UNIVERSIDADE DA CORUÑA

FACULTADE DE ECONOMÍA E EMPRESA

LA NUEVA GEOGRAFÍA ECONÓMICA DEL TRANSPORTE MARÍTIMO: ANÁLISIS DEL FORELAND MEDIANTE REDES COMPLEJAS

TESIS DOCTORAL

CARLOS PAIS MONTES

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TESIS DOCTORAL PRESENTADA POR:

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A CORUÑA, SEPTIEMBRE 2014

A mis padres

Agradecimientos

Sí que hay palabras para describir lo que Checha ha representado para mí desde que apareció en mi vida allá por 2007. Hay millones, y todas ellas relacionadas con aquello que incide en el crecimiento y la prosperidad de los países: amor, compromiso, generosidad, tenacidad, inteligencia, optimismo, paciencia, fortaleza, visión… ¿Cómo agradecer pues semejante legado si no es acogiéndolo como parte fundamental de mi entidad y transmitiéndoselo a las generaciones que me sucedan?

También encuentro muchas expresiones para describir lo que ha supuesto para mí el encuentro con Fernando, un inesperado y felíz vínculo respecto a lo que me enseñaron mis padres sobre la justicia, y que para mí es sagrado. Todas esas palabras también están relacionadas con lo mejor del género humano, y especialmente con el espíritu de cooperación, del cual estoy aprendiendo que está más relacionado con equilibrios que con igualaciones.

A priori nadie sabe lo que hay más allá del horizonte, excepto los que se atreven a navegar.

ÍNDICE GENERAL

Resumen

La tesis titulada “La nueva geografía económica del transporte marítimo: análisis del foreland mediante redes complejas” es una investigación sobre la geografía económica del transporte marítimo en la actualidad, que trata de cubrir los siguientes objetivos:

1. Mejorar la escasa metodología existente en la actualidad respecto a la medición de las zonas de influencia portuaria

2. Aportar nuevas evidencias de la relación entre transporte marítimo y crecimiento económico

3. Aplicar un análisis de redes complejas al problema de la economía del transporte marítimo

4. Realizar una contribución original al problema de la definición y medición cuantitativa del foreland portuario, planteando el cálculo de la estructura “foreland de proximidad”

La investigación se llevó a cabo usando las posiciones Automatic Identification System (AIS) de una muestra de buques de mercancía general y buques portacontenedores procedente del Lloyd’s Shipping Register. Esta nueva tecnología de trazabilidad especifica los atraques, las salidas y los datos de titularidad jurídica del buque a las autoridades portuarias.

Una vez obtenida y depurada la base de datos de las posiciones AIS (nodos) para cada clase de buque, se construye la estructura de la red utilizando un servidor postgresql. Esta plataforma incluye un lenguaje de programación sobre bases de datos que posibilita realizar los procedimientos necesarios para definir la matriz de adyacencia, que contiene la información de los nodos conectados y el peso de sus vínculos.

Las conclusiones más relevantes obtenidas hacen referencia a la evolución del tráfico marítimo de carga general en las modalidades contenerizadas y no contenerizadas teniendo en cuenta los años de crisis (2007-2011). Se constata, de este modo, el descenso en la demanda de los principales hubs del Norte de Europa, así como la emergencia de nuevas rutas comerciales dirigidas hacia las economías emergentes del Hemisferio Sur.

Resumo

A tese titulada “A nova xeografía económica do transporte marítimo: análise do foreland mediante redes complexas” é unha investigación sobre a xeografía económica do transporte marítimo na actualidade, que trata de cubrir os seguintes obxectivos:

1. Mellorar a escasa metodoloxía existente na actualidade respecto á medición das zonas de influencia portuaria

2. Aportar novas evidencias da relación entre transporte marítimo e crecemento económico

3. Aplicar un análise de redes complexas ó problema da economía do transporte marítimo

4. Realizar unha contribución orixinal ó problema da definición e medición cuantitativa do foreland portuario, plantexando o cálculo da estrutura “foreland de proximidade”

A investigación levouse a cabo usando as posicións Automatic Identification System (AIS) dunha mostra de buques de mercancía xeral e buques portacontenedores procedente do Lloyd’s Shipping Register. Esta nova tecnoloxía de trazabilidade especifica os atraques, as saídas e os datos de titularidade xurídica do buque ás autoridades portuarias.

