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Panarchy within a port setting

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Abstract

All facets of present day society are subjected to an ever increasing rise in uncertainty. Seaports are no exception. As complex clusters of industrial activity and gateways for distribution networks, they are vulnerable to external and internal shocks disrupting supply chains. This evolution forces stakeholders to ponder on "sustainable development," and to foster adaptive capabilities and create opportunities. The development and further substantiation of the notion of 'resilience' underlined the need to study how clusters and networks (should) respond to major disturbances. In this paper, we scrutinize the concept of port resilience by revisiting the Panarchy and adaptive cycle theorem of Holling (2001). The objective is to determine if this framework can be applied to a port development context . The paper outlines the literature on Panarchy and adaptive cycles and links it to ports. It also provides an overview of the general theorem and explains the value for maritime research. The framework is linked to a set of cases on port infrastructure and development.

Keywords: Panarchy, resilience, waterfront redevelopment, port resource management

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1 Introduction

Risk management can no longer be considered as being at the margin of strategic management. Most policies and management tactics try to apply fixed rules to keep the ‘business as usual’ mindset going as long as possible. This tendency to keep current norms in place often leads to an overall loss of resilience for the underlying structures. This gradual loss of resilience continues in most systems until shocks can no longer be absorbed (Holling, 1986). Unpredictable conditions demand a resilient, flexible and adaptive strategy that can adjust to uncertainty and change, which affects all levels of industries, including the maritime sector.

The theory of Panarchy, as developed by Holling (1986), provides a framework for understanding change in economic, ecological and institutional systems. It is a cross-scale interdisciplinary theory named after the Greek god Pan, the creator of chaos. The purpose of systems like Panarchy is not to explain what is, but rather in building narratives allowing to give sense to what was and what might be (Holling 2001). Its value lies in the power to suggest questions that are relevant when trying to understand transformations both in natural and socio-economic settings.

We introduce the Panarchy theorem in an exploratory way as a theory relevant to seaports. We believe that this framework is suitable for ports due to the variety of stakeholders involved in its processes. The Panarchy model can help to create a narrative on how the complex dynamics between all stakeholders involved in the system can progress. We argue that this research contributes to the extant literature on port geography, since this academic field is continuously challenged to analyse changing market environments. As stated by Ng and Pallis (2010), “evolving circumstances affect (often unexpectedly) market demand and stakeholders relations. The original setting has difficulties in executing stated functions, and, therefore, the sector adjusts to the new conditions.” (page 4) Most port reforms share key objectives: efficiency, economic benefits through competition, the minimization of bureaucracy, a reduced demand for public investments, the enhancement of management skills, efficient labour organisation, and organisational re-scaling so as to facilitate economic coordination between different social and spatial levels (Brooks, 2004; Cullinane & Song, 2007). It is not the goal of this paper to prove that the Panarchy theorem can be fully fitted to port systems. We rather attempt to introduce a new framework, which can in turn be tested and used to better our understanding of seaports.

Just as port reforms have been rather chaotic and unpredictable, the accompanying trajectory of the theoretical discourse on the modern seaport has not been a linear one (Olivier & Slack, 2006). From the seminal works by Bird (1963) and Taaffe et al. (1963) spawned a substantial body of research on the spatial development of ports (Hilling and Hoyle, 1984; Rimmer, 1967). Ng et al. (2014) analyse the extant literature in port geography. They argue that, in past decades, the focus on the study of the relationship between ports and their surrounding landscapes diminished. Also, along the same lines, they refer to the fact that “port geography research has become distanced from traditional geographical approaches, moving towards a more practical industrial focus‟ (page 88). The consideration of applying the Panarchy theory to ports fits nicely in this more business-oriented approach in port geography and the search for other frameworks than the ones linked to theoretical and conceptual discussions within human geography. The Panarchy framework is not intended to expand and renew existing theorems but rather to offer a possibility of clarifying the past transgressions and evolutions. It is well-suited for addressing city-port interactions, as described in the Anyport model and further expanded by Hoyle (1989) to account for the growing separation between port and city. An alternative model has been presented by Charlier (1992) outlining a diachronic model of urban port spaces by suggesting the concept of the port life cycle, a notion befitting Panarchy.

In this paper, we address the following research question: “Can certain aspects of port evolution be explained using the Panarchy theorem?”. We provide an answer by identifying and presenting examples in ports of the specific properties on which the Panarchy framework hinges. Various aspects linked to the Panarchy framework will be examined such as rigidity traps, poverty traps, hierarchical levels and multiple stability states. We also look at the implications for management purposes. The paper attempts to contribute to the emerging research on flexibility and vulnerability within the maritime industry, by focusing on the underlying mechanics that are causing stresses and actions that lead to threshold changes within ports. The limitations of this work are defined by the constraints of the Panarchy theorem and research conducted in the port geography field. At present, the research on Panarchy in ports is rather concise. Therefore, the notions proposed in this paper are more explorative and open avenues for further research and substantiation. New research questions could, for example, include: the further investigation of the links between Panarchy and the broader maritime sector. We believe that more scrutiny and inquiry towards the possible matches and scale investigations could benefit port geography research in general.

The first section of the paper will outline the literature on existing port management theories and models. Here, we attempt at identifying existing gaps that can be remedied by the Panarchy model. The second section introduces the model, including essential properties like adaptive cycles. The third section presents port-related examples of the theory's cornerstones. More in particular, we apply the framework to a set of cases on waterfront redevelopment and port sustainability challenges. Finally, we use a combination of the product life cycle model and Panarchy model to analyse management capabilities through the adaptive port cycle.

