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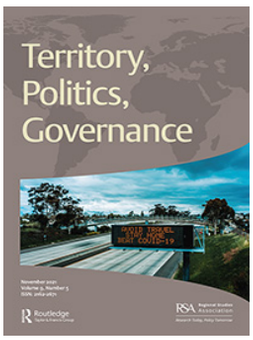

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Friends with benefits: the emergence of the Amsterdam–Rotterdam–Antwerp (ARA) polycentric port region

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ABSTRACT

This paper enacts a dialogue between planning literature on polycentric urban regions (PUR) and port geography literature on multi-port gateways. The main proposition is that polycentric systems are the emergent outcome of the interactions between three dimensions of polycentricity: morphological, functional and institutional. The focus is on the Dutch–Belgian Amsterdam–Rotterdam–Antwerp (ARA) port–industrial region: one of the world's largest concentrations of oil refining and petrochemical activity. The central question is to what extent is the ARA region a polycentric system and what explains this observed polycentricity? Our analyses demonstrate a high degree of morphological and functional polycentricity with each of the constituent (firms located in) ports connected through flows and specialization in processing and trading oil (products). However, this is not the intended result of formalized spatial planning, nor did the ARA ever became a frame of reference among planning agencies. Rather, it is the result of self-organization in the oil industry that has culminated in the emergence of the ARA as an internationally recognized spot market, later institutionally formalized in delivery contracts (oil futures) traded on international commodity exchanges. We conclude that polycentric systems could be understood as emergent systems that obtained generative capacities, in turn influencing its different constituting dimensions.

KEYWORDS

polycentricity; polycentric urban regions; multi-port gateways; ports; emergence; Amsterdam–Rotterdam–Antwerp (ARA); relatedness; product space

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INTRODUCTION: FROM A POLYCENTRIC URBAN REGION TO A POLYCENTRIC PORT REGION

Many large seaports are geographically located in relative proximity, serving overlapping and often contested hinterlands. Such areas have been referred to as multi-port gateway regions (Notteboom, 2010), with numerous examples such as the 'Rhine–Scheldt Delta' in Europe or the 'Pacific Northwest' (with the main ports of Seattle, Tacoma and Vancouver) in the United States and Canada. In many ways these ports compete to attract the same cargoes and investments. But in some cases, there is also a degree of complementarity between the various operations and industrial activity across different ports in the region (Ducruet et al., 2010; Hall & Jacobs, 2010). Ports in multi-port gateway regions not only share a hinterland but often also share a main nautical access route, are subject to similar types of regulatory requirements, and enjoy a shared labour market to a certain extent. The existence of such 'ports in proximity' (Notteboom et al., 2009) invokes the concept of polycentricity, as has been used by planners and urban scholars to discuss and analyse various degrees of connectivity and complementarity within regionalized urban systems to overcome the traditional core–periphery dichotomy (Albrechts, 2001; Dieleman & Faludi, 1998; Kloosterman & Musterd, 2001; Kunzmann, 1996; Lambregts, 2009; Meijers, 2007). Surprisingly, there has hardly been any reference to the concept of polycentricity in the analysis of these multi-port gateways or ports in proximity, but a notable exception is Monios (2019), who employs polycentric thinking to conceptualize the multi-nestedness of governance arrangements within ports. He rightly points out that port governance is essentially polycentric due to overlapping jurisdictions of government agency and through intra- and inter-port corporate networks. However, Monios' approach is informed by the works of Ostrom (1990) on collective action, and therefore takes polycentricity in governance as the unit of analysis, rather than the governance of a morphologically polycentric region, as is common in the debates on polycentric urban regions (PURs).

The port literature does not build on the conceptualization of polycentricity as commonly used in urban studies and in planning literature. On the other hand, studies on PURs often neglect the role of ports as specialized centres within those regions, despite ports being often strongly associated with the growth of cities (Fujita & Mori, 1996; Glaeser, 2005; Hall & Jacobs, 2012). Some of these port-cities indeed diversify into service-based economies, while others suffer from lock-ins into an economic development trajectory based upon logistics and heavy industry (Chapman, 2005). The very notion that within urbanized regions there can be a multitude of ports of similar and different sizes and with competing and complementary interests between which various flows and transactions can occur often escapes the attention both in concept and in empirics (Van den Berghe et al., 2018).

Given the resemblances between PURs and polycentric port systems, the wider aim of this study is therefore to move beyond urban systems when discussing polycentric development. More precisely, we explore whether the thinking, vocabulary and approaches that are associated with PURs are also useful to understand polycentric port systems. The other way around, we will inform the debate on PURs with insights derived from the emergence of polycentric port systems from the interaction between the three constituting dimensions of polycentric systems: morphological, functional and institutional.

Development strategies for PURs tend to focus on fostering interaction between the centres making up those regions. In contrast, in this paper, our point of departure is the emergent polycentric (spatial) organization of the port system to assess the role of agency (both public, particularly planning strategies, and private, such as corporate strategy of oil companies) and institutions in developing this polycentric system. Of course, this is enabled by the relatively much less complex spatial configuration of such a port system in comparison with a PUR, with less diversity in

types of flows, and especially with much fewer actors and institutions being involved in shaping the system, allowing for a clearer perspective on how the institutional dimension interacts with the morphological and functional dimensions. Other than the majority of the PUR literature that in particular focuses on public planning authorities, we see the institutional dimension more in terms of a set of rules and conventions that constrain and enable human interactions and in which governance is understood as a set of institutional arrangements or coordination mechanisms in the allocation of resources and which can vary from spot markets and contractual bargaining to hierarchy and bureaucracies (Williamson, 1985). Such an understanding implies taking into consideration that certain (spatial) development outcomes are rarely only the intended result of 'planning by design' by an appropriate public agent. Rather, these are the result of a complex system in which self-organization, non-linearity, exogenous shocks, learning and adaptation are linked with emergence. Note that within this complex system, we do not exclude the role of planning, in contrary. The question is to what extent planning played a role for a polycentric system to exist.

Therefore, we employ the concept of 'emergence' to analyse how polycentric systems exist out of the interaction between the three dimensions. Emergence is a key concept in relational geography and complexity theory that is used to understand the existence of regions and regional structures and processes (Balland et al., 2019; Kauffman & Johnsen, 1991; Krugman, 1996; Yeung, 2019). Yet, to our knowledge it has hardly been touched upon in the PUR literature (but see Nelles et al., 2018) and port and shipping literature (but see Van den Jacobs & Horster, 2020; Van den Berghe et al., 2018). As explained by Sunley (2008, p. 14), 'Emergence describes the significance of relations between properties at multiple levels of analysis and argues that higher-level properties emerge from the interactions of individuals in a complex system and exhibit their own dynamics.' As he continues, 'the emergent property … has the generative capacity to modify … its constituents …'. In other words, the concept of emergence allows us to understand not only the reciprocal relations between the three dimensions of polycentric systems (morphological, functional and institutional), but also the reciprocal relations between lower and higher level properties. Lower and higher level here does not refer to geographical scales, although they can be aligned (in this respect, see Marston et al., 2005). Higher properties should be seen as causal outcomes of interactions or coupling mechanisms (Sayer, 2000; Van den Berghe, 2018) between lower level properties, and from the moment they exist, influence these lower level properties and their interactions (Lawson, 1997; Massey, 1992). Important is that these higher level properties are not planned or foreseen by someone or something, but are emergent in themselves (Archer, 1982; Sawyer, 2001).