Unha vez obtida e depurada a base de datos das posicións AIS (nodos) para cada clase de buque, constrúese a estrutura da rede utilizando un servidor postgresql. Esta plataforma inclúe unha linguaxe de programación sobre bases de datos que posibilita realizar os procedementos necesarios para definir a matriz de adxacencia, que contén a información dos nodos conectados e o peso dos vínculos.

As conclusións máis relevantes obtidas fan referencia á evolución do tráfico marítimo de carga xeral nas modalidades contenerizada e non contenerizada tendo en conta os anos da crise (2007-2011). Constátase, de este xeito, o descenso na demanda dos principais hubs do Norte de Europa, así como a emerxencia de novas rutas comerciais dirixidas cara as economías emerxentes do Hemisferio Sur.

Abstract

The thesis entitled “The new economic geography of maritime transport: foreland analysis using complex networks” is a research about current maritime transport economic geography that tries to accomplish the following goals:

1. To improve scarce methodology currently existing about the measuring of port influence areas

2. To show new evidences of the relation between maritime transport and economic growth

3. To apply new computational techniques (complex networks analysis) to the problem of maritime transport economy

4. To develop an original contribution to the problem of the definition and quantitative measuring of port foreland, by developing the calculus of “proximal foreland” structure

The research was made using Automatic Identification System (AIS) positions of a general cargo and containerships sample coming from Lloyd’s Shipping Register. This new traceability technology specifies vessel calls, departures and juridical property to the port authorities.

Once obtained and optimized the AIS database (nodes) for each vessel class, a network structure is built using a postgresql server. This platform includes a database programming language that allows performing required procedures in order to define adjacency matrix that contains the information about connected nodes and edges’ weight.

Most relevant conclusions obtained explain the evolution of maritime general cargo traffic (in their containerized and non-containerized modes) taking into consideration the years of the crisis (2007-2011). It can be seen, this way, the decreasing in the demand of main Northern European hubs, as well as the emergency of new trade routes bound to South Hemisphere emergent economies.

Introducción

Al amparo del artículo 41 ("Tesis por compendio de artículos de investigación") del reglamento de estudios de doctorado, aprobado por el Consejo de Gobierno de la Universidade da Coruña el 23 de abril de 2013, se presenta la tesis "La nueva geografía económica del transporte marítimo: análisis del foreland mediante redes complejas", que incluye tres artículos publicados en revistas indexadas en el *Journal Citation Reports*.

El proyecto se compone de cuatro capítulos. El primero es la introducción, donde se expone el vínculo existente entre las publicaciones de acuerdo a la normativa, es decir, tanto desde el punto de vista del tema objeto de estudio, como de la metodología utilizada. El fin de esta introducción es presentar unas conclusiones robustas en este campo de investigación basadas en los trabajos aportados.

El segundo capítulo es una copia íntegra del primer artículo: "Maritime degree, centrality and vulnerability: port hierarchies and emerging areas in containerized transport (2008-2010)". Esta publicación es un primer acercamiento al tema de la tesis y supone la utilización de una metodología novedosa para describir la evolución del transporte marítimo de mercancía en los años de la crisis.

El tercer capítulo es una copia íntegra del segundo artículo: "General cargo and containership emergent routes: A complex networks description". Para la ejecución de esta investigación, se dispone de una base de datos muy sólida y amplia, y se profundiza, de modo fructífero, en la metodología matemática disponible para conocer regiones portuarias con especial actividad de comercio marítimo.

El cuarto capítulo lo compone la copia íntegra del tercer artículo: "Foreland determination for containership and general cargo ports in Europe (2007-2011)". En este apartado, se aborda el cálculo numérico del foreland de un puerto.

El objetivo principal de la tesis es analizar la evolución del transporte marítimo de carga general en el período 2007-2011, utilizando técnicas de análisis de redes complejas. Metodológicamente, este análisis se ha llevado a cabo calculando el grado de influencia que tienen determinados nodos o regiones portuarias, pertenecientes a un conjunto global de posiciones temporales de buques de mercancía general o contenerizada.