2 Existing literature on port management theories and models

The literature is abundant with port management and development models. Some of these models already acknowledge the existence of endogenous and exogenous cycles that affect port evolution. As stated by Wilmsmeier et al. (2014) economic and shipping systems together generate pressure on the port system in the form of ever-evolving specific requirements with respect to infrastructure, superstructure, equipment, efficiency and organisation. To fully understand the use and added value of the Panarchy theorem in port-related research, a fundamental understanding of the existing models and their shortcomings is required.

The earliest spatial development models on ports already dealt with interactions between different entities within a larger system. However, it has been suggested that early spatial port development models such as Bird (1963) or the more hybrid port generation model (UNCTAD, 1992) are unable to capture the complexity of port infrastructure, operations and services (Bichou & Gray, 2005). The UNCTAD model stated that the development of ports from first to second and then third generation was historically dependent primarily on size, but it was also driven by the one who exercises strategic control. A wide range of other factors, e.g. port size, geographical location, working culture and extent of public/private involvement, have exhibited significant changes. These should be added to better describe the situation that exists in ports and which cannot realistically be categorized into discrete 'generations' (Bichou and Gray, 2005). The WORKPORT model provides a clearer reflection of the developments that have taken place in ports since the 1960s by defining the key dimensions and milestones in this evolutionary process.

From a port authority perspective, the institution itself is limited in its set of actions stemming from its specific nature (Notteboom and Rodrigue, 2009; Ng and Pallis, 2010). Notteboom et al. (2013), based on Strambach (2010), argue that via the concept of institutional plasticity a port authority can achieve governance reform by a process of adding layers to existing arrangements within a path dependent environment. The inclusion of critical moments and shifts that require institutional adaptations are introduced in this particular strand of research.

Wilmsmeier et al. (2014) build further upon these existing models and frameworks by insisting that the entity normally considered a unified port is not only created by numerous actors but is endlessly being recreated with each new relationship or network in which the port is embedded. The authors introduce a concept similar to resilience as noted in the Panarchy theorem, when they state that 'Transport systems exhibit a self-organising structure; however, transport autopoiesis is likely to have a particularly high inertia when it comes to changing system variables, due to its ‘‘lumpy’’ or time-lagged investments.’ This temporal analysis resulted in a port life cycle theorem that stated that since ports develop in a discrete manner, their adjustment to global import and export flows will always lead to a scarcity or surplus (i.e. a mismatch between supply and demand) on infrastructural levels. In addition to such natural cycles, there is the long-term lifecycle of the port, through development, introduction, growth, maturity and decline (Cullinane & Wilmsmeier, 2011).

To fully understand the full plethora of dynamics present in previous frameworks, specific attention has to be given to the effect of different interacting hierarchical scales. As the Panarchy theorem is already quite extensively documented and applied in other branches of research like ecological and social sciences (Garmestani, Allen, & Gunderson, 2009), it possesses a solid accepted structure and set of definitions. With the introduction of Panarchy in port research, a narrative can be obtained to frame most of the historical development patterns described by previous theorems.

3 Panarchy explained

The Panarchy theory is a systems-thinking adaptation of ecological and complexity theorems that is used to explain the evolving nature of complex adaptive systems. It acknowledges the complexity of dynamic states in constant evolution and subject to a particular hierarchy. Also, it allows for the incorporation of lower, smaller and faster-changing scale levels, as well as the larger and slower supra-regional and global levels in one general theorem.

The core framework of this paper is based on the seminal work of Holling and Gunderson (2002) who first used the term Panarchy to describe changing complex environments. The Panarchy theorem recites the interaction between three dimensions, i.e. resilience, connectedness, and potential. Connectedness is the internal capacity of the system for reorientation. The term potential refers to the external possibilities of the system. The term resilience captures the amount of shocks the system can endure before either collapsing or shifting towards a new stability system. Figure 1 visualizes the interaction between scales using port-related examples.

<insert fig 1 about here>

There are four phases that should be present in any complex adaptive system. They have been observed and described across multiple fields albeit often labelled in different terms. Holling and Gunderson (2002) term these phases as exploitation (r); conservation (K); release (Ω); and reorganization (α). They can be grouped into a front loop, or a maturing phase of a system, and a back loop, also described as the collapse or renewal.

- The exploitation stage is characterized by waves of rapid expansion, due to low regulation within the system. Growth occurs unhindered but chaotic. Resilience increases, connectedness increases and potential increases;
- The conservation stage is one in which growth levels become constant. Resource-use stabilizes and resource-use/output reaches carrying capacity. Connectedness increases to a maximum, resilience decreases and potential decreases;
- The release occurs rapidly and is often induced by a shock, leading to a decline in resilience. Due to a high connectedness, internal conditions cannot be changed. Resilience increases, connectedness decreases and potential increases;
- Reorganization can also occur rapidly, either from the internal environment where the best surviving units thrive or from the external environment where the competitor takes advantage of the changing conditions that triggered the release. Resilience increases, potential decreases, and connectedness is low.

The Panarchy method was used in the entrepreneurial market description literature by Baron (1998) who links the theorem back to the sources of creative destruction. This theorem is a well-known principle for over half a century (Schumpeter, 1942).