We take the Dutch–Belgian cross-border polycentric port region Amsterdam–Rotterdam–Antwerp (ARA) as our case study. Next to these three large ports giving their name to the region, it also includes the ports of Ghent–Terneuzen–Flushing (a cross-border port authority known as 'North Sea Port' – NSP), Moerdijk and Zeebrugge. Interestingly, this ARA region largely overlaps with two PUR archetypes, namely the Dutch Randstad (Zonneveld & Nadin, 2021) and the Flemish Diamond (Albrechts, 2001). In port studies, the ARA area is sometimes referred to as the 'Rhine–Scheldt Delta (RSD)' (Notteboom, 2010), but this is based upon container terminals rather than bulk commodities such as oil.

While RSD is mainly an academic analytic concept, the ARA as a coherent region does not originate from a public policy vision, territorial planning document or by planning by design. The concept of the ARA is the explicit geographical reference for physical delivery of oil products in commodity futures and forward contracts traded both off and on commodity exchanges. This geographical denomination in a highly liquid traded oil futures contract[1] corresponds to the function of the ARA as one of the main spot markets for trading physical crude oil (and products). Therefore, the existence of the ARA spot market implies a certain functional coherence within the port region whereas the existence of a futures market implies an institutional

arrangement that governs the allocation of financial risk and reward in physical delivery promises in the future. As such, looking at this polycentric port region through the lens of the 'product space' (Hidalgo et al., 2007) or production network (Henderson et al., 2002) of crude oil, with both functional and institutional dimensions, could possibly aid our understanding of the relations between the morphological, functional and institutional dimensions of polycentric (port) systems. Our research question is therefore: To what extent is the ARA region a polycentric system and what explains this observed polycentricity?

To answer this question, the paper is structured as follows. We start in the next section with a brief historical overview of the concept of polycentrism, focusing on the main normative ideals with which polycentricity has been associated, which leads to the identification of possible motivations for the actions of actors shaping a polycentric system. Subsequently, we introduce in the third section our analytical framework in which we state that a polycentric system is an emergent property constituted by reciprocal relations between morphological, functional and institutional dimensions. In the fourth section we empirically explore the interrelationships between these dimensions for the ARA region, introducing, among others, a new methodology that enables analysing and visualizing the functional relations between ports. In the fifth section we discuss the emergence of polycentric systems. In the sixth section we present our conclusion, drawing lessons from our analyses that are relevant for understanding both PURs and polycentric port systems.

RATIONALES FOR THE EMERGENCE OF POLYCENTRICITY SYSTEMS

A polycentric system, irrespective of it being urban or port related, will only emerge or become the object of normative (planning) strategies if it entails advantages over the initial situation in which the ports or cities act independently from each other. In this section we will first explore ideas on the rational of polycentric systems, because these may explain polycentricity as an outcome of either a planned top-down process or of a more bottom-up self-organized spatial structure. To do so, we first take a step back by considering normative objectives with which polycentricity in general has been associated over time, drawing largely on the planning literature. Arguably, there are three main, but in time overlapping, perspectives on the merits of polycentric systems.

Perspective 1: Polycentricity to avoid agglomeration costs and sprawl (early 20th century–present)

The origin of the concept can be traced to the early 20th-century work of urban sociologists in the American Chicago School of Sociology (Davoudi, 2003; Green, 2007; Rauhut, 2017). Polycentricity gradually became a new model or expansion to the traditional monocentric urban structure and growth model. Both models were strongly policy driven and eventually became urban planning concepts aimed at mitigating the negative externalities of the fast growing industrial city (Howard, 1902 [1898]; Geddes, 1915; Mumford, 1945 [1938]). The monocentric urban structure model proposed to allocate different land uses within concentric circles around a central business district, thereby building on land prices and use intensity, echoing the location theories of von Thünen (1864) and Weber (1929). In contrast, the polycentric urban model proposed the growth of a spatially dispersed settlement system in which purposely small-sized urban centres were linked by infrastructures and transport systems (Howard, 1902 [1898]). The size limitations were particularly normative, based on an 'ideal' situation (e.g., Howard proclaimed that a city may consist of not more than 32,000 inhabitants). This idealized model was grounded in observations and descriptions of, for example, Greater London and the railway structure (cf. Geddes, 1915). In other words, polycentricity combined planned urban growth with an improvement of the social and economic situation. In particular, the goal was to develop cities that remained small

to avoid agglomeration costs. These ideas guided the construction of many new towns during the interbellum in many Western countries (van Meeteren, 2016) and still resounds today in the more US-based literature on dispersal/sprawl versus more concentrated (polycentric) forms of intra-metropolitan expansion.

Perspective 2: Polycentricity allowing for agglomeration economies and world city status (1960s–present)

The second rationale for considering polycentricity as a desirable spatial organization is rooted in the work of Hall (1966 [1984]) and particularly his *The World Cities* (Kloosterman & Musterd, 2001). In this book he described how world cities increasingly started to dominate the economy, which was explained by the relatively more intense connections between people and companies within these cities and between these cities, certainly in comparison with smaller and less well-connected cities. Interestingly, Hall stated that PURs such as the Randstad and the Ruhr could be regarded as world cities, next to their more well-known monocentric counterparts such as London and New York. The main difference with the first perspective is the starting point. While within the first perspective the quest is about monocentric cities restructuring into polycentric systems (an intra-metropolitan process of dispersion), within the second perspective the focus is more on integrating existing fragmented forms of urbanization into a coherent polycentric urban system – an inter-urban process of integration (Davoudi, 2003; Rauhut, 2017).

Perspective 3: Polycentricity as a means to achieve balanced development on larger territorial scales (1999–2010s)

A third rationale for considering polycentricity as a desirable spatial outcome is its association with less regional disparities, and hence a more balanced development of all parts of the system. This view became prominent when the concept of polycentrism was put forward as a key spatial planning tool to achieve social and economic cohesion at the level of the European Community in 1999 (Davoudi, 2003; Faludi, 2005), in particular when it was subsequently adopted as an important concept in planning circles (Albrechts, 2001; Meijers, 2008). This perspective clearly focuses on a larger interregional spatial scale (Jacobs, 2002; Meijers & Sandberg, 2008). The explicit goal of inter-urban polycentrism is to overcome Europe's monocentric urban economic structure as exemplified by the iconic 'Blue Banana' (Rauhut, 2017; Waterhout et al., 2005) with a focus on the endogenous growth outside the core. Polycentricity became a 'bridging concept' whereby competitiveness arguments were combined with ambitions for 'territorial cohesion' at the European scale (or what is referred to in the European Spatial Development Perspective, 1999, as 'balanced competitiveness'). In the end, 'territorial cohesion' never institutionalized as a third pillar in the EU's Cohesion Policy (next to economic and social cohesion) nor did spatial planning became a European Community competence. Attention for this perspective on polycentrism on greater territorial scales has waned somewhat (but see Rauhut et al., 2021). Nevertheless, Meijers and Sandberg (2021) associate polycentric urban systems at the national scale with less regional disparities, but such proof came probably too late in this debate.