Este tipo de aproximaciones al problema de la evolución de las redes de transporte marítimo han sido introducidas recientemente por economistas (Fremont, 2007; Notteboom y Rodrigue, 2005), geógrafos (Ducruet 2008; 2009) y físicos (Kaluza y Kölzsch, 2010). Configurando un ámbito multidisciplinar de investigación en el que se entrecruzan concepciones geográficas especializadas basadas en criterios funcionales, como los espacios de interacción hinterland y foreland (Bird, 1971; Rodrigue, 2009; Villaverde y Coto-Millán, 2011) y diseños computacionales basados en la actual disponibilidad de soportes de cálculo vectorial para grandes bases de datos, restringidos hasta hace poco a los usuarios de *mainframe* (Auber et al., 2012; Bastian et al., 2009).

A nivel general, todas estas investigaciones están basadas en la aplicación de una nueva generación de dispositivos automáticos de señalización marítima, denominados Automatic Information System (en adelante, AIS), que la Convención SOLAS[1] 2002 de la Organización Marítima Internacional[2] (en adelante, IMO) obliga a instalar en los buques construidos con posterioridad a 2007[3]. Esta nueva tecnología de posicionamiento, alternativa a los actuales sistemas de radar y comunicación por radio/vía satélite, supone la puesta en funcionamiento, por primera vez en la historia de la marina mercante, de un sistema de información estandarizado que permite la identificación de la posición geográfica y de las características estructurales y de propiedad jurídica de cualquier buque en cualquier parte del mundo.

Los dispositivos AIS emiten públicamente secuencias estandarizadas de información (Rico-Secades, 2014) en canales convencionales marítimos VHF (alta frecuencia de radio). Cada unidad de información se compone de un tramo estático (matrícula OMI, Eslora y Manga, régimen de propiedad, tipo de buque, situación de la antena de posicionamiento) y otro dinámico (posición del buque, rumbo/velocidad respecto a tierra, rumbo de proa, estatus de navegación y relación de viraje). Esta

[1]International Convention for the Safety of Life at Sea, o SOLAS, es probablemente el tratado internacional de seguridad marítima vigente más extendido en la actualidad

[2]Institución técnica dependiente orgánicamente de las Naciones Unidas cuyo cometido fundamental es promover la cooperación entre Estados y la industria del transporte para mejorar la seguridad marítima y para prevenir la contaminación marina (IMO, 2013).

[3]La instalación de estos dispositivos es obligatoria para buques de más de 300 *Gross Tonnage* (arqueo bruto). Esta medida indica el volumen total interior, medido en m^3, que desplaza la nave.

configuración hace posible la instalación de receptores en otros buques o en instalaciones especiales en la costa, así como una amplia difusión de los datos obtenidos descodificados. A nivel español y en el marco de la iniciativa comunitaria INTERREG III-A, Puertos del Estado ha diseñado una red de estaciones base[4], situadas fundamentalmente en los faros gallegos y en los andaluces (Rebollo y Tortosa, 2006), que suministran información AIS a los dos dispositivos de separación de tráfico marítimo más importantes del espacio de navegación español (Finisterre y Gibraltar).

La obligatoriedad de los dispositivos AIS incluida en la convención SOLAS 2002 estaba destinada en un principio, únicamente, a mejorar la seguridad durante la navegación comercial, pero la enorme difusión que han tenido, en los últimos años, los servidores privados de internet especializados en el tratamiento de Sistemas de Información Geográfica (Kraak y Ormeling, 2011), ha provocado la aparición de soportes telemáticos que ofrecen la información AIS en tiempo real (www.marinetraffic.com, http://www.space.aau.dk/aausat3) e históricos sobre las trayectorias AIS seguidas por los buques (www.sea-web.com, www.fleetmon.com).

De este modo, una información con un importante nivel de profundidad sobre el posicionamiento y las características estructurales y jurídicas del buque, se abre más allá del puente de mando y las capitanías marítimas, para entrar en mercados de grandes bases de datos destinados a cargadores, profesionales de la logística, *policy-makers*, medios de información especializados y a investigadores en economía del transporte marítimo (Feixiang, 2011).

Es preciso, llegados a este punto, indicar la reticencia y las reservas que la OMI ha mostrado en algún momento en lo que respecta al grado de accesibilidad a este tipo de datos que, por motivos de seguridad, deberían quizá tener alguna capa adicional de protección:

> *"The Maritime Safety Commitee agreed that the publication on the world-wide web or elsewhere of AIS data transmitted by ships could be detrimental to the safety and security of ships and port facilities and was undermining the efforts of the Organization and its Member States to enhance*

[4] Red AIS SW-AIS

the safety of navigation and security in the international maritime transport sector.”

