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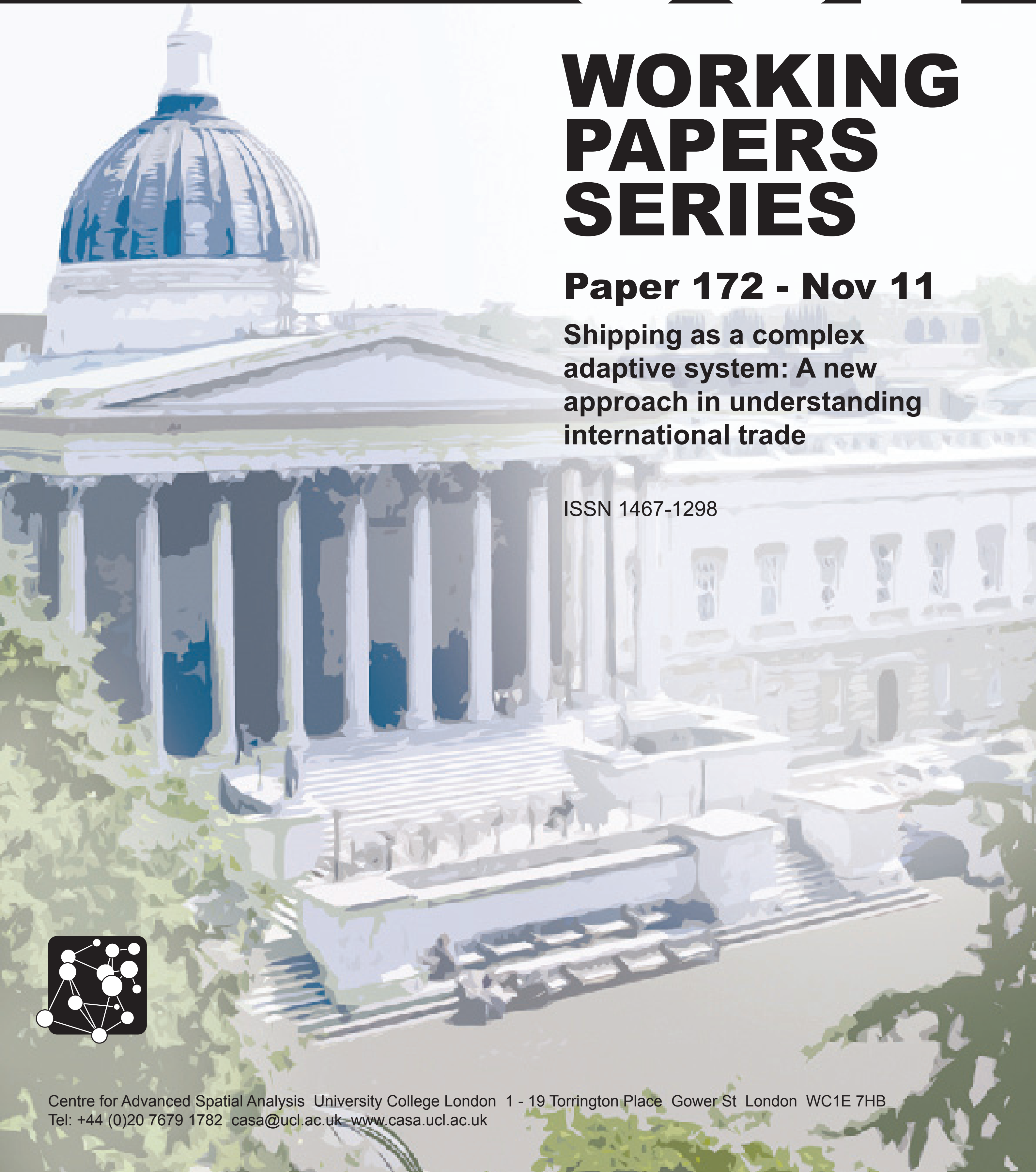

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SHIPPING AS A COMPLEX ADAPTIVE SYSTEM: A NEW APPROACH IN UNDERSTANDING INTERNATIONAL TRADE

