro-level testing. In this vein, a more constraining approach focused on the patterns of terminal locations under the same governing body could provide some more nuanced results. While DWT and the number of vessel calls metrics provide a means of exploring the spatial characteristics of all types of port trades, it might be useful to separate containers from the totals in order to analyse the spatial characteristics of non-container terminals. Despite the differences between the trades, bulk cargoes exhibit trajectories of growth that need to be examined more carefully.

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Fleet type	Place type		1950	1960	1965	1970	1975	1980	1985	1990	1995	2000	2005	2010	2015
All vessels	Port city		-	-	-	-	-	0.217	0.247	0.181	0.179	0.158	0.177	0.189	-
	Urban area		-	-	-	-	-	0.640	0.650	0.629	0.617	0.603	0.599	0.592	-
	All cities		-	-	-	-	-	0.366	0.415	0.270	0.237	0.204	0.218	0.221	-
Fully cellular container ships	Port city		-	-	-	-	-	0.226	0.247	0.208	0.262	0.302	0.295	0.308	0.261
	Urban area		-	-	-	-	-	0.398	0.440	0.381	0.281	0.310	0.452	0.367	0.312
	All cities		-	-	-	-	-	0.312	0.329	0.275	0.324	0.350	0.347	0.382	0.348
Vessel calls	Port city		0.494	0.477	0.423	0.397	0.349	0.346	0.356	0.327	0.375	0.313	0.281	0.494	-
	Urban area		0.379	0.522	0.635	0.680	0.658	0.582	0.581	0.586	0.640	0.592	0.605	0.379	-
	All cities		0.546	0.578	0.559	0.581	0.551	0.502	0.515	0.486	0.528	0.458	0.402	0.546	-

Table 1: Correlation (Pearson) between urban size and vessel traffic size, 1950-2015

N.B. calculations based on extended urban areas

	1950	1960	1965	1970	1975	1980	1985	1990	1995	2000	2010
Antwerp	0.3	1.3	0.1	0.7	0.2	0.4	0.7	1.2	1.2	1.4	0.9
Busan	7.7	21.9	14.9	30.2	40.4	34.2	38.1	46.5	49.8	-	-
Chicago	3.5	1.7	0.0	0.0	100.0	0.0	50.0	-	-	100.0	-
Cleveland	-	0.0	0.0	50.0	0.0	100.0	25.0	50.0	0.0	-	-
Guangzhou	0.0	0.0	0.0	0.0	0.0	0.0	2.7	1.3	5.7	14.3	23.6
Hamburg	0.3	2.0	1.4	0.0	0.6	0.5	0.4	0.9	0.5	1.1	1.2
Ho Chi Minh City	2.1	0.0	0.0	0.0	0.0	0.0	6.5	0.0	9.7	10.5	21.3
Le Havre	4.9	4.6	3.6	4.2	2.5	5.0	9.1	9.7	8.0	15.0	14.1
Los Angeles	1.8	1.7	1.1	0.4	0.4	0.0	0.3	0.0	0.0	0.0	64.1
Montreal	1.5	2.9	5.9	8.5	12.9	11.5	7.8	5.2	9.3	16.9	14.6
Ningbo	-	-	-	-	-	-	0.0	0.0	2.7	1.8	32.5
Rotterdam	6.7	3.2	1.7	2.4	2.3	2.6	6.2	5.5	9.1	10.8	8.4
Shanghai	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.6	4.6	10.4	21.7
Vancouver	7.0	8.2	11.2	7.7	8.6	7.9	7.7	8.2	6.5	7.9	0.0

Table 2: Outer traffic share evolution at selected ports (1950-2010)