IMO, Maritime Safety Commitee – 79th sesión: 1-10 december 2004

La actual abundancia de investigaciones basadas en datos de navegación AIS muestra, no obstante, lo importante que pueden resultar estos grandes conjuntos de información geográfica estructurada, para políticas públicas destinadas a la gobernanza portuaria o para la optimización de las perspectivas comerciales de la industria marítima:

a) En lo que respecta a la planificación de políticas portuarias, los puertos son instituciones que, usualmente, movilizan importantes recursos económicos, y que demandan no sólo simulaciones de tráfico marítimo utilizando la distancia interportuaria y las ecuaciones de coste (Veldman et al., 2013), sino también modelizaciones adicionales basadas en datos reales de navegación (Perez-Labajos y Blanco, 2004).

b) Dentro de las estrategias comerciales de optimización en determinados sectores de la industria asociados al transporte marítimo se pueden citar, como significativas: el tratamiento de datos AIS para analizar las rutas emergentes de los buques de Maersk, MSC y CMA-CGM[5] (Ducruet y Notteboom, 2012), el control y distribución de la cola de atraque a la entrada de las radas (Han Tun et al., 2007), las posibilidades de utilizar esta información para evitar las colisiones con otros buques o con grandes cetáceos (Min Mou et al., 2010; McGillivary et al., 2009) y la reducción de las emisiones de gases de efecto invernadero causadas por navegaciones deficitarias en términos de sostenibilidad medioambiental (Ng et al., 2013).

En definitiva, la progresiva implementación del sistema de posicionamiento AIS, ha redefinido el concepto de trazabilidad de un buque impulsándolo hacia una dimensión global, de máxima accesibilidad, y de nuevas posibilidades en términos de toma de decisiones a nivel estratégico, tanto por parte de las autoridades portuarias, como de los distintos actores públicos y privados implicados de algún modo en el negocio naviero.

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[5] Actualmente las tres compañías navieras más poderosas del mundo, con planes de operar en julio de 2014 las rutas este-oeste conjuntamente bajo la denominación P3 (Containerisation International, 2013)

En su primera descodificación, la base de datos AIS es una secuencia alfanumérica con marcadores de posición diferenciando el tipo de dato contenido en la cadena. Esta situación inicial exige una intervención posterior en términos de computación para extraer significado de lo que es, en principio, una secuencia continua e indiferenciada de texto. Para la elaboración de la presente investigación se han seleccionado, de entre el amplio conjunto de variables disponibles en la secuencia AIS, únicamente cadenas de tipo: [matrícula OMI, clase del buque, capacidad máxima, posición geográfica, ETA[6], ETD[7]]. Al disponer de un conjunto lo suficientemente amplio de este tipo de estructuras de datos, la concatenación de posiciones geográficas temporalmente sucesivas produce una secuencia coherente que puede ser identificada como la ruta de navegación para un buque determinado.

Con las variables seleccionadas de la secuencia AIS, no sólo es posible fijar la matrícula de un buque y analizar el conjunto de posiciones anteriores y posteriores que recorre en un intervalo temporal determinado, sino que también existe la posibilidad metodológica de fijar un puerto y analizar el conjunto de trayectorias que los buques de la muestra efectúan en instantes temporales anteriores y sucesivos.

El segundo pilar metodológico de la tesis es la Teoría de Grafos. Esta rama de las matemáticas[8] estudia las propiedades de las redes mediante la aplicación de resultados teóricos procedentes de otras áreas como la Matemática Discreta, el Álgebra, la Topología y las Ciencias Computacionales. Los métodos de análisis de sistemas reticulares han adquirido un extraordinario desarrollo en otros ámbitos, debido, fundamentalmente, a la multiplicación y abaratamiento de la capacidad de computación, y a la emergencia de numerosas plataformas de software de almacenamiento y consulta en grandes bases de datos y #bigdata (Boyd y Crawford, 2011). La propia estructura interna del buscador de información más usado en la actualidad (google) incorpora este tipo de cálculo como elemento crucial para definir la importancia y jerarquía de los contenidos solicitados por los clientes (Altman y Tennenholtz, 2005; Cheng y Friedman, 2006).

[6]Estimated Time of Arrival (Tiempo estimado de llegada)
[7]Estimated Time of Departure (Tiempo estimado de salida)
[8]La American Matemathical Association clasifica a la Teoría de Grafos como la rama 05C del Análisis Combinatorio. En concreto las redes complejas, que son el objeto de estudio de esta tesis, son la subrama 05C82 y la 90B1 de Investigación Operativa.