Adaptive cycles occur at many levels within a system. A port can be viewed as an example of a system where fast moving business units clash with slower moving investment decisions. The port authority needs to make decisions to manage the land in the most optimal way for the foreseeable future within an uncertain business environment. Dooms et al. (2013) mentioned that port authorities, which are often formally responsible for strategic seaport planning, must take into account the diverging goals and preferences of various stakeholder groups. They balance the need for efficiency in day-to-day port operations and efficient implementation of long-term port development plans. In such systems, the possibility exists that one malfunctioning level can have an escalating or collapsing effect on the other levels. This effect has been noted by Ng and Pallis (2010) in their examination of how local port governance is nested in higher scales of (territorial) governance and institutional structures.

The Panarchy framework bridges the gap between ecological, economic and social models of change and stability. It attempts to simplify a complex system in which resilience is triggered by the three aforementioned dimensions. Since the unit of analysis in this paper is a port, which is a hybrid organisation where social, ecological and economic interests interact, we must take into account all literature discussing Panarchy in a broader social sense. We therefore push the boundaries of the theorem away from its pure ecological roots.

Some authors argue that the Panarchy approach can be too conservative (Swanstrom 2008) and too focused on external threats rather than internal resilience, as is often the case with risk and hazard science theorems. The concept of resilience tends to put the responsibility on the lowest common denominator, relieving the organizational organisms out of harm's way. This particularity leads to a situation where one group (e.g. economic actors) can try to maximize its resilience by undermining a similar group (e.g. social actors). This phenomenon is captured by Cote and Nightingale (2012) in the sentence "Does the resilience of some livelihoods result in the vulnerability of others?" (page 482), a question worth pondering in a port system where the strength of one port (company) may lead to the vulnerability of another. This notion becomes particularly relevant if a regulatory organization determines the required resiliency/desirability thresholds. Within the port sector, this dichotomy could be visualized by looking at the tension between ecologists and economists in the optimal land distribution in the port area. The success of one means the loss of the other.

A second note to be made on the resilience topic is the failure to accommodate the critical role of the state, culture, and politics (Evans, 2011; MacKinnon and Derickson, 2012). This critique is often directed at the ecological origins of resilience thinking like the Panarchy method and claims that these methods are too restrictive. The discussion finds its parallels in port geography literature surrounding path dependence. Overall, research on port governance (implicitly) accepts the concepts of path dependence and locked-in situations (Notteboom et al., 2013). Jacobs (2007) argued that "institutions resemble territorially rooted structures of power". Because of the institutional environment, port development is being stretched and layered but does not necessarily diverge from the main development path. This situation can lead to a situation that is not always the most conducive path to commercially oriented and de-territorialized port authorities. It would seem that the reservations of geographers towards concepts such as resilience or other top-down imposed theorems carry some weight in the port sector.

It is not the goal of this paper to assess the extent or success of the Panarchy theorem within ports or port systems. The goal is to see if the Panarchy model is applicable for use as a supporting narrative mechanism in a larger resilience analysis and port geography in general. To apply Panarchy to the port industry, the entire sector and all of its surroundings have to adhere to five main principles of which the first four were initially outlined by Gotts (2007):

1. Multiple metastable regimes. Rather than a single equilibrium point, or state, the system can exist in various „base states". Once a stable regime is obtained fluctuations may occur but the system will revert to the base state currently in place;
2. The importance of episodic change. Systems with multiple metastable regimes can alter the base state once critical thresholds are reached;
3. Resilience. Holling and Gunderson (2002) define ecosystem resilience as " ...the magnitude of disturbance that can be absorbed before the system changes its structure by changing the variables and processes that control behaviour." Within the Panarchy framework, resilience is the buffer a certain base state has before shifting;
4. Multiple distinctive scales with cross-scale interactions. Holling and Gunderson (2002) argue that ecological and social-ecological systems form a multilevel hierarchical structure. Therefore, transformations and adaptive cycles can occur at any level affecting each other. One level influences and affects what happens at a different level both in time and space (Simmie & Martin, 2010). Dynamic interactions take place within and between the sub-systems contained in a system;
5. Resource management. For the Panarchy theorem to be upheld there has to be a finite resource to be managed and distributed within the system. For example, in ecosystems these resources are often considered nutrients.

4 The Panarchy framework adapted to the maritime sector

In this section existing and cases will be matched to all parameters mentioned before in order to tie the Panarchy model to the port sector. Firstly the investigation of base states and the occurrence and possibility of episodic change and the shifting of these base states. Also, the nesting of different layers and adaptive cycles can be observed as mentioned before, not only on a scale base but also on a cross-sectorial base as is visible in figure 2. A functioning port system is challenged to find a delicate balance between social, economic and sustainable (environmental) values, each with their needs and capacity of adaption to change. The figure is an adaptation of the earlier work of Elkington (1997) who coined the term "Triple bottom line" in the context of sustainable capitalism in his 'people planet profit' model.

<insert fig2 about here>

4.1 The existence of multiple stability regimes with one 'traditional' base state

The first principle to adhere to is the existence of multiple stability regimes with a base state in place. To obtain a regime shift, a large, abrupt, persistent change in the structure and function of a system must occur. Due to the hierarchical nature of the Panarchy model this shift does not have to be in the entire port layout. It suffices if it takes place in a smaller subscale like the port-city interface or the use of a particular subset of terminals.