N.B. calculations based on urban areas and vessel calls

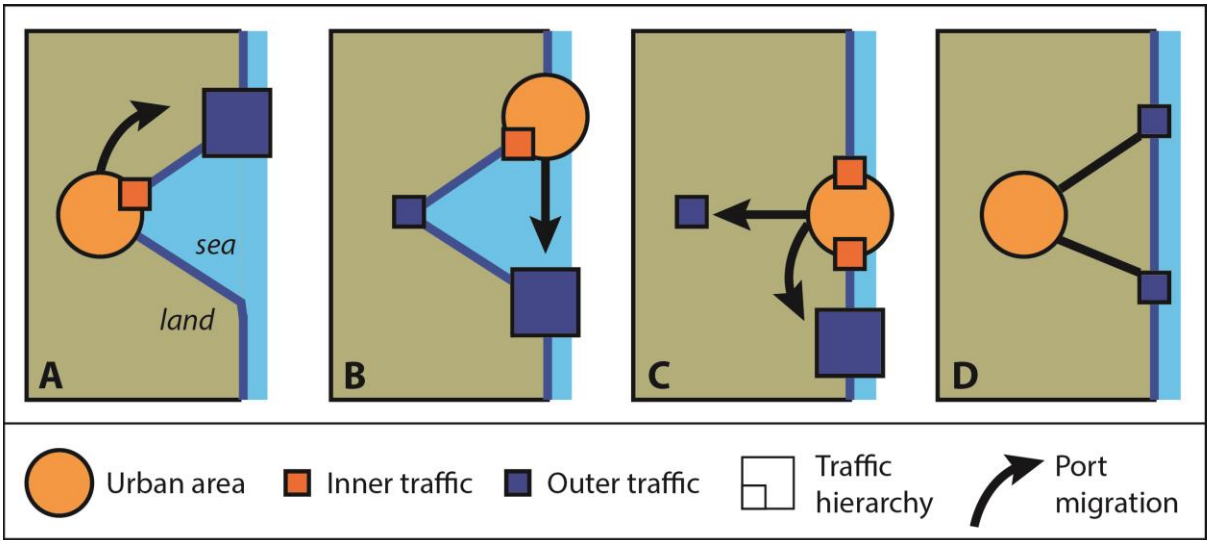

Figure 1: Spatial typology of port migration

Source: own elaboration

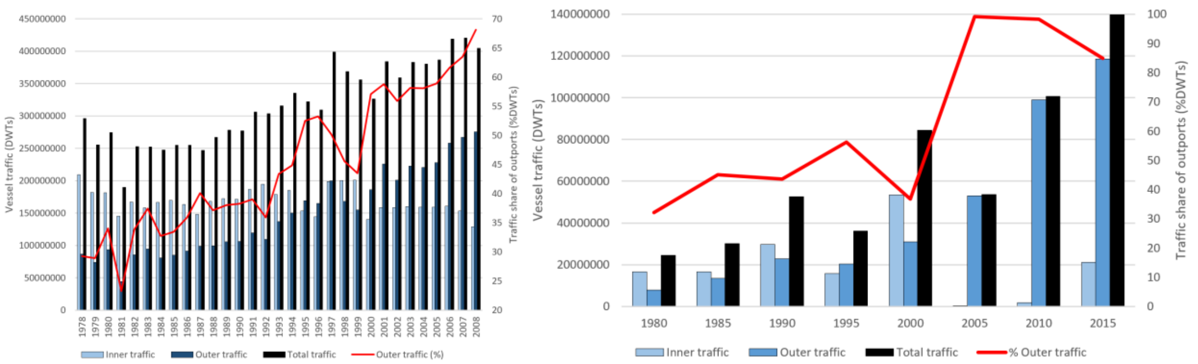

Figure 2: London's vessel traffic evolution, 1978-2015

Source: own elaboration based on Lloyd's List data

Vessel traffic	Class	Quantile	1951	1960	1965	1970	1975	1980	1985	1990	1995	2000	2005	2010	2015
Total tonnage	Traffic	1						10,3	10,2	10,1	8,6	10,1	10,2	14,3	
		2						17,2	18,7	17,9	16,2	17,1	15,6	14,7	
		3						15,3	14,0	14,6	14,1	14,8	14,5	14,7	
		4						18,3	18,2	18,4	19,7	17,4	19,3	19,9	
		5						19,0	21,1	21,2	21,1	22,4	22,6	23,3	
		Average						16,0	16,5	16,5	15,9	16,4	16,5	17,4	
	Population	1						8,7	8,7	7,5	6,7	6,7	6,9	4,4	
		2						11,1	12,5	12,5	11,8	11,8	12,6	9,2	
		3						19,8	20,7	20,8	20,8	20,8	21,3	13,5	
		4						24,7	26,2	26,5	24,8	24,8	28,1	25,6	
		5						28,4	29,0	29,0	28,8	28,8	27,3	27,4	
		Other						6,9	7,5	7,3	7,1	7,1	6,7	9,6	
		Average						16,0	16,5	16,5	15,9	15,9	16,5	17,4	
Total calls	Population	1	7,2	6,1	8,4	8,7	11,7	12,9	13,4	11,4	12,9	13,0		6,8	
		2	18,2	12,7	13,2	14,3	12,0	9,4	10,6	13,7	13,7	11,0		11,2	
		3	19,0	15,7	17,5	15,1	20,1	20,5	19,8	20,0	20,2	23,1		14,7	
		4	25,1	20,9	19,4	21,6	22,1	23,1	24,3	26,2	27,1	25,4		23,9	