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ABSTRACT

If we consider worldwide maritime shipping as a system, we observe that a large number of independent rational agents play a role in achieving predominant positions and in increasing market share: port authorities, shipping service providers, shipping companies and commodity producers. The maritime industry can, from this perspective, be defined as a Complex System composed of relatively independent parts that constantly search, learn and adapt to their environment while their mutual interactions shape hidden but recognisable patterns. In this work we examined the world maritime system through the Complex Adaptive System (CAS). Although CAS has been widely applied to the study of biological and social systems, its application in maritime shipping is scant, therefore our objective is to examine international trade shipping characteristics as a CAS and identify emerging global trends in the international maritime industry. We conclude presenting some of the goals that will be achieved by applying CAS approach in maritime trade: the construction of a tenable ontological framework will allow scholars to have a compressive view of the maritime industry and test the reliability of standard economic theories.

KEY WORDS

International Trade, Maritime Shipping Industry, Complex Adaptive Systems

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INTRODUCTION

The increase of free trade and advances in technology and geopolitical changes have typified the contemporary trade market. At present, many authors estimate that the maritime shipping ranges between 77% and 90% of the intercontinental transport demand for freight by volume, while in 1980 shipping comprised around 23% [1, 2, 3, 4]. The total number of Twenty-foot Equivalent Unit (TEU) carried worldwide ranged from 1,856,927 in 1991 to 7,847,593 in 2006 [5], and the average vessel capacity has grown from 1900 TEU in 1996 to 2400 TEU in 2006 [6]. Kaluza et al. [7] attribute this noteworthy increase to the growth in transpacific trade. Another reason for maritime shipping success can be found in the lower cost per TEU-mile in long distance transport for large quantities of goods [1]. Moreover, significant technical improvements such as size, speed and ship design as well as automation in port operations, have affected maritime shipping activities [5, 2]. For instance, in 1991 the use of vessels larger than 5000 TEU was unheard of, but by 1996 large vessels constituted about 1% of the world's fleet, increasing to 12.7% in 2001 and 30% in 2006.

In this context, maritime freight transport has experienced a rapid expansion over the last decades, and this growth highlights the presence of various independent rational agents (shipping companies, commodity producers, ports and port authorities, terminal operators, and freight brokers). We can observe that in the global maritime system this large number of independent rational agents plays a role, and through their mutual interactions they determine the development and growth of this industrial sector. From this perspective we can view shipping as a Complex System of relatively independent parts that constantly search, learn and adapt to their environment while their mutual interactions shape hidden patterns with recognisable regularities that continuously evolve. In this context the science of Complex Adaptive System (CAS) provides a useful framework to analyse a shipping system [8, 9, 10, 11, 12, 13, 14, 15, 16]. In the literature CAS refers to a field of study in which its strategic analysis is based on reductionism (bottom-up investigation). CASs are generally composed of a set of rational, self-learning, independent, and interacting agents whose mutual interrelations generate non-linear dynamics and emergent phenomena.

Since the 1980s, maritime rational agents have continuously evolved in their organisation, in response to both external stimulus and market competition. In the logistics and management perspective, a new form of inter-firm organisation has emerged in the shipping industry. Rodrigue et al. [2] succinctly explain how this change has occurred:

[…] *many of the largest shipping lines have come together by forming strategic alliances with erstwhile competitors. They offer joint services by pooling vessels on the main commercial routes. In this way they are each able to commit fewer ships to a particular service route, and deploy the extra ships on other routes that are maintained outside the alliance. […] The 20 largest carriers controlled 26% of the world slot capacity in 1980, 42% in 1992 and about 58% in 2003. Those carriers have the responsibility to establish and maintain profitable routes in a competitive environment* [2].

The evolution of the shipping industry has gone hand-in-hand with the changes in port organisation. According to a recent study for the European Parliament [17], from the growth of containerisation to what is known as the terminalisation era, where ports have become multi-functional operations through the development of highly specialised terminals, ports have undergone a major transformation in their management structures.

The role of port authorities has also changed as the maritime shipping system has evolved. Their main duties now involve the optimisation of process and infrastructures, logistics performance, promotion of intermodal transport systems, and increased relations with their hinterlands.