We present suitable examples on both the larger and smaller scales. The case of London, which used to be a typical cargo port, can be used to describe this principle. Shifts in markets, geopolitical power and technology, reduced the success of the traditional port system in London focussed on cargo handling for the British Empire. The stability state of the port shifted gradually. London lost most of its port function and evolved into a maritime financial and legal centre, adapting and changing its core business model (Jacobs et al., 2010; Hall and Jacobs, 2012; Fainstein, 2001). Cargo handling activities moved downstream to ports such as Tilbury, Thamesport and Felixstowe. The opening of the London Gateway terminal in 2013 meant that port development moved closer to the city of London for the first time in decades. However, the location of this DP World terminal does not point to a reactivation of port activities in the London urban area.

Examples are also available on lower hierarchical scales. For instance, depending on the port authority, a different emphasis can be put on certain cargo groups or activities thereby affecting the characteristics of the harbour while keeping the core function (cargo handling) intact. Even beyond the purely economic aspect, the interaction with the port city or environment offers a myriad of options to consider concerning multiple stability regimes.

4.2 The alteration of a base state, from successful shift to poverty trap

For a Panarchy theorem to uphold, the base state or stability regime of the system must be mutable once in encounters a shock or evolution that it cannot manage in its current form. There are ample examples of these shifts available in seaport systems. We focus on the shift in infrastructure use in an older section of seaports following waterfront redevelopment schemes.

The dynamics of waterfront redevelopment in (historical) ports are a result of a combination of fast-moving cycles, like industrial developments and ship size growth and slow-moving cycles, like port infrastructure development (economic) and city master plans. Examples can be found all over the world and have been avidly documented by researchers (Gordon, 1996; Jauhiainen, 1995; Lehrer and Laidley, 2008; Lee and Ducruet, 2006). .

The case of waterfront redevelopment is a particular example of shifts between multi-stable regimes. Before the shift, this part of the system was a classic example of a poverty trap, another typical element of the Panarchy theorem. Bowles et al. (2006) provide a full overview of precise definitions, models, and estimation techniques describing poverty traps. In a port context, we will use the definition provided by Holling and Gunderson (2002): a poverty trap is a situation in which connectedness and resilience are weak, and the potential for change is not realized. The system leaves the adaptive cycle or gets „stuck" in the back loop, never initiating the „renewed" front loop. Next to abundant ecological examples, illustrations can also be found in social systems.

Waterfront redevelopment matches the characteristics of a poverty trap as well as those of a base state shift. Infrastructure developments of old port systems are in this case the large adaptive cycles that could not adapt to the faster moving smaller scale cycles of ships and their increasing sizes. These developments lead to a loss in output, resulting in a low connectedness and vulnerability to shocks. Since ships berthing near the original warehouses became increasingly uncommon, value was lost, and poverty increased. This situation lasted in some cases for over 50 years. A new adaptive cycle started when city development took over the management of this infrastructure from the port. The resulting processes of waterfront redevelopment became a wide-spread and accepted tool against urban dereliction of inner-city waterfronts (Jauhiainen, 1995).

We limit the description of this particular poverty trap and the application towards the general theorem. There is, however, the opportunity for future research aimed at assessing the adaptive capacity of ports. A geographical and economic comparison of the speed and efficiency with which ports and cities have adapted to the poverty trap of waterfront redevelopment could prove to be a valuable addition to resilience-related research.

4.3 Resilience inherent in the system, the extreme case: the rigidity trap

As mentioned before, the resilience of Panarchy framework is defined as the magnitude of disturbance that can be absorbed before the system changes its base state. This buffer is hard to quantify. To present examples, we have to find cases in which traditional business or activities are disrupted but are still ongoing.

We argue that the breakbulk segment in the port of Antwerp can serve as a compatible case. The Port of Antwerp is a crucial port in Europe for the handling of steel, project cargo, fruit, forest products and cars (Antwerp, 2013). However, recent strategic decisions on land management were influenced by the rise of containerization and the increasing importance of the industrial cluster. As a result, Antwerp opted for more specialised types of terminals like container terminals and dedicated terminals linked to industrial sites. The moderate revival of the break-bulk market (Vonck & Notteboom, 2013) as a specialised niche for specific products like steel, fruit and heavy lift gave smaller, often cheaper, ports a window of opportunity to capture a significant part of this market. The impact of Antwerp's strategic decision of favouring specialised container terminals over more flexible breakbulk terminals, partly explains the drop in Antwerp's market share in the breakbulk market (figure 3). Antwerp had a 50% market share in 1980 which diminished to 32% in 2011. Zeeland Seaports benefited the most of the changing market dynamics. The land management strategy of the port authority is only one of the factors behind the weakening position of the port of Antwerp in the breakbulk cargo segment. Dock labour issues in Antwerp and (aggressive) port pricing by neighbouring rivals with ample land available have also contributed to an increasing pressure on Antwerp as a leading breakbulk port. Belgian seaports are subject to a dock labour act of June 8, 1972 (B.S. 10/08/1972), better known as the Major Act ('Wet Major'). Only recognized dockers part of a rather closed dock labour pool system are allowed to perform dock work in the port areas. The Major Act is not limited to the loading and unloading of ships only (Notteboom, 2010). The labour-intensive breakbulk terminal operations are affected by the rather rigid and expensive dock labour pool system in Antwerp. Partly because of regulatory pressure from the European Commission, the existing dock labour system is being revised towards a more open and less rigid structure.