		5	22,0	25,0	24,2	25,8	25,7	27,0	28,4	30,5	29,2	30,5		30,2	
		Other	8,9	8,9	7,3	9,2	5,2	6,1	8,1	8,3	9,2	8,9		9,4	
		Average	17,0	15,6	15,3	16,9	16,8	17,4	17,8	18,9	19,3	19,2		19,5	
	Traffic	1	15,2	11,9	12,3	16,5	13,5	13,6	14,5	16,4	17,1	16,8		16,7	
		2	15,8	17,9	12,2	15,3	17,2	15,8	14,7	23,7	20,5	18,2		14,3	
		3	18,4	15,9	18,7	15,9	14,1	18,2	18,6	16,4	15,5	17,1		19,6	
		4	18,0	15,6	15,3	17,7	19,9	19,7	20,9	18,4	19,3	20,5		20,1	
		5	16,9	18,3	18,0	18,7	19,0	19,4	19,7	22,9	23,3	23,2		25,3	
		Average	17,0	15,6	15,3	16,9	16,8	17,4	17,8	18,9	19,3	19,2		19,5	
Total container tonnage	Population	1						3,6	10,7	8,4	6,0	8,2	7,0	5,9	7,7
		2						7,7	12,7	11,4	12,7	10,1	11,0	8,2	7,8
		3						14,9	14,2	15,0	17,4	16,2	17,1	18,4	17,0
		4						17,6	21,2	17,7	18,7	18,6	16,0	19,2	18,9
		5						25,8	23,6	26,1	24,2	26,5	28,0	30,0	29,7
		Other						2,6	8,0	7,3	3,9	4,5	2,7	7,7	11,8
		Average						15,9	16,9	16,7	15,9	16,1	15,8	17,8	17,7
	Traffic	1						15,1	17,4	17,4	14,9	11,2	10,8	14,0	17,0
		2						11,0	15,4	19,1	17,0	14,4	15,4	16,3	15,5
		3						17,7	19,7	15,1	16,2	16,8	14,8	17,6	19,7
		4						21,2	16,5	17,8	14,1	18,3	18,5	21,5	16,9
		5						14,7	15,3	14,1	17,3	19,5	19,6	19,6	19,5
		Average						15,9	16,9	16,7	15,9	16,1	15,8	17,8	17,7

Figure 2: Average share of outer port traffic per type of flows and places, 1950-2015