Polycentricity: a desirable way of organizing a system?

What these three perspectives emphasize is that, in comparison with monocentric systems, polycentric systems would be characterized by (1) the lack of agglomeration diseconomies that are characteristic of more concentrated forms of development (e.g., congestion, costs of land and real estate, concentration of environmental pollution), while (2) the development of functional relationships between the elements constituting a polycentric system allows for agglomeration economies to develop (more aptly referred to as network externalities), and (3) polycentricity would also avoid a 'winner-takes-all' approach leaving others behind, and instead be associated with a more stable and balanced development of all constituting elements of the system.

These three perspectives in the PUR literature have commonalities: all three perspectives adopt a bird's-eye view of the entire territory, and start with politically endorsed premises about what seems best for the region at large and to correct for market failures including a set of planning interventions such as infrastructure development, building restrictions and spatial redistribution of economic activity. This reflects the top-down nature of much of the planning approaches aimed at polycentric development. Less attention is paid to the role of micro-level decisions of actors (public and private) in the region that may build the system bottom up, and how subsequently out of these lower level properties and their interactions (polycentric) structures emerge. Given the complexity of urban systems and the many actors involved, these may also be hard to identify. This is where an analysis of polycentric port systems is of value – its comparatively reduced complexity of a smaller set of companies and clearer (logistical) relations actually allows to study the complexity of polycentric development.

RESEARCH APPROACH: TOWARDS AN ANALYTICAL FRAMEWORK

In this section we again turn to the PUR literature to develop an analytical framework that can be applied to polycentric port systems. With so many perspectives on polycentricity circulating, it is no wonder that it led to a 'Babylonian confusion' with many different conceptualizations and types (van Meeteren et al., 2016). As a response, several authors have proposed different nuances and typologies to bring clarification when applying the concept of polycentricity (Münter & Volgmann, 2021; Rauhut, 2017; van Meeteren et al., 2016). van Meeteren et al. (2016) propose to organize the concept of polycentricity along the specific geography (cf. scale), or along the particular spatial–economic mechanism that one takes into account (e.g., agglomeration effect). Davoudi (2003) and Rauhut (2017) continue this argumentation and explain that the ambiguity of the concept comes with the variety of scales on which the concept is applied. They argue that on the local to regional scale, the discussion focuses mostly on 'polycentricity' in an analytical, measurable way, capturing the morphological and/or functional aspects of polycentric systems. Certainly from the national level, the discussion on 'polycentrism' is more normative, with polycentric development being a strategy to achieve some of the associated benefits discussed above.

What follows is that it is the regional scale where analytical and normative dimensions most converge. Analyses on this scale often identify (one of the) three dimensions: a morphological, a functional and an institutional dimension, while sometimes a fourth symbolic dimension is added (Kloosterman & Musterd, 2001; Meijers & Romein, 2003; Münter & Volgmann, 2021). This echoes Rauhut (2017, p. 14), who argues that the analytical polycentricity and the normative polycentrism cannot be seen apart, otherwise one could not explain how 'an imprecisely defined and immeasurable concept, with little empirical support, can survive for so long'.

Therefore, we argue that polycentric systems are an emergent outcome of the reciprocal interaction between the three dimensions: morphological, functional and institutional. In our proposition, the three dimensions are the lower level properties, while the polycentric system is the higher level property (Figure 1). The important difference between lower and higher level properties is the relational direction. Higher level properties emerge out of the interaction between its constituting lower level properties. In this paper, out of the triangle of interactions, the polycentric system emerges (the dotted lines in Figure 1). From the moment the polycentric system comes into existence, it constitutes the development of the three dimensions it is constituted by Paasi (2010, p. 2297). Note that much like the metropolization literature on PUR (Cardoso & Meijers, 2020), analytically one cannot show the existence of a polycentric system. One can only understand or examine a polycentric system by examining the three dimensions, and their interactions.

Regarding polycentric systems that simultaneously condition and are conditioned by lower level properties, arguably answers the concern of Davoudi (2003, p. 996), stating that

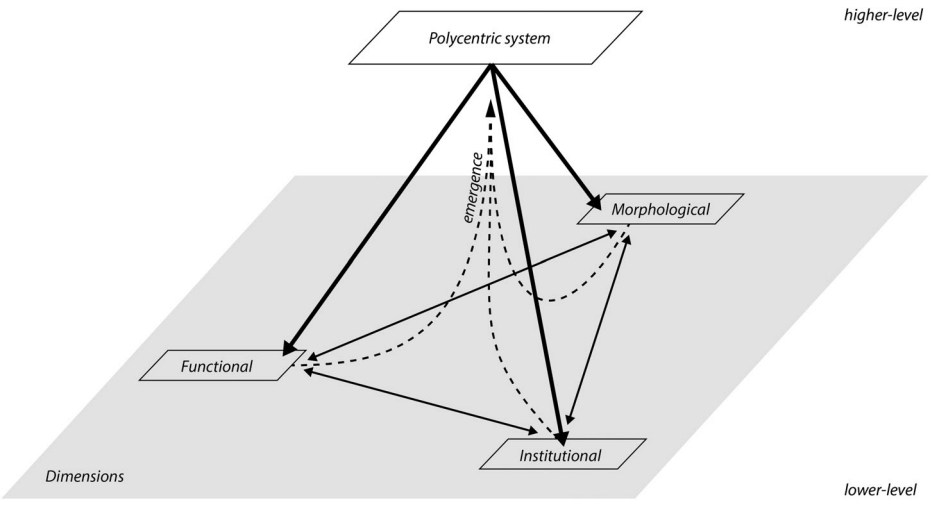

Figure 1. Emergence of a higher level polycentric system, which simultaneously conditions and is conditioned by the lower level three dimensions.

polycentricity has become hardened into an *idée fixe*: instead of using polycentricity as a concept to describe an emerging reality, it is coming to determine that reality (in this respect, see Boelens & de Roo, 2016). But as Cardoso and Meijers (2020, p. 372) state when discussing the process of integration in the Randstad PUR, 'this metropolisation process comes in waves, with different scales, sectors and dimensions of integration prevailing at different times. The historical interaction of functional, institutional and cultural dimensions created barriers as well as incentives to the process'. Consequently, analyses need to adopt a holistic view on this emergence.