<insert fig3 about here>

Next to being an example of inherent resilience in the system, the Antwerp case is also an example of a rigidity trap. A rigidity trap occurs when all three variables, i.e. resilience, potential and connectedness, are positive. It transpires in maladaptive systems where the top of the front loop gets stuck or when a system moves outside the adaptive capacity cycle. A purely ecological example is an old-growth forest, in which nutrients are locked up in biomass of a few shade-tolerant species that can reproduce under the thick canopy. In the social realm, the Hindu caste system (Berkes & Folke, 2002) matches the description. In more business-oriented systems, typical examples are visible in rigid bureaucratic systems or companies that are unable to innovate (for example the decline of General Motors as discussed in (Keller, 1989).

In case of a rigidity trap, a system is unable to adapt to changing circumstances because, although it has much potential, both connectedness and resilience are high. In this case, connectedness is extremely high since the investment choice for a container terminal created a significant sunk cost (more expensive infrastructure and superstructure compared to general cargo terminals). In theory, this should reduce resilience since less cargo differentiation is possible. However, this parameter remained high since containers are still a valuable cargo group to have in most ports.

4.4 Cross-scale interactions, nested cycles and hierarchy

To adhere to the hierarchy aspects contained in the Panarchy framework, we should be able to identify different adaptive cycles manifesting themselves on multiple scales within the system. Some might be fast moving, others slow moving but all in some way interconnected. When assessing the interconnectedness, we need to be able to measure the impact of different cycles on each other. It is not the goal of this publication to create a thorough resource management analysis but just to outline the general underlying principles.

A port system typically tries to maximize the output derived from resources (in this case we focus on land as a resource), but at the same time has to take into account social and environmental issues. The port output or PCo for a system as depicted in figure 2 can be written as:

$$PCo = f(Co + Po + No)$$

With Co = social value, Po = money/throughput and No = nature output. The determination or definition of scales within a port system is quite a complex matter. According to the type of analysis performed, a multitude of possible scales can be defined, the formula above represents scales on a horizontal level so without clear hierarchy. This scale definition is one aspect of the application of the Panarchy theorem that merits further research and is a subject on its own. An alternative approach is based on figure 1where a clear hierarchy of adaptive cycles is visualised.

An example of scale interaction as depicted in figure 1 can be found in the rise of containerization. This new technology introduced in the 1960s had a major effect on traditional cargo handling operations. The operational level was not the only scale affected by the introduction of the new cargo group. It introduced new economies of scale in transportation, induced processes of port regionalization (Notteboom, Rodrigue, 2005) on the supply chain side, created a new generation of terminals on the infrastructure scale and forced the regulatory agencies to ponder upon new rules and regulations (Notteboom, Rodrigue, 2009).

4.5 Resource management in ports

One of the five central principles outlined in the previous section relates to resource management. Land is a crucial resource for the managing body of a port, be it a landlord port authority or some other public body. Since land is a finite resource in ports, this type of system adheres to the limitation of limited resource management. Within a port setting, the potential is generated by the wealth of a system or, in this case, the total amount of land available or land that can become available through conversion.

The classic port development models, namely those of Bird (1963) and Taaffe et al. (1963) deal with the relationship between ports and port cities. Also, the importance of hinterland connections in association with particular urban centres comes into play. Minor „industrial revolutions" restructured the urban waterfront (fast moving cycles), where the port once dominated the surroundings. New spatial requirements imposed by containerization, as well as new bulk-shipping technologies, scale increases and new industrial evolutions forced a spatial reorganization and a migration of terminals (Hilling, 1988; Hayuth, 1982). A port is no longer a homogenous structure. The focus of attention tends to shift towards terminals and their terminal operators. Due to the high specialization and the need to free up land, some activities are "outsourced" to regions located in the surrounding hinterland of the port area. This action leads to processes of port regionalization (Notteboom and Rodrigue, 2005).

Ports are not only challenged to provide traditional services to port users but are expected to increase their service provision for tourists, recreational activities and logistic parks. This trend is in line with the previously discussed dichotomy between social, economic and sustainable land use. As a result, the finite amount of port space must be used in the most productive way possible depending on the strategic goals of the port authority. Furthermore, port authorities need to take into account the growing complexity of the market with specialised niches. Each of these niches has their vulnerabilities towards economic and global shocks and new decisions concerning capacity organisation and development (Pallis and De Langen, 2010). All these developments affect land use decisions in ports and land concession systems of landlord port authorities (Notteboom, 2007). In this light, a concession awarding authority, deciding on the utilization of a port site, might want to ponder upon the main use of the terminal in the pre-bidding phase of a concession procedure (Theys et al., 2010). In essence, this comes down to the choice between a multifunctional terminal, which demands less dedicated investments, or a highly dedicated/specialised terminal, which limits the use of the terminal to very specific flows and commodities.

Vonck and Notteboom (2013) concluded that large Hanseatic ports seem to allocate their concession activities based on market whim. For these market leaders, expansions are modelled and distributed according to the most popular cargo type of the period and land use over time follows the path of this decision. Smaller ports, on the other hand, often focus their development on a clear strategy and specific cargo group, attributing land only to a limited number of cargo types to maximise output. The left-hand graph in figure 4 shows the allocation of land to activities in each port separately while the right-hand graph shows the percentages of each activity relative to the entire set. For example, the medium-sized port of Zeebrugge has 8% of its land allocated to LNG cargo and is the only port in the set with a dedicated LNG shipment terminal, and has therefore 100% of all the dedicated LNG allocated land in the investigated set of ports.