In light of these observations, our objective in this study is to examine how maritime shipping can be modelled through the use of CAS theory. If we assume that emergent global behaviour such as international trade can be explained through bottom-up phenomena arising from the local interaction among individual agents, our main goal is to understand how patterns emerge in the global shipping system.

The argument of our analysis is organised as follows. In the next section we summarise the main features regarding the worldwide movements of goods. Section 3 provides a detailed discussion of the CAS methodology and in Section 4 we discuss the opportunity to apply CAS modelling to the maritime system. In Section 5 we conclude with a research agenda for future studies.

COMPLEXITY SCIENCE AND COMPLEX ADAPTIVE SYSTEMS: KEY CHARACTERISTICS

Some scholars [14, 18, 19] define Complex Systems by observing particular features within a given system such as: *emergent*, *self-organizing/adaptive*, *non-linear interactions* and *in evolution*. For instance, emergent phenomena are classifiable by demonstrating their unpredictable behaviours when we account for each part of the system. This concept is epitomised by the famous sentence "*the whole is greater than the sum of the parts"* [19, 20]. Recessions and financial growth are, for example, emergent phenomena of national economies.

The class of CAS is one of the conceptualisations belonging to the framework of Complex Systems. According to Anderson [21], scholars have theorized approaches in order to better understand Complexity: Mathematical (Turing and Von Neuman), Information Theory, Ergodic theory, Artificial Entities (cellular automata), Large Random Physical systems, Self-Organised Critical systems, Artificial Intelligence, and Wetware. Anderson's classification places CASs into the class of Artificial Intelligence approach. What characterises this peculiar class of Complex System are the processes of adaptation and evolution. A system is adaptive when its agents "*change their actions as a result of events occurring in the process of interaction*" [22]. Evolution is created by the local interactions among agents. In this sense, adaptation can be seen as a passive action in which the agents absorb information from the surrounding environment (or from previous experience).

Conversely, evolution is generated by the mutual actions among agents. Fig. 1 shows how adaptation and evolution are embedded in different classes of systems. In our view, based on the previous definitions, complex systems are adaptive and evolving systems. Unintelligent evolving systems evolve through interaction processes but they do not adapt. For example, a crystal is generated by the mutual interactions among atoms or molecules that have no intelligence of the process in which they are involved. Furthermore, complicated systems are made by numerous interacting elements that do not adapt or evolve in the system. Complicated artifacts such as a car engine belong to this class. The IV quadrant of the graph in Fig. 1 is empty, as no system that is adaptive shows static structures. Adaptation and evolution play off each other and by this we mean that the adaptation process includes the concept of evolution but not the reverse.