For the operationalization, our methodology therefore requires a holistic approach. First, it needs to examine the three constituting dimensions of polycentric systems. Second, it needs to understand how out of their interactions in time higher level properties emerge that subsequently influence the three lower level dimensions by which it is constituted. For the morphological and functional dimensions, we apply quantitative methods, in line with the vast majority of the PUR literature. We turn to mapping transport data. In particular for the functional dimension, we developed a new method. This paper presents the essence; for the full details of the method, see the Appendix in the supplemental data online. For the institutional dimension, we predominantly followed an iterative historical research methodology, explaining what were the key moments that explain how the ARA contracts came into existence, and finally how all three dimensions interacted and how the port polycentric system emerged.

THE THREE DIMENSIONS OF THE ARA POLYCENTRIC PORT REGION

We begin this section by first explaining the broader setting of the upcoming of the oil market, which started at the end of the 19th century and grew during the 20th century, interacted with the ports in Belgium and the Netherlands. Second, we look at the ARA region and explain the three dimensions of polycentricity.

The foundation and fragmented development path of the petrochemical sector

The first petroleum is said to have arrived in the port of Rotterdam from the 1890s onwards (Boon, 2014). At the dawn of the 20th century Royal Dutch Shell started shipments from the Dutch colony in Indonesia, mainly to supply the lamp oil-based lightning market. It took

some decades, however, before Shell's first modern refinery was operational in the port at Pernis (1936) to cater for new demand in the emerging automotive and (petro-) chemical industries in Germany and Northern France. After the Second World War, petrochemical processing really scaled up, initially in the war-wrecked German industrial heartland of the Rhine–Ruhr that was quickly rebuilt via the American financial Marshall Plan, but now with oil as a major feedstock rather than coal. American oil companies, the spinouts of the illustrious Standard Oil, and British Petroleum (BP) also moved in directly after the war. Esso, BP and Royal Dutch Shell opened refineries in the area, which needed to be supplied via the ports in Rotterdam and Antwerp and further shipped via the River Rhine by barge. On its turn, in both the Netherlands and Belgium, the national governments, also with American financial support, quickly started to redevelop their main ports, but it was decided that these ports should reduce their dependency on demand in their German hinterland, contrary to coal transhipments before the war. Local demand for cargoes and value-added activity thus needed to be created by awarding international oil companies land concessions in newly developed and redeveloped port sites to start their refining operations (de Goey, 2003).

With the vast growth of demand in Western Europe in the 1950s, and a steady source of cheap supply from the Middle East, inland shipping from the ports to Germany via barge or road simply lacked the capacity to keep up. At the end of the 1950s, the oil companies developed plans for commercial pipelines between the ports and their assets in West Germany. Already in the first decade after the war and at the dawn of the Cold War, governments developed a pipeline structure connecting ports with major civilian airports and military airbases in Western Europe, including one from Rotterdam to Amsterdam Schiphol Airport, as part of Central European Pipeline System under the direct command of NATO. Despite this collaboration out of security policies, the development of commercial pipelines happened in a far more fragmented fashion, as eloquently documented by Boon (2014): pipeline politics in which national interests were prevailing and with fierce competition between various consortia and projects led by the oil majors. In this atmosphere, Shell managed to obtain approvals for the Rotterdam–Rhine Ruhr Pipeline (completed in 1957), directly linking the Shell refineries in Pernis and Goldorf (Cologne), and which was eventually extended to the Esso (ExxonMobil) and BP refineries at the newly developed Europoort terminals in the 1960s.

Pipeline politics and fragmented governance continued to prevail into the 1960s, in which local port authorities competed with each other for continued investment and national industrial policies now favouring regional economic development in nearby but underdeveloped areas such as Zeebrugge, Ghent, Flushing and Terneuzen. The German company BASF chose the port of Antwerp as the location for its chemical refinery plant over Rotterdam in 1965 (cf. de Goey, 2003), while Amsterdam, for instance, managed to lure the refinery project by Mobil Oil away from Rotterdam in 1968, custom built to produce gasoil for shipments to the US market. Stakes were particularly high between 'arch rivals' Antwerp and Rotterdam, especially with the arrival of the *supertanker*.[2] As oil tankers increased in size during the 1960s, these were no longer capable of navigating the Westerscheldt access route to the port of Antwerp. Refiners in Antwerp (Total, Esso, Petrofina) therefore pressed for the construction of the 100 km long Rotterdam–Antwerp Pipeline (RAPL), connecting their refineries with the Europoort oil terminals in the port of Rotterdam via Moerdijk (where Shell developed a chemical plant), and which was completed in 1969. Interestingly, the government stakeholders in Antwerp and Belgium initially were not in favour of this project at all and explored a number of alternatives in order to not become dependent on Rotterdam for the crude supply (Boon, 2014). The turbulent 1970s, however, would change the oil industry for good with exogenous events in the Middle East, but with a profound impact on the emergence of the ARA, as explained below. Nonetheless, these pipelines proved to be foundational for the interconnections of the ARA oil complex and its development into a polycentric

system: crude oil supplies arrived by supertanker in Rotterdam and were subsequently refined; Antwerp would now be supplied by pipeline from Rotterdam and could further specialize in fine chemicals; Amsterdam, in turn, developed into a storage and blending hub for fuels following its conversion into tank storage facilities, especially due to the closure of the Mobil Oil refinery in 1982.

The ARA today: morphological, functional and institutional

In the introduction we explained that ARA being an international traded contract already signals an existing polycentric morphological and functional system. In the following we explore these three dimensions.

The morphological dimension

The ARA ports have relatively different economic profiles and sizes. In descending order, the area of the Rotterdam port is approximately 413 km^2, Antwerp 243 km^2, NSP 142 km^2, Amsterdam 80 km^2, Zeebrugge 47 km^2 and Moerdijk 23 km^2. These different surfaces partly explain the relative differences in total throughput in 2019. Rotterdam handled 469 million tons (Mt), Antwerp 235, NSP 131, Amsterdam 87, Zeebrugge 46 and Moerdijk 17 Mt. Given our focus on oil and derivative products, our interest is primarily on 'liquid bulk'. In this category, Rotterdam is the largest with more than 211 Mt, almost half of its total throughput; Antwerp accounts for 76 Mt and Amsterdam for 50 Mt. The other ports handle significant lower volumes. While Rotterdam and Antwerp are important in every throughput category, Amsterdam's expertise on liquid bulk comes from its focus on storage and blending oil products such kerosene, gasoil and diesel.

Throughput figures do not tell the whole story. Therefore, it is useful to combine throughput figures with the total direct employment (TDE) and the total direct added value to understand what activities are happening within each port. While Rotterdam is larger in throughput than Antwerp, in terms of TDE and total direct added value (in million euros), Antwerp (61,737 TDE; €11,453 m) is now closer to Rotterdam (86,364 TDE, €14,208 m). In other words, more jobs and more added value are created per unit throughput in Antwerp. In contrast, Amsterdam (17,609 TDE; €2159 m) and Zeebrugge (9686 TDE; €1038 m) are foremost logistical handling ports. An exception is NSP (44,736 TDE; €7968 m) with a high amount of jobs and added value in relation to the lower throughput figures. Using the throughput and absolute number of jobs and added value, eventually the relative percentage of the different categories of added value together make up the overall profile of the ARA ports (Figure 2).