<insert fig4 about here>

5 Linking management theory to Panarchy

The four phases in the Panarchy model strongly resemble the four stages of the business lifecycle model of Porter (1980). Although the life cycle model has its applications to port management research, this theorem limits the scope of the examination to pure business and economic parameters. The concrete added value of the Panarchy theory is that it also allows for different approaches to the ecological and social aspects of ports and port systems. As such, a purely descriptive framework of spatial adaptive cycles can be linked to one with a more managerial output focus. According to the life cycle model, new products progress through a sequence of stages from introduction to growth, maturity and decline. Each phase requires a different management approach, so one could argue that an extension of each phase of the adaptive cycle model also requires a different management style.

Table 1 shows the links between the Panarchy model applied to ports, and the life cycle model used to describe management actions in traditional product research. We investigate each of the samples further. We present a first and non-exhaustive list of possible subjects for new Panarchy related research. A full description would require the input of ecologists, economists, sociologists, industry experts, and geographers alike.

<insert tab1 about here>

The different stages in both models are not a perfect match. The product life cycle model does not allow different phases to interact compared to the Panarchy model. The multidimensionality of the Panarchy model renders the narration of the investigated case more complete but also more complex. However, the similarity is sufficient to outline a particular "management path" for systems moving through an adaptive cycle. The Panarchy exploitation phase matches with the introduction and growth phases of the business cycle model. In essence, this means that once the new adaptive cycle is correctly launched (so no poverty or rigidity traps have occurred) the initial focus should be on attempting to shape and regulate the surrounding environment (see the match in table 1). This means that we are in an "anything can happen" mindset with high potential and low connectedness according to the Panarchy framework. We saw this going on in the port sector after the decline of the general cargo market and during the rise of containerization. More standardized parcels were developed and due to a lack of regulation many options were present in the market. Until the introduction of the ISO norms, the investment in container gear was still somewhat of a gamble. Transportation companies tried to gain as much market share as possible using their proprietary technique to shape the market around them. In the second part of the exploitation phase (growth phase), the successful businesses were bought or merged, and high brand development occurred. Niche creation and specific pricing strategies emerged forming a more mature landscape.

After the initial start-up and growth phase or exploitation phase, the market/product/system reaches a mature state or conservation state. Here management will do anything in its power to maintain the "business as usual" mindset. Primary marketing and niche decisions have already been made (increasing the connectedness parameter as depicted by the Panarchy model) and the focus shifts towards techniques to improve efficiency. Margins slink due to increased competition, and the system risks to enter into a rigidity trap. At present, the container market is witnessing such a state. Large players are locked in their initial strategy choices and are trying to find ways to keep the business model afloat. They typically rely on further scale increases in vessel size and large-scale operational cooperation through strategic alliances (e.g. the alliances 2M, G6, CKYHE and Ocean Three).

The final phase of the business cycle model coincides with the release and the reorganization part of the Panarchy theorem. The management tactics in Table 1 have been split according to the two different Panarchy segments. In the decline phase, the market shows little demand, leading to a decrease in profits and increased competition as turnover gets smaller. Here, managers of systems have the choice to opt for active renewal or divest. During the release phase, where a system loses connectedness and potential, a manager can choose from three possibilities. The first option concerns market leadership by becoming the only player enforcing economies of scale. The second option is to „harvest" by selling off all non-core activities. The last option is to divest and let the resource flow back to the regulatory agency starting a different adaptive cycle (e.g. waterfront redevelopment). When a management entity actively chooses for reorganization two main options exist: the first option involves a focus on a particular niche. The breakbulk market witnessed this during the past decade with the rise of heavy lift cargo. When going for the second option, the management entity tries to turn the business concept around. IBM is a non-maritime example of this last tactic. In a port setting, this occurs when terminal managers adapt the full infra- or superstructure to allow for a different cargo group.

6. Conclusions

This work tried to link the Panarchy model, which was until now primarily used in ecological and socio-cultural systems, to port systems. By introducing a narrative on port resilience and adaptive change, this work potentially contributes to the emerging research on flexibility and vulnerability within the port industry. A functioning port system is challenged to find a delicate balance between social, economic and sustainable (nature) actors each with their needs and capacity of adaptation to change.

This chapter elaborated on the general Panarchy theorem and its particularities including three dimensions (i.e. connectedness, resilience and potential) and four phases (i.e. exploitation, conservation, release and reorganization). In order to answer the research question: "Can certain aspects of port evolution be explained using the Panarchy theorem?", we tried to uncover cases illustrating the five main principles of Panarchy. We discussed the possible existence of multiple stability regimes, prone to change and disruption. The example of multiple states in which a port can exist was explained by the case of London, which lost most of its port function and evolved into a maritime financial and legal centre, adapting and changing its core business model.

The occurrence of shifts between these base states was outlined by using waterfront redevelopment serves as an example. This illustration is more than just a base state shift; it can be reprised as a poverty trap, which is the result of fast moving cycles, like industrial developments and ship size growth, and slow-moving cycles like port infrastructure development (economic) and city master plans or housing plans (social). Infrastructure developments in old port systems act as large-scale adaptive cycles that could not adapt to the faster moving smaller scale cycles of ships and their increasing sizes. This evolution leads to a loss in output, resulting in a low connectedness and greater vulnerability to any shock.