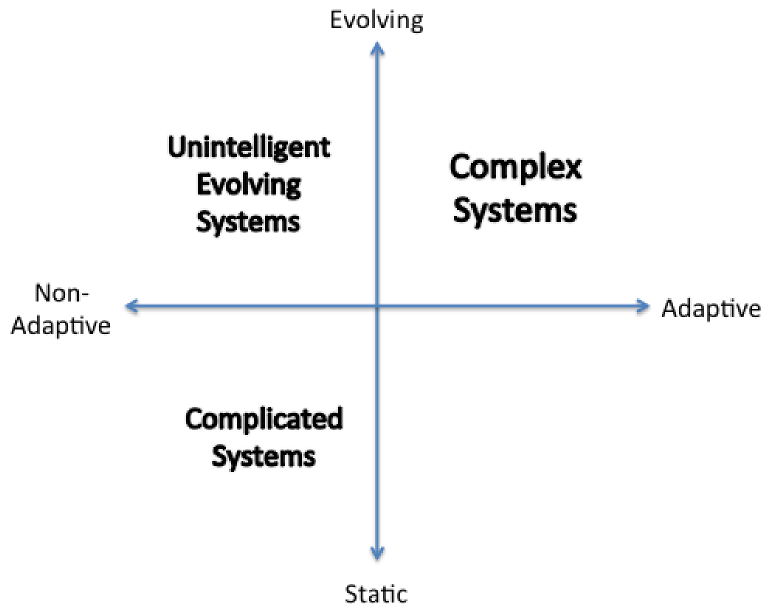

Figure 1. Graph of systems showing their ability to evolve and adapt

According to Wallis [23] there is no consensus on CAS unified theory. Holland [12] nonetheless calls for the need for a unified theory of CAS. Although many authors developed compressive frameworks [10, 11, 9, 8, 15], in this work we focus on Holland's [13] approach to modeling CASs. His framework is used widely in much of CAS literature, especially in economic applications. In one of the most robust works towards a theory of CAS Holland [13] suggests four properties and three mechanisms a CAS must possess. Wallis [23] states that Holland seven attributes for CAS are not the only ones a CAS may possess, but we agree with him "*other candidate features can be derived from appropriate combinations of these seven.*" We present below a summary of the seven basic features, and group them into properties and mechanisms.

FOUR PROPERTIES

- **Aggregation:** The concept of aggregation is twofold. The first facet involves how the modeller decides to represent a system. What features to leave in and what to ignore are of paramount importance. In this sense, elements are aggregated in reusable categories whose combinations help in describing scenes, or to be more precise, "*novel scenes can be decomposed into familiar categories*." The second meaning we can ascribe to aggregation properties for CASs relates to the emergence of global behaviours caused by local interactions, where agents tend to perform actions similar to other agents rather than to adopt independent configuration. Furthermore, aggregation often yields co-operation in that the same action of a number of agents produces results unattainable by a single agent. We can explain this concept through the example of the ant nest. An ant survives and adapts to different conditions when its action is coordinated with a group of ants (ant nest), but it will die if it works by itself. Likewise, in a CAS, a new action will survive and induce global effects if it is adopted by a large number of agents.

- **Nonlinearity**: Agents interact in a nonlinear way so that the global behaviour of the system is more than the sum of its parts.

- **Flows**: Agents interact with one another to create networks that vary over time. The recursive interactions create a *multiplier effect* (interactions between nodes generate outcomes that flow from node to node creating a chain of changes) and a *recycling effect* (in networks cycles improve the local performance and create striking global outcomes).

- **Diversity**: Agent persistence is highly connected to the context provided by the other agents to define "*the niche where the agent outlives*." The loss of an agent generates an adaptation in the system with the creation of another agent (similar to the previous) that will occupy the same niche and provide most of the missing interactions. This process creates diversity in the sense that the new specie is similar to the previous but introduces a new combination of features into the system. The intrinsic nature of a CAS allows the system to have progressive adaptations, further interactions and be able to create new niches (the outcome of diversity).

THREE MECHANISMS

- **Tagging**: Agents use the tagging mechanism in the aggregation process in order to differentiate other agents with particular properties; this facilitates a selective interaction among the agents.

- **Internal models**: these are the basic models of a CAS. Each agent has an internal model that filters the inputs into patterns and learning from experience. The internal model changes through agent interactions, and the changes bias future actions (agents adapt). Internal models are unique to each CAS and are a basic schema for each system. The internal model takes input and filters it into known patterns. After an occurrence first appears, the agent should be able to anticipate the outcome of the same input if it occurs again. Tacit internal models only tell the system what to do at a current point. Overt internal models are used to explore alternatives, or to look to the future.

- **Building blocks**: With regard to the human ability to recognise and categorise scenes, CAS uses the building blocks mechanism to generate internal models. The building block mechanism decomposes a situation evoking basic rules learnt from all possible situations it has already encountered. The combination of the seven features has allowed analysts to define environments where adaptive agents interact and evolve. In the next section we examine two specific studies dedicated to global cargo ship network through the lens of CAS.

CARGO SHIP NETWORK

Two recent articles [6, 7] examine the main characteristics of the Global Cargo Ship Network (GCSN). Other studies focus on sub-networks of the GCSN. Ducruet et al. [24] have analysed the Asian trade shipping network, McCalla et al. [25] the Caribbean container basin, Cisic et al. [26] the Mediterranean liner transport system, and Helmick [27] the North Atlantic liner port network. But the two studies of Kaluza et al. [7] and Ducruet and Notteboom [6] are particularly interesting because they examine the complete global network and give us a view of the macroscopic properties of the global maritime network. However, one main drawback is their inability to forecast future trends or changes in the networks. Nevertheless, suitable to our purpose, the aim of both studies is to characterise the global movements of cargo in order to define quantitative analyses on existing structural relations in the rapidly expanding global shipping trade network.