Focusing on the oil product space, we mapped and categorized the different facilities: oil terminals, oil refineries and petrochemical plants (Figure 3). Oil terminals are at the beginning and end of the production chain. Crude oil is imported and either stored to manage price movements or refined and blended into derivatives for export or further chemical processing. Rotterdam has a relatively large number of oil terminals and even five oil refineries, but fewer petrochemical plants. The port of Antwerp has fewer oil terminals and three oil refineries, and both are on average also smaller in size. But in Antwerp there are relatively more and bigger petrochemical plants than in Rotterdam. This observation is in line with the big difference in throughput figures, and small difference in added value between Rotterdam and Antwerp. Amsterdam is clearly a logistics oil port. Considering that there are no oil refineries or petrochemical plants in Amsterdam, these are foremost used to blend and store the end products of oil: fuels. The other ARA ports have a relatively small number of facilities. The NSP hosts the sixth oil refinery of the Netherlands (Lukoil/Total), a large chemical plant and some minor oil terminals. Moerdijk hosts a petrochemical plant, while in Zeebrugge there are no oil-related facilities.

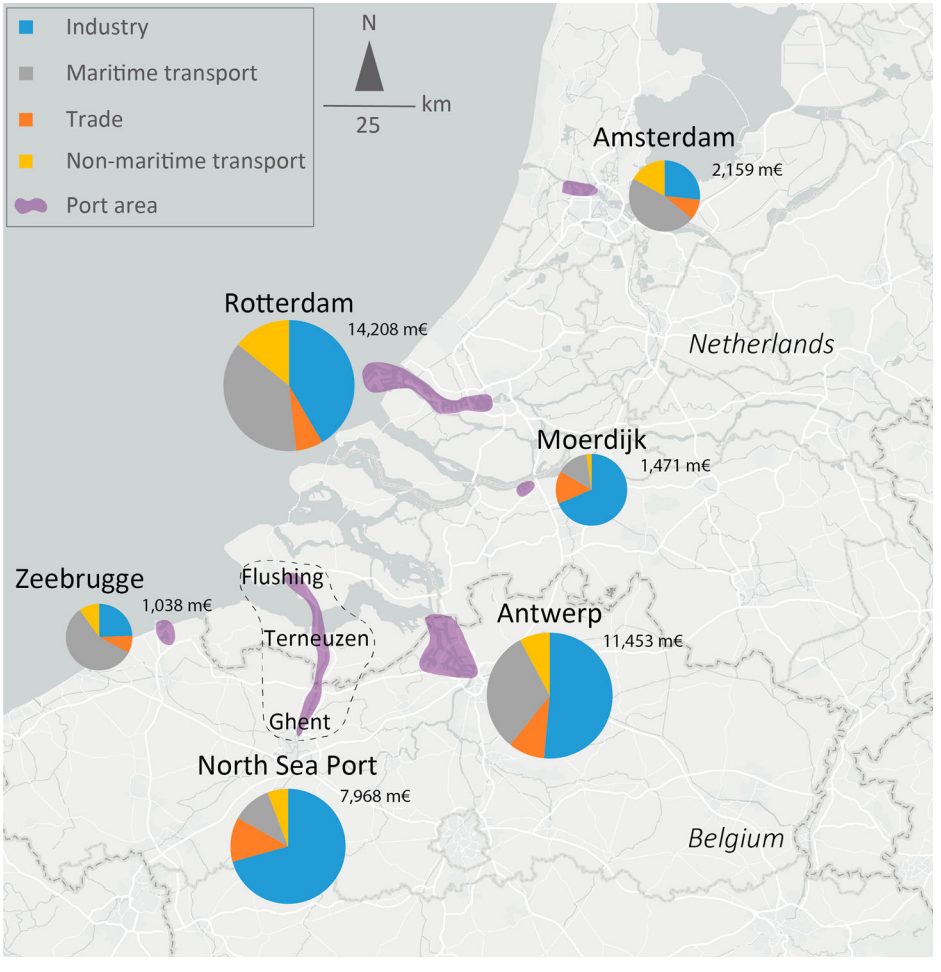

Figure 2 . Relative added-value (€ millions) in 2017 of the different ports part of the Dutch–Belgian Amsterdam–Rotterdam–Antwerp (ARA) region per major activity.
Sources: Authors using data from NBB (2019) and van der Lugt et al. (2018).

The functional dimension

Compared with morphological dimensions of polycentric systems, measuring functional relations is much more complicated (Burger et al., 2014; Burger & Meijers, 2012; Hall & Pain, 2006). The first challenge is to measure the flow itself. In most PUR studies, the focus is on physical flows and information flows that are proxied rather than actual flow data, making it an assumption-rich endeavour. Second, polycentric systems tend to be multiplex and heterogeneous. Multiplexity refers to the spatial organization of different types of functional relations not being necessarily identical. Heterogeneity occurs when a variety in spatial interactions occurs, although the same type of flow is taken into consideration (Burger et al., 2014). Here we focus on the oil product space. Since our morphological analysis revealed specialization among the ports, we may assume that we are dealing with a multiplex and heterogeneous network. Luckily, oil and its derived products are transported in the same way, by ship or pipeline, allowing us to detect flows.

Nonetheless, most data on intra-firm and inter-port oil transports are confidential and not captured in official statistics, where they are aggregated to larger (e.g., regional) spatial entities