Source: own elaboration based on Lloyd's List data and Wessa (2019) software

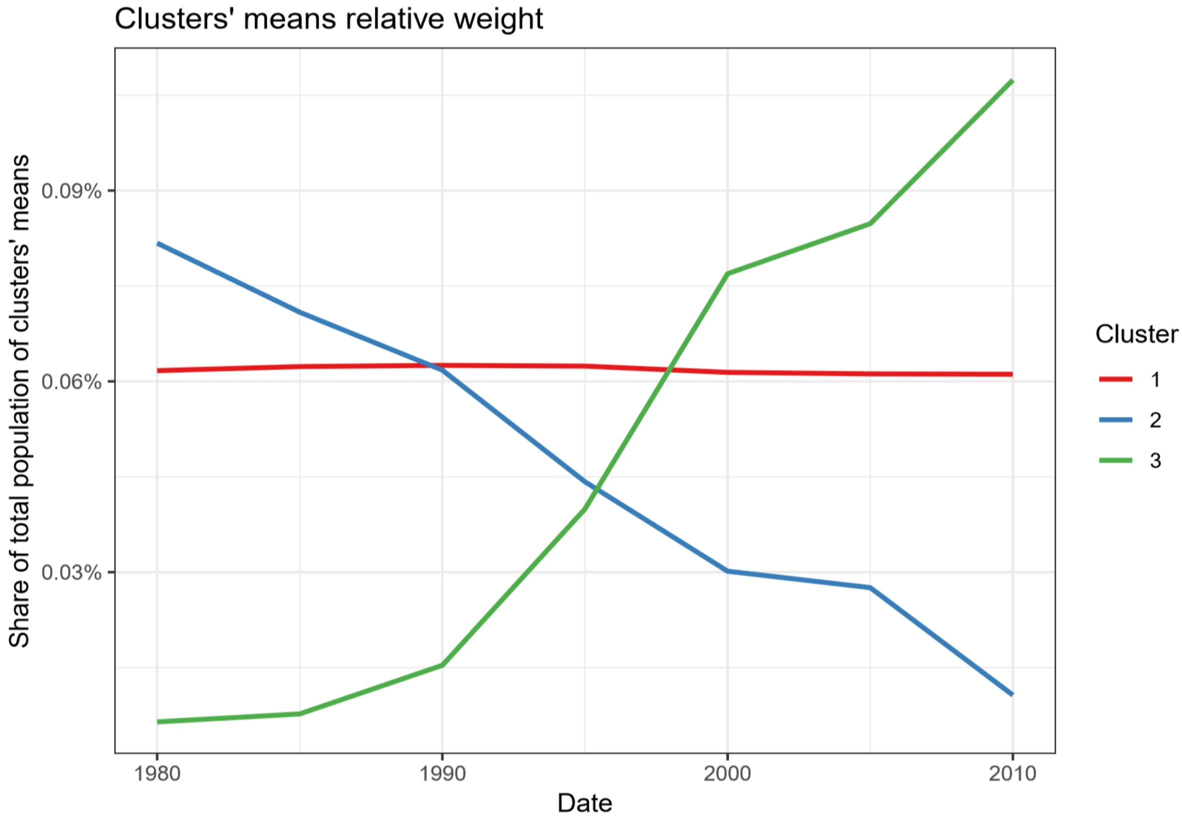

Figure 3a: Trajectories of urban areas based on outer port traffic share, 1980-2015

Source: own elaboration based on Lloyd's List data and Trajpop software
N.B. figure refers to total traffic all fleets included