Table 1 highlights similarities and differences between the two studies on the GCSN. Kaluza et al. use the Lloyd's Register Fairplay for the year 2007, while Ducruet and Notteboom utilise the dataset from Lloyd's Marine Intelligence Unit for the years 1996 (post-panamax vessels period) and 2006 (introduction of 10,000+ TEU vessels).

Table 1. Overview of the main features of the GCSN as proposed in the studies of Kaluza et al. [7] and Ducruet and Notteboom [6].

	Kaluza network (2010) [7]	GAL (1996) [6]	GAL (2006) [6]
Main features	Asymmetric (59% connections in one direction); structural robustness (densely connected)	Weighted indirect network; smallnetwork	Weighted indirect network; smallnetwork
# Vessels	Tot=11,226; Container ship=3,100; Bulk dry carrier=5,498; Oil tankers=2,628	Container ship=1,759	Container ship=3,973
Weights	Sum of cargo capacity between port i and port j	Not specified	Not specified
# Nodes	951	910	1205
# Links	36,351	28,510	51,057
Min shortest path	2.5	2.23	2.21
Clustering coef.	0.49	0.74	0.73
Average degree; Max degree	76.5; -	64.1; 437	87.5; 610
P (k)	Right skewed but not Power law	-0.62	-0.65
P (w)	Power law (1.71 +/- 0.14)	-	-
Betweenness Centrality	Strong correlation between degree and centrality with some exceptions	Suez and Panama canals have high centrality (vunerability of the GCSN)	

Both studies apply different approaches to the network analysis and sometimes reach different conclusions. Ducruet and Notteboom built two different network structures: the first (Graph of Direct Links -GDL) takes only into account the direct links generated by ships mooring at subsequent ports, and the second (Graph of All Linkages - GAL) includes the direct links between ports which are called by at least one ship. Kaluza et al. [7] differentiate between the movements according to the type of ship. Four networks are subsequently constructed: all available links, sub-network of container ship, bulk dry carriers, and oil tankers. Despite the clear differences between the approaches adopted in the two studies, in order to compare them we have considered the complete network of ships' movements by Kaluza et al. and the GAL network of Ducruet and Notteboom.

All the networks are quite dense (on average, the ratio between number of edges and nodes is 37.2). Some network measures indicate a tendency of the GCSN to belong to the class of small world networks[1] given the high values of the Clustering Coefficient[2]. Small world networks are a special class of networks characterised by high connectivity between nodes (or in other words, low remoteness among the nodes). In an economic setting this property has an underestimated value, for example, in the retail market, connections among firms can create clusters of small-specialized firms that gravitate around a big firm (hub). This large firm uses small sub-peripheral firms to sub-contract production. Thus, both firms (the hub and peripheral ones) reach their goals and increase the economic entropy of the system [28].

The degree distribution P (k)3 shows that "*most ports have few connections, but there are some ports linked to hundreds of other ports*" [7]. However, when the authors examine the degree distribution in detail, they find that the GCSN does not belong to the class of scale free networks4. Both studies show low power law exponents or right skewed degree distributions. In this sense, the degree distribution analysis would have had a higher significance if the authors had showed a ranking of the ports over time. This would have allowed them to understand if there was ever a turnover of dominant hubs that in turn had led to the detection of competitive markets in maritime shipping. Opposite results would have depicted a constrained market.

Kaluza et al. [7] also studied the GCSN as a weighted network where the distribution of weights and Strength5 displays a Power law regime with exponents higher than 1. These findings agree with the idea that there are a few routes with high intense traffic and a few ports that handle large cargo traffic. The detection of Power law regimes is often associated with inequality (i.e. distribution of income and wealth) or vulnerability in economic systems [28, 29]. The correlation between Strength and Degree of each node also fits a Power law; this implies that the amount of goods handled by each port grows faster than the number of connections with other ports. Hub ports also do not have a high number of connections with other ports but the connected routes are used proportionally by a higher number of vessels.