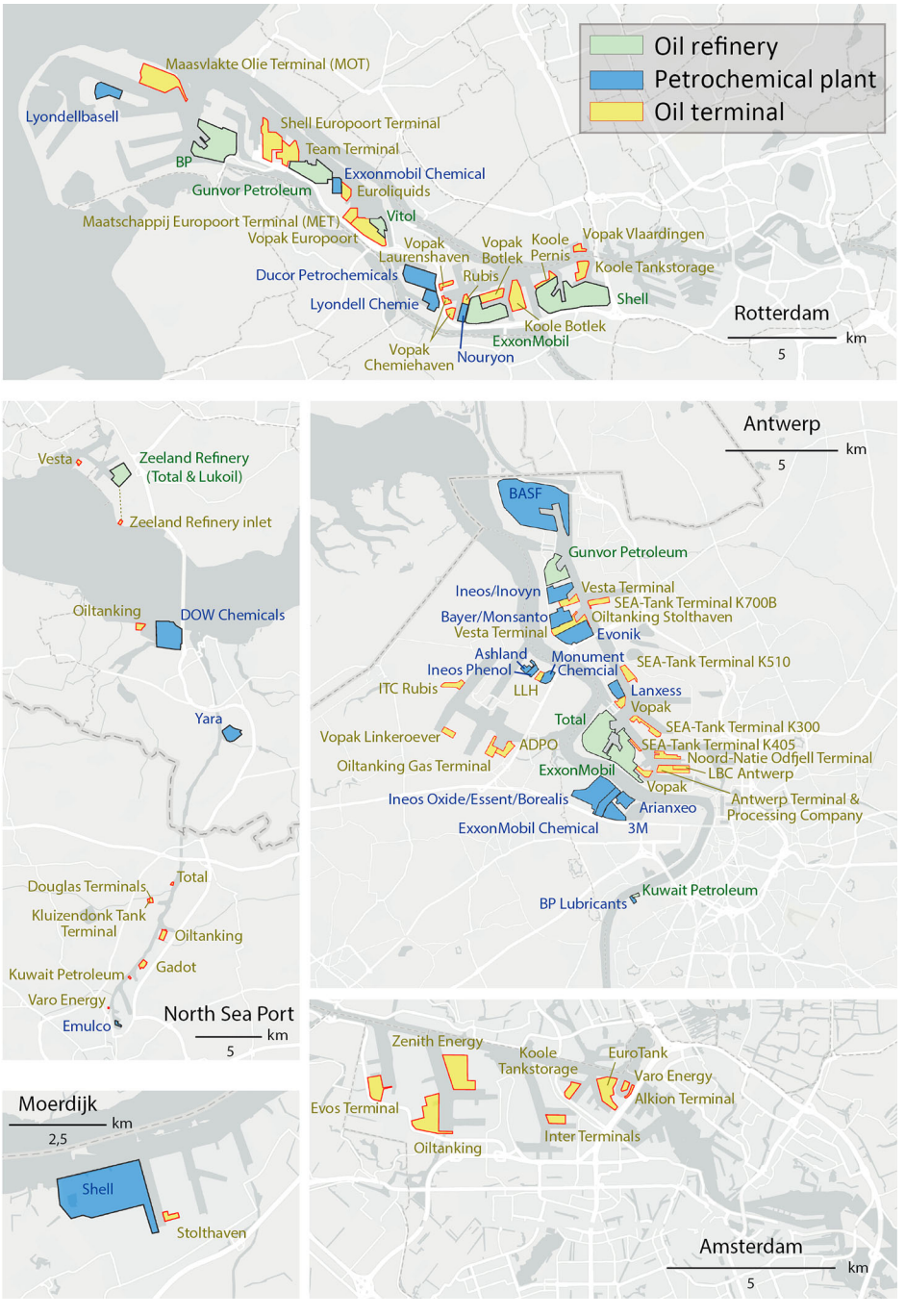

Figure 3 . Oil refineries, petrochemical plants and oil terminals in the different ports of the Dutch–Belgian Amsterdam–Rotterdam–Antwerp (ARA), 2020.
Sources: Port authority websites; map: authors.

rather than individual ports. Moreover, a significant amount of national and international oil transport goes via pipelines. These data are in many cases not available because the pipelines are privately owned, or the oil transport is confidential. What is known are aggregated figures.

In 2018, first, in total the Netherlands imported 87.6 Mt of crude oil, mainly from Russia (25.4), the UK (16.5) and Norway (10.4). A large volume of those imports are transported to Belgium (29.4), which for Belgium is 85% of the total import (35.5) (Chatham House, 2021). Of the latter, 28.8 Mt was transported by pipelines. From Belgium to the Netherlands the export was only 1.6 Mt. For refined oil products, the total amount of refined oil products from the Netherlands to Belgium was 14.9 Mt, vice versa 17.1 Mt. These are foremost transported by barges (respectively, 80% and 90%), instead of pipelines (CBS, 2020). The aggregated numbers confirm that relatively more crude oil activities are located in the Netherlands and are exported by pipelines, while the petrochemical activities are located in Belgium. These figures do not show regional flow data, thus we cannot see what the different roles are of the different Belgian and Dutch ports in these networks. Therefore, to analyse these inter-port data, we developed a methodology that is able to estimate these flows in a much more detailed and novel way.

In order to identify the functional relations at different scales (intra- and inter-ports, cf. intra- and inter-urban), we decided to follow the movement of individual ships by using data from their automatic identification system (AIS). AIS is a tracking system originally designed for anti-collision devices. Several times per minute ships equipped with transponders emit information about their position, course, speed and dimensions, as well as their unique identifier. The latter makes it possible to trace their movement at a very fine spatial scale. Previous studies have shown that these data can be used to reconstruct the hierarchical spatial network of maritime routes at the global scale (Kaluza et al., 2010) as well as more local channels for accessing a port or anchorage areas (Le Tixerant et al., 2018). AIS data from the ARA region were retrieved from AISHub for a period of four months in 2019. We worked on about 16 million ship positions, among which 15% were from tankers.

The method we designed to study inter-port and inter-terminal relations is extensively described in the Appendix in the supplemental data online. It is based on a four-step mechanism to go from raw Global Positioning System (GPS) traces of ship positions to origin–destination matrices estimating flows between ports and between terminals. First, buffers are created around the docks, then vessels' stops and trips are detected by computing the time spent within and out of the buffers; we then weighted the trips based on data on the carrying capacity of the vessels; and finally we aggregated the weighted trips and stops at terminal and port levels to map the network between the spatial entities of interest. In a subsequent analysis, functional relations between two spatial entities i and j are defined as the sum of the trips weighted by the deadweight tonnage (DWT) of the ships travelling between the two nodes (see the figures in the Appendix in the supplemental data online).

The spatial representation of the network, aggregated per port, confirms the presence of a well-integrated polycentric system, in which Rotterdam is the central logistical node (Figure 4). Indeed, while Antwerp received almost the same number of tankers from the English Channel, the ships that docked in Rotterdam where much bigger, that is, supertankers. Based on our estimation using the DWT, we conclude that the flow of oil to Rotterdam through the Channel is 159% more important than the flow to Antwerp. In the case of ships coming from the North Sea, the difference is even greater, with Rotterdam receiving four times the quantity of Antwerp. A more precise look at the relations between the different types of terminals described in Figure 2 gives additional information on the interdependencies in the ARA port region. This analysis is presented in the Appendix in the supplemental data online. Looking at the flows of tankers between oil facilities (see Figure A6 online), one can see that the oil terminals and refineries of the port of Rotterdam are at the core of the system of relations, and well connected to both Amsterdam's tanking facilities and Antwerp's terminals. However, looking at the network between petrochemical facilities gives a totally different picture (see Figure A7 online), with factories from Antwerp, notably that from BASF, acting as the most central nodes of the system. It also reveals the centrality of NSP terminals that are almost absent from the network of oil