Resilience inherent in the system was the third aspect we needed to uncover in order to match all Panarchy parameters to port system evolution. The resilience of Panarchy framework is defined as the magnitude of disturbance that can be absorbed before the system changes its base state. This buffer is hard to quantify. To present examples, we had to find cases in which traditional business or activities are disrupted but are still ongoing. We argued that the recent (de)evolution of the breakbulk segment in the port of Antwerp could serve as a compatible case. This situation can actually be presented as an example of a rigidity trap, which occurs when all three variables, i.e. resilience, potential and connectedness, are positive.

Examples of cross-scale interactions, nested cycles and hierarchy, governed by resource management were demonstrated by outlining that ports are in essence a grouping of social, ecological and economic activities which need to be balanced. This requires resource management applied to the available land area. This area is a scarce resource allocated by a regulatory agency (for e.g. a landlord port authority). These organizations need to take into account the increasing complexity of the market with specialised niches each with their vulnerabilities towards economic and global shocks.

Next to the central research question, a second objective was to link the Panarchy model to the management literature and, more in particular, the business life cycle model. By altering tactics and management styles throughout the adaptive cycle, a complex adaptive system like a port can adjust and reach maximum potential so as to avoid poverty or rigidity traps. Therefore, a port manager should be aware of the changing environment, and decision makers could benefit from a better understanding of the core issues. This in turn, would help decisions on physical investments and managerial capabilities.

Given the complexity of the Panarchy theorem, further research is required to solidify the findings of this work. All port research areas focused on social, economic and ecological factors, the geographical descriptions of different scales and the management literature could benefit from the usage of this framework. The framework allows for a better-integrated understanding of the multitude of adaptive cycles interacting with each other.

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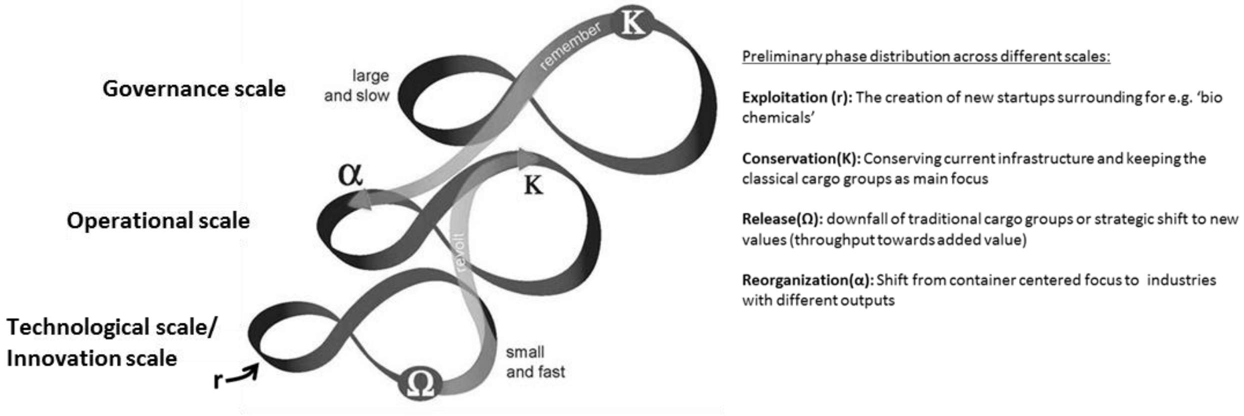
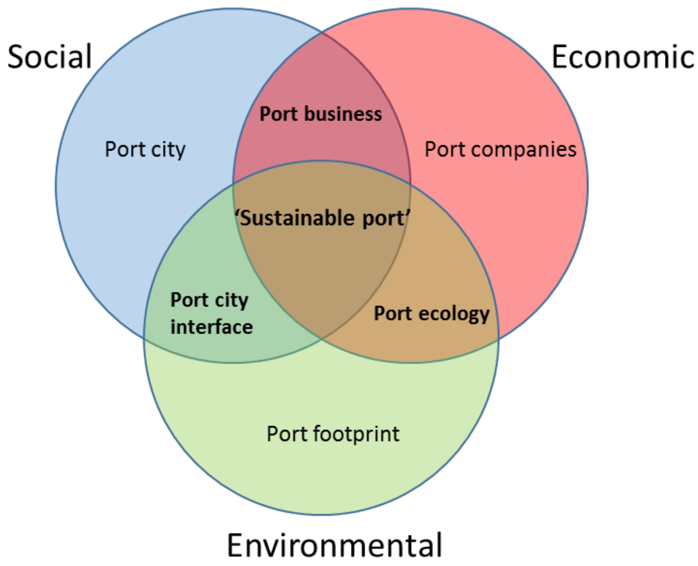
Figure 1 Representation of the Panarchy model, scales and adaptive cycles