Unfortunately, Ducruet and Notteboom's work [7] does not provide results of the weighted network analysis over the years 1996 and 2006. Such as analysis would have allowed us to discuss relevant facts about the dynamics of flows in the main transatlantic routes as well as address constructive criticism of the influence of the introduction of large loading vessels (post-panamax era) on specific routes.

The centrality of ports in a network (i.e. the importance of a node) can be inspected with other topological measures rather than the crude number of connections per node (degree k). In the case of GCSN, both studies use measures of the Betweenness Centrality6. Kaluza et al. [7] highlight a high correlation between the degree k and Betweenness Centrality then validating the theory that hub ports are also central points of the network. Ducruet and Notteboom detect interesting anomalies in the centrality of certain ports. Large North American and Japanese ports are not on the top rank position in terms of network centrality

[1] For an extensive review of complex networks, see Watts and Strogatz (1998), Albert and Barabasi (2002) and Newman (2003).

[2] A measure of the tendency of nodes to cluster together.

[3] In Network Theory the degree k is meant to be the number of connections of every node.

[4] For an extensive review of complex networks, see [30, 31, 32].

[5] In the case of ship networks, Strength represents the sum of goods that pass through a port in a year, in other words, the sum of the links' weights that converge on a node.

[6]The Betweenness Centrality of a node is the number of topologically shortest paths that pass through that node.

despite their traffic volume. The most central ports in the network are the Suez and Panama canals (as they are gateway passages), Shanghai (due to the large number of ships that “visit” the port) and ports such as Antwerp (due to its high number of connections.)

Although maritime shipping has been going through a tremendous period of expansion in last decade, the underlying network has a robust topological structure that has not changed in recent years. Kaluza et al. [7] observe the differences “in the movement patterns of different ship types.” The container ships show regular movements between ports, which may be explained by the nature of the service they provide. Dry carriers and oil tankers tend to move in a less regular manner because they change their routes according to the demand of goods they carry.

Finally, maritime shipping appears to have gained a stronger regional dimension over the years. In 1996 there was a strong relation between European and Asian basins while in 2006 these connections appear to be weaker. Ducruet and Notteboom [6] explain this as a twofold phenomenon. Each basin has reinforced the internal connectivity while the Asian basin is witnessing a strong increase in the volume of goods shipped. The direct consequence is that Asian countries have been splitting their links with European countries. Physical proximity also helps to explain the increase of regional basins as well as the establishment of international commercial agreements such as the NAFTA and MERCOSUR between North and South America [6].

COMPARISON OF MARITIME TRADE AND CAS FRAMEWORK

In the previous section we have discussed two recent studies that take into account a static analysis of the global cargo-shipping network. From the previous studies [6, 7] we conclude that GCSN is a small world network with some Power law regimes when it is examined as a weighted network. This evidence indicates that the underlying structure is not dominated by random rules, and that the complex organisation emerges from the interaction of lower-level entities.

In shipping, *self-organisation* is identified as a bottom-up process arising from the simultaneous local *nonlinear* interactions among agents (i.e. vessels, ports, shipping alliances or nations according to the scale of analysis). This allows us to notice that in GCSN our aim is to understand why certain ports are able to play a leading role and also to estimate the shipping trade trends. Using an example from the nature, flocking birds generate patterns based on local information. Each bird learns from other birds and adapts its speed and direction accordingly in order to reach the next spot. In the same way shipping companies compete in the market according to their own interests. The introduction of innovation makes a company more competitive and sets new rules in the market that force other companies to co-evolve accordingly in order to be profitable. This adaptive process has been witnessed in maritime shipping at different stages with the introduction of new technologies such as improvements in the fleets (launch of post-panamax ships) or in the management processes in the seaports (automation of loading and unloading services).

Based on the work in [6, 7], our next step is to identify a set of CAS features related to shipping systems. We select ten characteristics extracted from a number of works that have proposed applications of CAS modelling (Wallis, 2008). In Table 2 we relate each characteristic to Holland’s classification described in Section 2 and to a possible CAS modelling application for shipping systems. In the reminder of this section we discuss how these ten characteristics are constructive elements for a CAS shipping system.