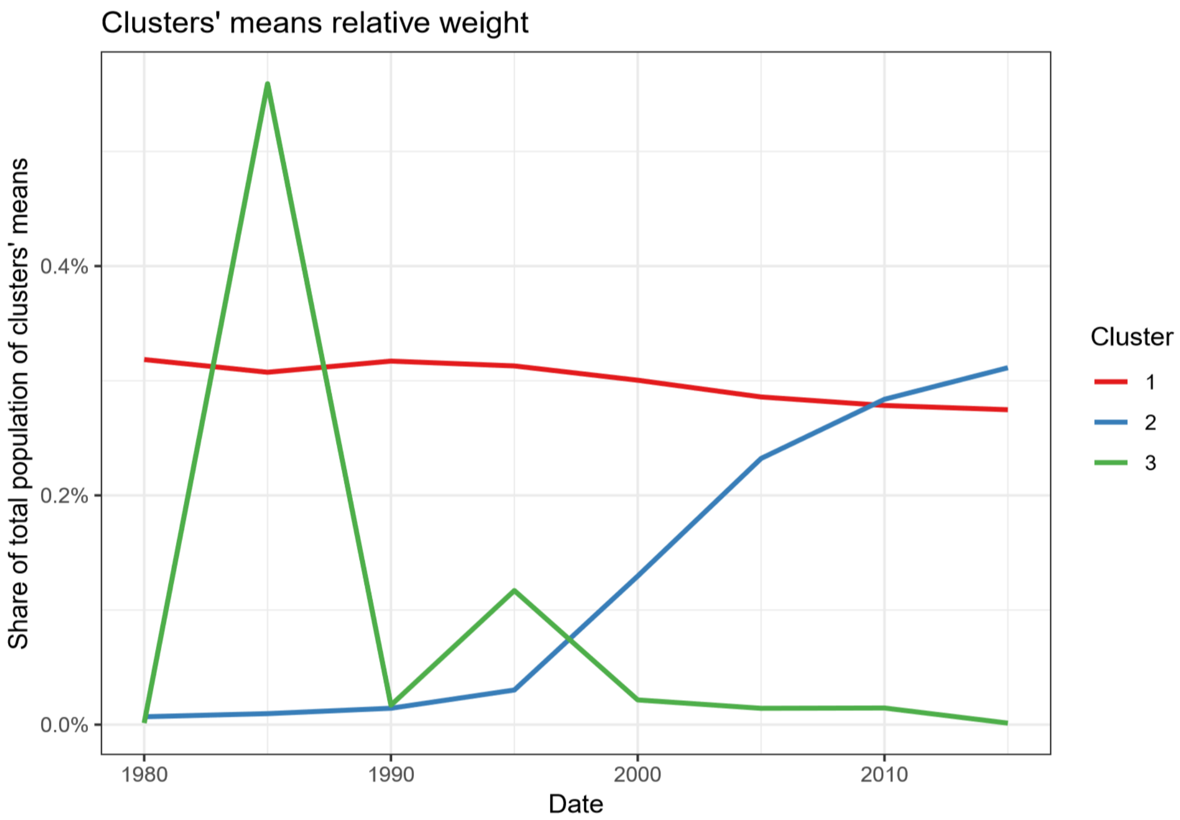

Figure 3b: Trajectories of urban areas based on outer port traffic share, 1980-2015

Source: own elaboration based on Lloyd's List data and Trajpop software
N.B. figure refers to container traffic only

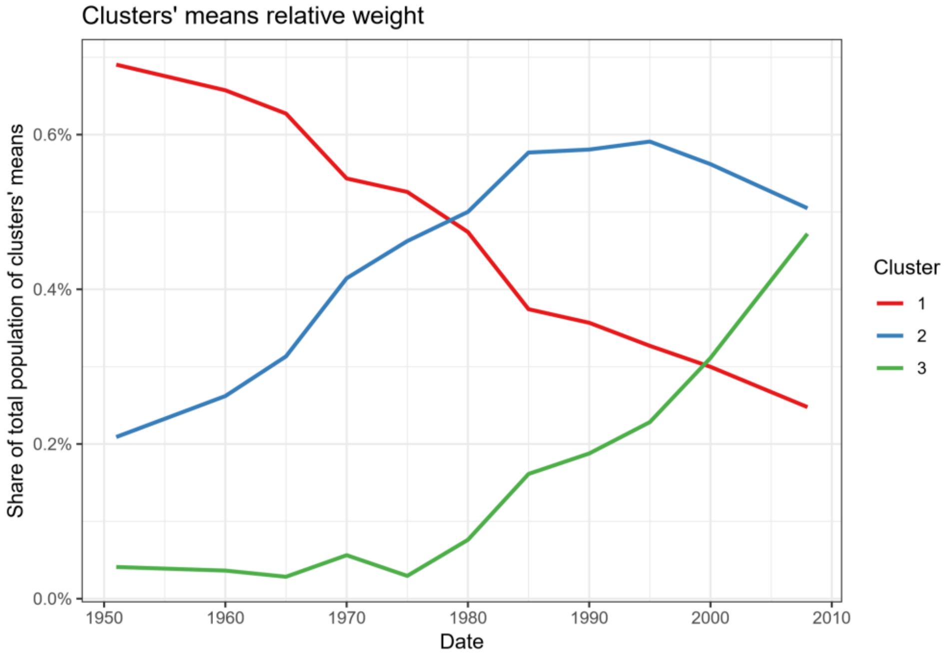

Figure 3c: Trajectories of urban areas based on outer port traffic share, 1950-2010