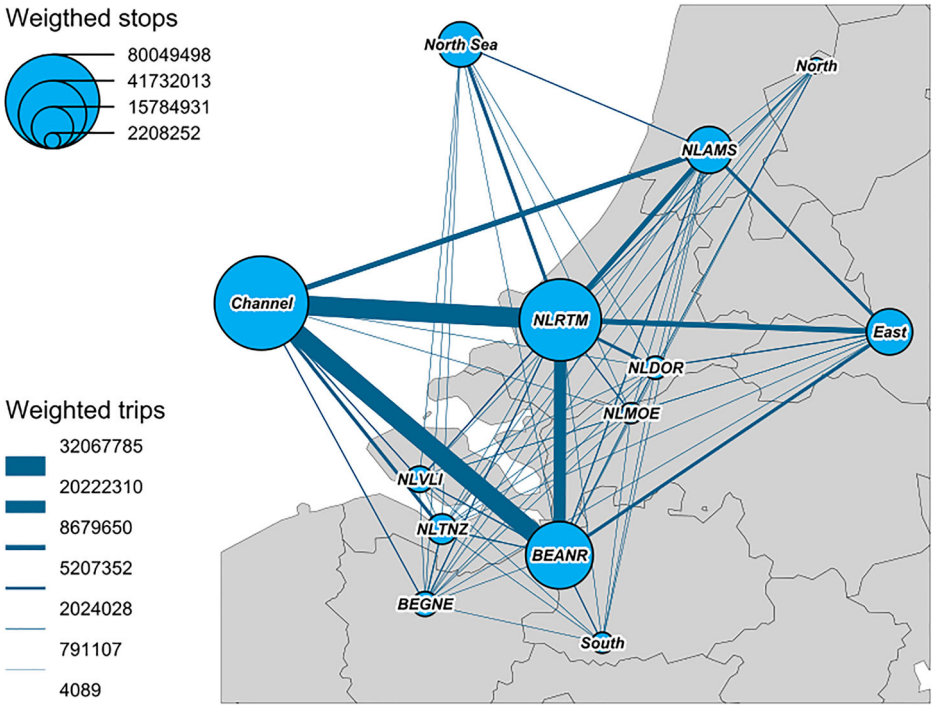

Figure 4 . Spatial representation of the network.
Source: Authors' calculation from AISHub data.

facilities. These elements give hints about both the multiplex dimensions of the system and the functional specialization of the different ports, which are two essential features of polycentric systems.

Institutional dimension: the ARA spot market and the creation of the ARA oil futures delivery contract

The ARA polycentric (port) system identified above in morphological and functional terms has no corresponding administrative–territorial institutional arrangement that has the agency to coordinate its development. Far from it, the area is administratively divided in two countries, a number of provinces, and six ports administered by their own local and semi-public port authority – all with competing and sometimes converging interests and claims. The ARA also never materialized in a normative planning concept and/or discourse in the way, for example, the Randstad did, to guide its spatial polycentric development trajectory. Development occurred fragmentally and incrementally, with both public (national and local) and private actors pursuing their own agendas and self-interests. Nonetheless, the ARA did institutionalize, but therefore not via 'planning by design' but via 'spontaneous order' (cf. Hayek, 1960) and 'self-organization' (Buitelaar et al., 2007). The pipeline network that now forms both the backbone of an internal polycentric system and the external connector came into existence only through the temporary and project-based coalesce of self-interests in which private actors clearly had the initiative. And among these private actors there was initially no notion or reference to the 'ARA' as the intended outcome. This was about to change in the late 1970s and early 1980s with the emergence of a spot market and the creation of a financialized oil delivery contract with specific reference to the ARA that serve as the main governance mechanisms and institutional arrangements

in the global trade of oil up till today. In retrospect, the ARA contracts became the 'missing' third dimension, besides the (non-coordinated) morphological and functional dimension, because they further formalized the morphological and functional dimensions of the oil trades in the region, creating what we have shown here: a polycentric port system. And although a corresponding public institutional framework covering the ARA as a whole still does not exist, we can still argue that also the public institutions have and are adapting to the polycentric ARA port system in one way or another via infrastructure planning and increasingly more formalized coordination, even mergers (e.g., the NSP in 2018), between the various port authorities in the ARA region.

DISCUSSION: THE EMERGENCE OF HIGHER LEVEL POLYCENTRIC SYSTEMS

The ARA region is one of the world's largest spot markets for trading physical oil and as a corresponding specific delivery location in the financial derivate contracts (oil futures) created at the New York Mercantile Exchange (Nymex) and London-based International Petroleum Exchange (IPE) in the early 1980s. Spot trading of oil (crude and products) takes place daily and prices are negotiated bilaterally on the spot (location of the cargoes) without any disclosure of the price paid to third parties. These spot markets are typically linked to major refining and oil storage hubs, mainly located in ports, where there is ample demand and shipping is easy. The most important oil spot markets are the US Gulf Coast (centred around Houston), Singapore and the ARA.

But the institutionalized ARA contracts did not appear out of nowhere. Spot trading happened ever since there was refining capacity in the area, dating to the 1950s and 1960s, but traded volumes were slim and mainly done by small trading companies who took over residuals (mainly heavy fuel oil for household heating) from the main refineries (Boon, 2014). This changed due to geopolitical events in the Middle East (at that time the ARA's main supplier of crude) from the 1970s onward (cf. exogenous events). Due to the Iranian Revolution in 1979 and the subsequent second oil crisis, the 'oil majors',[3] such as BP, were cut off from long-term supply contracts with governments of oil-producing countries. As a result, oil majors had to turn to the, until then, small spot market as an alternative source of supply. Despite this supply disruption, oil inventory in ports nearby refineries became abundant, partly stimulated by government stockpiling policies in Europe, partly by the oil majors building up their own reserves. Spot prices started to rise further as OPEC member states undercut their own pricing policies and started selling on spot market conditions themselves (US DoE, 1980). There are two, interrelated, reasons why the ARA became an important sport market (cf. Clubley, 1998). First, there is the historical presence of major oil refineries and the availability of abundant tank storage capacity. Second, the ARA ports are the intermediate location between deep water and the main inland refineries and chemicals industry located in the Rhine–Ruhr and from there on close to Europe's main consumption market for fuel products (and thus largely overlapping with the 'Blue Banana'), in particular by barge shipping and pipelines.

As oil spot markets are more volatile and less transparent due to their bilateral negotiated nature, the oil majors became more exposed to price risks. Major refining companies therefore needed financialized instruments that would allow them to mitigate their exposure to price risks on the spot market and which would allow for a more transparent price-discovery process and price benchmarking. Together with existing commodity exchanges in New York (Nymex) and London (IPE), investment banks, and storage companies, the oil majors pressed for the launch of a futures market for oil and products. Futures contracts are essentially financial derivatives in the form of standardized delivery contracts with a specific (monthly) date, volume (one futures contract equals 1000 barrels of oil) and delivery location, which are used by traders to hedge against price risks of their physical trading book (by taking the opposite position on the futures market). Physical delivery in spot markets, forward contracts and futures are based

upon the so-called Incoterms,[4] of which cost, insurance and freight (CIF) and free on board (FOB) are most widely used. For crude oil, the FOB ARA is used, which implies that the sellers are only responsible for transport to the port for offloading, which can in this case be any port in the ARA. For oil products, the CIF ARA implies that sellers are responsible for the transportation from any port in the ARA to the port of discharge.