As shown in section 3, international shipping is a large collection of entities (Table 2 – Feature: *Many interacting/interrelated agents*) whose interactions create non-linear trends (Table 2 – Feature: *Non-linear/Unpredictable*). Given these two analytical perspectives, we can examine the local interactions among ships and how they are assigned to different ports according to price and demand of the goods they carry (Table 2 – Feature: *Goal seeking*). On the other hand, according to the modelling proposed by in [6, 7], seaports may be considered as agents of a CAS. In this case the most interesting questions revolve around understanding how a shipping system evolves in relation to external shocks (Table 2 – Feature: *Coevolutionary*). For instance, in cases of sudden undesired events such as terrorist attacks or extreme natural phenomena (earthquakes and hurricanes), the cargo-shipping network would *co-evolve* in order to maintain the same level of provided service if a big seaport hub were to disappear or be severely damaged.

Table 2. Comparison of Complex Adaptive Systems (CAS)s features with shipping.

Features	Description	Authors	Holland basics	Maritime shipping system
Self-organisation	Formation of regularities in the patterns of interactions of agents that pursue their own advantages through simple rules.	[34, 35, 36, 37, 38, 39, 40, 41, 42]	Tagging, non-linearity	The GCSN is a smallworld network with some Power law regimes when inspected as a weighted network. This evidence shows that the underlying structure is not dominated by random rules and that complex organisation emerges from the interaction of lower-level entities.
Many interacting/ interrelated agents	Large number of locally-interconnected and interacting rational agents that are continually pursuing their advantageous interests.	[43, 34, 35, 44, 45, 46, 36, 47, 37, 38, 48, 49, 50, 51, 52]	Flows, tagging	This concept is already embodied in the definition of the trade shipping system. If we take into account the mere fleet system and the connections established between ports, we observe around 10,000 vessels, 1,000 ports and 50,000 connections (see table 1 for details).
Distributed control	The outcomes of a CAS emerge from a process of self-organisation rather than being designed and controlled externally or by	[12, 14, 43, 51, 52]	Flows, internal model	Although there are international trade agreements that unavoidably influence maritime shipping, these pacts can be seen as external forces that increase the system's entropy and prompt more economic relationships.

	a centralised body.			
Non-linear/ Unpredictable	Interactions are non-linear and thus intractable from a mathematical point of view.	[14, 43, 45, 46, 36, 47, 37, 38, 48, 49, 40, 53, 22, 28]	Non-linearity	The GCSN shows Powerlaw fit distributions and not random topological structures. This signals the emergence of nonlinear interactions between system's agents.
Coevolutionary	The environment is influenced by the activities of each agent.	[43, 45, 46, 36, 39, 54, 41, 52]	Diversity, tagging	i.e.: introduction of post panamax and 10,000+ TEU ships change carriers routing networks and tariffs as well as the volume of transshipped cargo handled at main ports.
Emergence	The interplay between agents shapes a hidden but recognizable regularity. (i.e. the brain has consciousness but not the single neurons.)	[52, 12, 14, 53]	Aggregation, flows, internal model	i.e.: emergence of regional clusters of ports.
Goal seeking.	The agents try to adapt in order to fulfil their goals.	[43, 34, 44, 50, 54, 41]	Flows, internal model	Dry carriers and oil tankers tend to move in an irregular manner because they change their routes according to demand of goods they carry.
Nested systems	Each agent can be considered as a system. Each system is a part of something bigger, thus each system can be a sub-system of a bigger system.	[55, 52]	Diversity, internal model	i.e. ports alliances at national or international level are nested clusters of ports. The same port may belong to a cluster of ports at national level and to a cluster of ports at international level, but this category may not necessary include all the ports it belongs to within the national cluster.

If we now return our attention to natural systems, the fundamental questions are: how would an ecosystem evolve if a species disappeared? Would it be replaced by new species and would other species be able to survive without it? Similarly, we could apply those questions to the case of maritime shipping in order to forecast future configurations as well as prevent global breakdowns in national and international markets (Table 2 – Feature: *Self-organisation*).