Source: own elaboration based on Lloyd's List data and Trajpop software
N.B. figure refers to all traffic types based on the number of calls

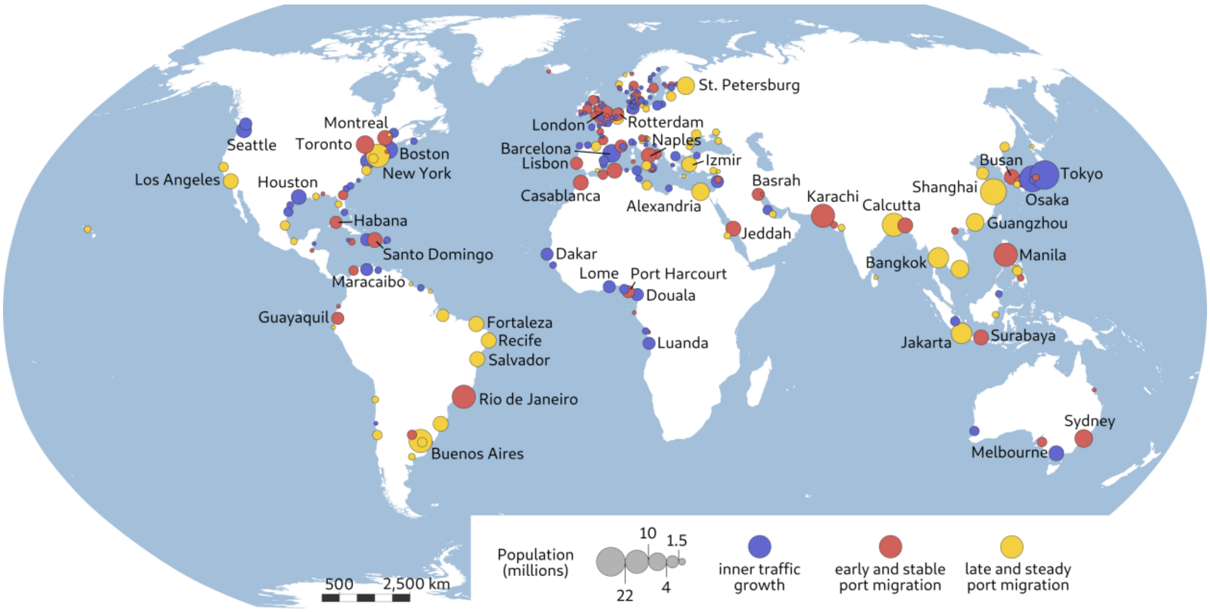

Figure 4a: Typology of world port cities based on outer port traffic share, 1950-2010

Source: own elaboration based on Lloyd's List data and Trajpop software
N.B. figure refers to all traffic types based on the number of calls