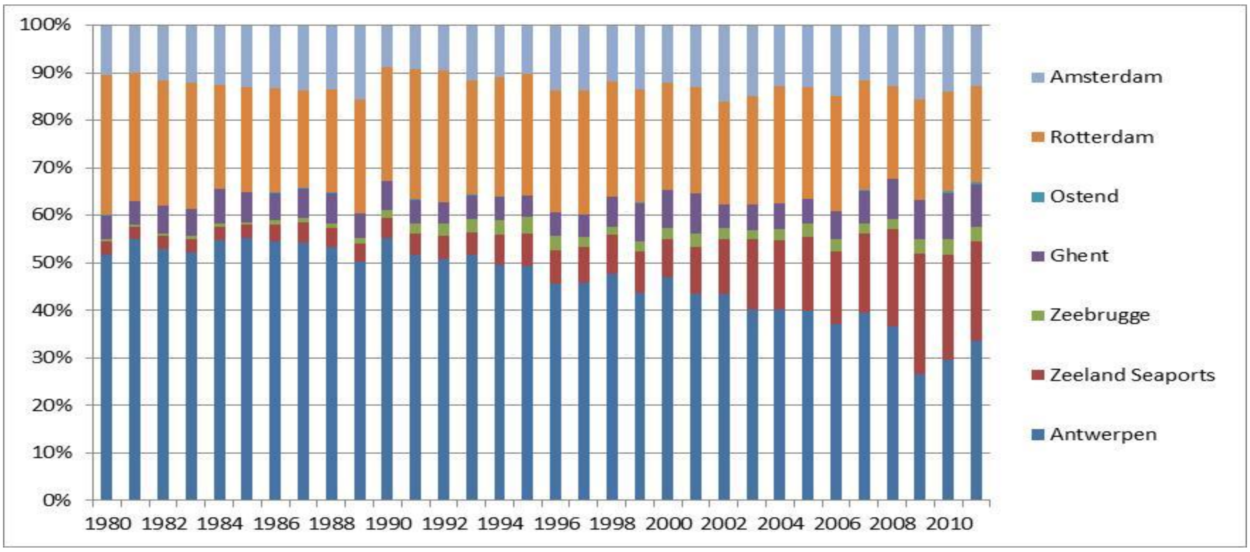
Source: Own elaboration adapted from Holling and Gunderson (2002)

Figure 2 Triple bottom line adapted to the port industry



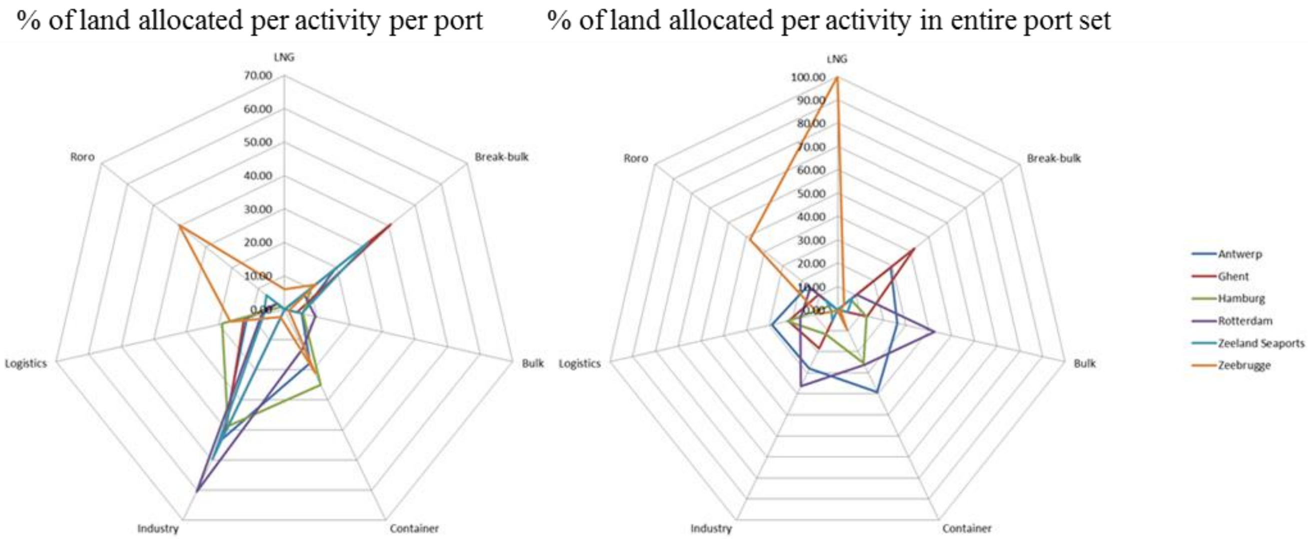
Source: own elaboration based on Elkington (1997)

Figure 3 Rigidity trap consequences, the breakbulk drop of Antwerp – market share of ports in the Hamburg-Le Havre range in the conventional general cargo/break bulk cargo flows (based on tons)



Source: Vonck and Notteboom (2013)

Figure 4 Spatial land distribution in ports- Case Hamburg-Le Havre range



Source: Vonck and Notteboom (2013)

Table 1 Link between the Panarchy model and the life-cycle model

Panarchy	Business cycle	Properties	Management style	Maritime example
Exploitation	Introduction	• Dominated by technological and strategic insecurity • High investment cost • Low competition • Governed by innovation • Lack of regulation	• Scenario based forecasting use • Attempts to shape industry • First mover advantage	• Rise of cyclical economies, blue economics • Introduction of Incubators in ports
	Growth	• M&A action • Increasing market penetration • Focus on production • Strong growth	• Client binding • Focus on production • Brand development	• Renewable energy • Bio industry
Conservation	Maturity	• Oligopoly • Slow growth • Knowledge evenly distributed • Start of overcapacity • Efficiency barriers reached	• Focus on efficiency • Business as usual mindset	• Container trade post 2008 • Chemical and bunkering industry
Release	Decline	• Low demand • Obsolete product/service • Price wars	• Attempt market leadership • Harvest and cope • Divest	• Evolution of breakbulk post containerization
Reorganization			• Move to specific niche • Adapt and attempt turnaround	

Source: own elaboration based on Porter (1980)