The cargo shipping industry is comprised by several sectors such as international maritime transport, maritime auxiliary services and port services, which play a relevant role; they have a fairly long history of co-operation since the 1990s with the formation of consortia and alliances. Each co-operation is regulated by a wide range of "*national and international regulations responding to specific issues that have arisen as the international trading system has evolved*" [33]. The outcomes of these collaborations influence the setting of freight rates and shipping companies' tariffs. In light of the previous remarks, co-operation among agents (shipping companies, port authorities, and so on) should be included in the modelling (Table 2 – Features: *Distributed control* and *Nested Systems*).

In particular, the international economic alliances in trade agreements play a significant role in the definition of trade flows and development. For instance, China's admittance into the WTO has affected the bilateral negotiations between WTO countries and China itself as well as among former members (Table 2 – Feature: *Coevolutionary* and *Self-organisation*), but other examples of international trade agreements show similar impacts on international trade processes (NAFTA among North American countries, MERCOSUR in South America, ASEAN-AFTA among five Asian countries, the Trans-Pacific Strategic Economic Partnership (TPP) in the Asian-Pacific region).

Based on these observations, when modelling shipping relationships, trade agreement memberships should be included for two reasons: first, in order to understand the actual effects on agents involved in the agreements, and second, to understand the effects generated on agents who are not members of a specific trade bloc. In this regard, a CAS application on maritime international trade would help us to better understand the role of alliances in trade, the effects of the establishment of new alliances, or the admission of new members in existing agreements (Table 2 – Feature: Emergence).

The aforementioned are some of the questions a CAS application should potentially be able to answer when policy constraints are reckoned with the agents' behaviour modelling (Table 2 – Feature: Distributed control). Referring to Holland's classification, the modeller has to set up the internal model of each agent so that it takes into account the distinguishing factors an agent uses to direct its economic choices. For example, national and international port alliances are nested clusters of ports. A single port may belong to a cluster of ports at the national level and also belongs to a cluster of ports at the international level. Conversely, not all ports in national cluster are necessarily part of an international cluster. These structures emerge at the time of mutual interactions between the agents.

CONCLUSION: CHALLENGES, BENEFITS AND FLOWS OF CAS

In an article in Nature Farmer and Foley (2009) call for more applications of CAS in economics, asserting that "*agent-based models potentially present a way to model the* *financial economy as a complex system, as Keynes*[7] *attempted to do, while taking human adaptation and learning into account, as Lucas advocated*."

Opposite from classic top-down approaches, whose modelling components are carefully designed and evaluated, the CAS theory proposes bottom-up methods based on the modelling of simple interactions among its components (or agents) that generate complex, robust and flexible phenomena and macro regularities. The only duty of the modeller is to set the initial rules that regulate the agent-agent interactions and report the initial conditions of the environment where the agents act.

CAS application may be useful for multiple aims. Immediately below, we list some of the goals that may be achieved in applying CAS theory in maritime trade:

- To test standard economic theories;
- To understand the spatial structure and organisation of economies such as the formation of regional clusters of ports, business agglomerations and industrial alliances;
- To understand why certain types of co-operation among shipping firms appear to be more adaptable than others and to know what factors regulate the stable relationship among them;
- To provide policy makers with a set of comprehensive tools able to address issues of growth, distribution and welfare connected to global trade trends;

To put into practice an integrated multidisciplinary approach among fields belonging to social science. Many scholars have thrown down the gauntlet to the scientific community for a multidisciplinary approach in the CAS paradigm [13, 56]. Communication across disciplines may allow discerning clues from different fields and quicken theoretical and practical advances.

In our view, complexity in economics is lacking its provision of a more general theory and instead is characterised by the application of ideas and concepts in an ad-hoc manner. This is due to the scarcity of a universally-accepted complexity theory. In previous paragraphs we have argued that even in CAS theory there is not a shared theoretical framework whose scholars gather in the application of its notions. Most of these notions derive from physical, chemical and biological studies and their assumptions are "*restricted to the content of the specific scientific models used* [57]. Economic systems are unambiguously complex systems, as they are highly interconnected, adaptive, self-organising and emergent systems. The scientific community should take steps towards the construction of a more tenable ontological framework while scholars and modellers should derive a common approach from that framework.

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