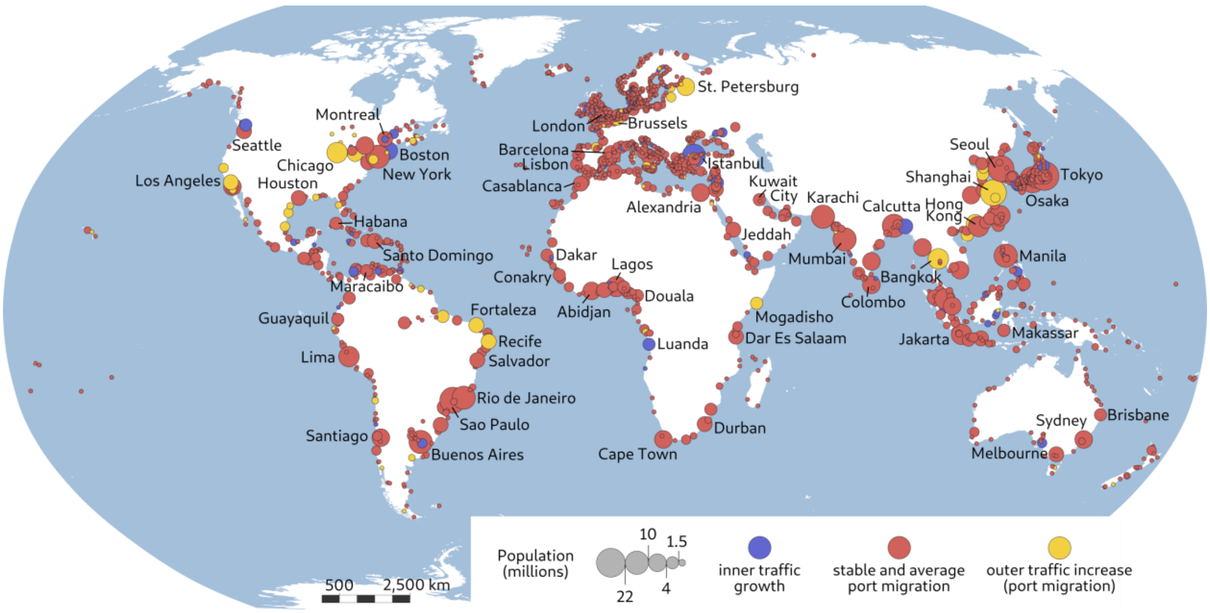

Figure 4b: Typology of world port cities based on outer port traffic share, 1980-2015

Source: own elaboration based on Lloyd's List data and Trajpop software
N.B. figure refers to total traffic all fleets included

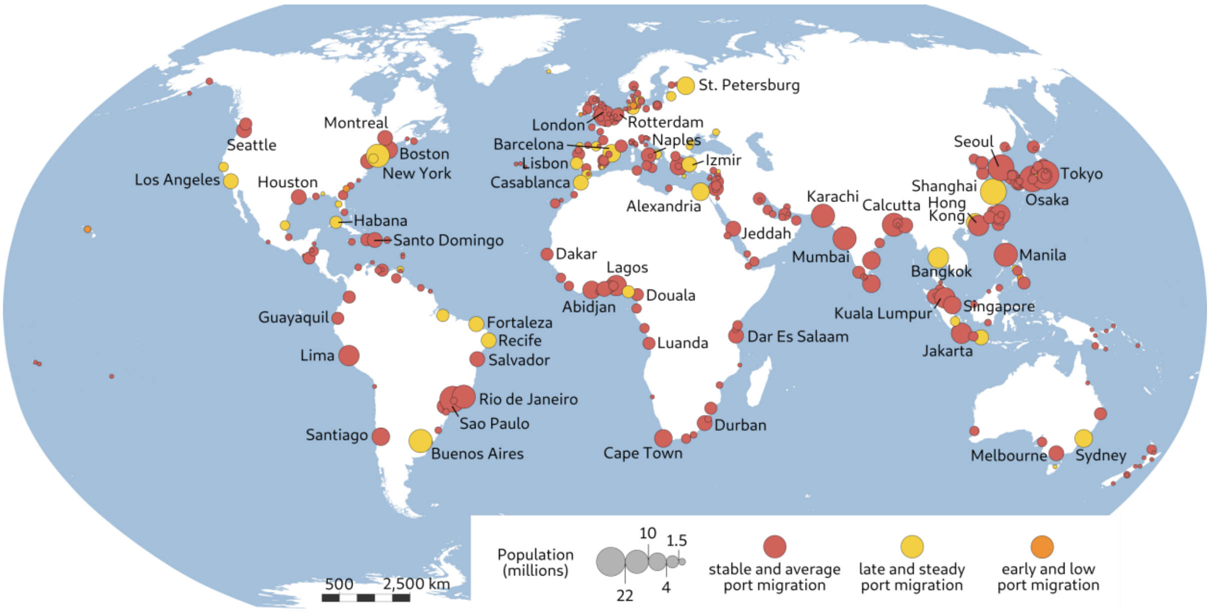

Figure 4c: Typology of world port cities based on outer port traffic share, 1980-2015

Source: own elaboration based on Lloyd's List data and Trajpop software
N.B. figure refers to container traffic only