The CIF and FOB ARA contracts are thus essential institutional arrangements, initiated by market players, that specify geographically the ARA as a polycentric port region. In contrast to the majority of the PUR literature, the institutional relevant planning actor here is not public. The ARA contracts state that oil products can be imported to and exported from tank storage facilities in *any port* situated within the ARA geographical area. This implies that any ARA port benefits from the well-functioning of another ARA port, because when (unforeseen) problems arise (e.g., labour strikes, natural phenomena, traffic jams), the activities can continue because ships and tank storage facilities can make or take delivery in other ports. The specification of the ARA in a financial instrument that resembled an underlying physical spot market to be traded on the Nymex and IPE was carefully deliberated upon by the initiators: the exchanges, the oil majors, investment banks and storage companies. The inclusion of multiple ports in the region provided flexibility for traders; it ensured more liquidity (more buying and selling transactions) and thus a better price discovery and finally it would prevent markets being more easily 'cornered' if only a few storage facilities in only one port were included in the contract.

The polycentric ARA port region as it exists today is thus not derived from a clear spatial planning strategy, a dimension that is often emphasized in other PUR research. However, this does not imply that the ARA can be considered as solely a bottom-up process. To some extent, one could argue that the polycentric ARA port region was potentially there for some time already. This is reflected in the presence of morphological elements and functional relations, which rose from many local, path-dependent and non-coordinated bottom-up processes in the different ARA ports. But exactly out of this situation, the ARA contracts became a reality, adding the third 'missing' institutional dimension. Subsequently, we argued that from that point one could say the ARA polycentric port region emerged as a 'higher level' property out of the existence and interactions between the three 'lower level' constituting dimensions. And in line with the definition of emergence (Sunley, 2008), from that moment the overall polycentric port system started to influence the different dimensions, further intensifying inter-port relations and fostering specialization and cooperation between the different ARA ports.

CONCLUSIONS

The main goal of this paper was to enact a dialogue between the PUR literature and the literature on multi-port gateways. We focused on the ARA region that entails the range of Dutch and Belgian ports within the region of Amsterdam–Rotterdam–Antwerp (ARA). Our central question was to what extent is the ARA region a polycentric system and what explains this observed polycentricity?

To answer this question, we used the PUR vocabulary and analysed the three dimensions that constitute a polycentric system: morphological, functional and institutional. All dimensions gave a different perspective on the existing polycentric port system. First, the morphological dimension showed the specialization of the different ports. Second, we identified a functional polycentric port system. Third – and here the PUR vocabulary was not sufficient enough – we explained the ARA polycentric system exists without an external (planning) agency in control, but with an important role of (non-local) private institutional arrangements (cf. the CIF and FOB ARA contracts). Within the PUR literature, the existence of a polycentric urban system

is too often considered a top-down planning exercise, while the true agents of the unfolding polycentric system are firms and households. This focus on non-public sectors is especially important to understand the development of functional relations (flows) between polycentric systems. Our case study shows that private actors often lead the way, and public government follows, in different ways at different levels. In the ARA case, the creation of the spot and futures market in response to the need to manage price risk and trade imbalances for oil refineries was of great importance. This interaction stresses again the need to understand how morphological, functional and institutional dimensions interact, rather than zooming in on just one of these dimensions. Also our research shows that we need to look beyond the region itself, and identify how exogenous factors impact regional development.

The concept of emergence is key to understand the existence of the ARA. As explained, and this in line with the definition of Sunley (2008), the ARA emergent system obtained generative capacities that in turn influenced the different dimensions by which it is constituted. The lower level properties are morphological the petrochemical infrastructures, functional the different logistical movements, and institutional the ARA contracts and the spot market reference, which was the last piece of the puzzle that was needed to let the ARA polycentric port system emerge as a higher level property. From the moment it came into existence it started to influence the three dimensions by which it is constituted. Or to paraphrase Paasi (2010, p. 2297), 'a polycentric system is conditioned by the morphological, functional and institutional dimensions, and at the same time conditions these three dimensions'.

For the polycentric literature and port literature, we conclude with some main insights. First, our paper shows that polycentric systems are higher level complex systems of local and non-local assets, actors and institutions (cf. Yeung, 2005) that emerge out of the interaction of its constituting lower level three dimensions. Key to emergent systems, and what is also part of the ARA polycentric port area, is that there is no 'one clear agency' in control. Second, our research findings were derived from a different look at polycentric systems and at multi-port gateway regions. We examine a product space (Hidalgo et al., 2007), in our case the product space of oil. Product space focuses, similar to polycentrism, on the relatedness in networks, in particular how products are produced and imported and exported; and how technology, capital, institutions and skills are needed to do so. Relatedness is key, because it explains that some products have a higher chance to be produced in some places than in others. Third, the ARA to a large extent concedes with the second perspective on polycentric systems, wherein polycentricity allows fostering agglomeration economies. In line with the work of Hall (1966 [1984]), we also observed the fragmented development paths of ports or maritime industrial complexes that entered a process of integration eventually becoming an emergent polycentric system.

As a last conclusion, we highlight some insights for researchers and policymakers. To some level, arguably focusing on the product space of oil brings insights that are not of interest anymore as one could argue we are entering a post-fossil fuel world; although this in itself is until now all but certain. Taking into account our insights of emerging polycentric port systems, combined with the principle of relatedness, it is safe to say that if, for example, (circular) biochemical, biofuels and/or hydrogen become key elements of the new economy (Haezendonck & Van den Berghe, 2020; Williams, 2019), chances are high the ARA polycentric port region will play a key role on a global level in achieving this. In other words, probably the regions that are specialized in petrochemicals will also be the places of this new economy. What our research has learnt is that similar to the ARA oil product space, no single actor will be able to plan or steer this. If it happens, it will be the emerging result of the interactions between different local to non-local formal and informal actors, assets and institutions. Further research could explore in what sense this 'new' ARA polycentric system emerges/is emerging, and whether a stable partnership will develop between port authorities that are now first and foremost 'friends with benefits'.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

NOTES

1. It is estimated that oil futures trading outstrips physical oil trade by a factor 30. On the two most important exchanges, New York and London, total oil futures trade recorded over 2.5 billion barrels of oil per day in 2010 (cf. Reuters, 2010). Only a tiny fraction of those trades (1–3%) actually results in physical delivery as most of the positions (long and short) offset one another before the expiration date of the contract and financial settlement.
2. See https://www.sciencedirect.com/topics/engineering/supertanker for more information.
3. The oil majors refer to the Western-based, publicly traded oil companies: Royal Dutch Shell, ExxonMobil, Chevron, BP, Total and ENI. They are often set apart from state-controlled oil companies in supply countries such as Saudi Aramco, Rosneft, Petronas, Kuwait Petroleum, Abu Dhabi National Oil Company (ADNOC), etc.
4. International commercial terms, a standardized set of commercial terms and rules set up the International Chamber of Commerce (ICC) in 1936 and which serves in international commercial transactions and sales contracts and is related with commercial law.

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