El análisis de la topología de una red consiste en analizar nodos interconectados sometidos a una evolución temporal en lo que respecta a los vínculos incidentes, y determina posteriormente las vulnerabilidades del sistema reticular. Es decir, consigue caracterizar a elementos lo suficientemente influyentes como para provocar un cambio significativo en el flujo global de la red si son minorados o completamente eliminados del conjunto inicial.

La idea de la construcción de una red aparece como una posibilidad natural de resolver problemas del tipo: ¿qué puertos tienen más actividad? ¿cuáles reciben más carga? ¿qué puertos concentran la mayor parte de las rutas y cuáles actúan como subsidiarios? ¿qué regiones portuarias son las más influyentes?

A nivel conceptual este tipo de análisis incluye propiedades como las que aparecen en la figura 1, cada una con toda una serie de desarrollos matemáticos que posibilitan su cálculo, representadas para esta introducción de acuerdo al mayor o menor valor obtenido en su cálculo. Para la realización de este ejemplo, se ha generado una red aleatoria de 55 nodos y 71 aristas, con una probabilidad de que un nodo emita una conexión del 3,5%:

a) La propiedad de grado, expresa el número de conexiones directas que inciden en un nodo determinado. De este modo, en la figura se aprecia un nodo en la parte superior con grado máximo (9) y que, por tanto, recibe un número significativo de vínculos directos.

En términos portuarios, el grado de un puerto sería la cantidad de rutas regulares o *tramp* que conectan directamente a una rada con otras situadas en su vecindad. La mayor parte de los puertos importantes están constituidos en realidad por grandes y laberínticos[9] complejos portuarios, agrupaciones de terminales diseñadas para la estiba o desestiba de distintos tipos de mercancías. Es frecuente, en estos casos, que un registro AIS de entrada y salida en uno de ellos, por ejemplo en Rotterdam, suponga en realidad diferentes sub-escalas en diferentes terminales (Rotterdam-Pernis, Rotterdam-Vlaardingen, Rotterdam-Maasvlakte) situadas en ocasiones a distancias bastante considerables las unas de las otras, lo

[9] Las maniobras de entrada de los buques en grandes puertos como Hamburgo, suelen tener poco que ver con aproximaciones sencillas hacia diques situados en áreas de fácil acceso y suponen, más bien, un recorrido tortuoso y delicado para capitanes, prácticos y remolcadores, a través de angostos canales de navegación plagados de bifurcaciones.

que muestra una limitación a la hora de determinar la conectividad únicamente en base al grado.

b) La centralidad[10] expresa el número de veces que un nodo aparece en el camino más corto que une dos nodos arbitrarios de la red. Es, por tanto, una medida de conectividad relacionada con la capacidad de intermediación de ese nodo, y suele denotar posiciones críticas para la topología global de la red analizada. En este caso, los nodos de mayor centralidad están situados en “puntos de corte” del grafo, es decir, en lugares donde se aprecia una especial vulnerabilidad en el sentido de que si se eliminan esas posiciones, la red queda dividida en varios *clusters* desconectados.

En términos de transporte marítimo, un puerto tiene mayor centralidad cuanto más aparezca como escala en la oferta de servicios de las compañías navieras. Por tanto, los puertos con mayor centralidad son aquellos que muestran una gran capacidad de intermediación (vía *transhipment*[11] o en base a rápidas operaciones multimodales dirigidas hacia el hinterland).

c) La propiedad pageRank[12] también es una medida de conectividad, pero esta vez desde el punto de vista de la influencia en nodos cercanos. El cálculo matemático varía mucho con respecto a los dos parámetros anteriores[13] y, fundamentalmente, expresa lo influyente que resulta un nodo con respecto a otras posiciones vecinas. En este caso, se observa que el nodo con mayor pageRank, es el situado en la parte inferior izquierda de la figura, ya que sirve como *hub*[14] para diferentes y relevantes subredes situadas en su vecindad.

Un puerto marítimo con elevado pageRank tiende a tener elevado grado y centralidad (aunque no es condición necesaria), pero, sobre todo, es un puerto importante para las subestructuras de red que lo circundan, por lo que el concepto

[10] Betweenness centrality

[11] El término de *transhipment* usualmente se asocia a “transbordo”, pero en realidad tiene un significado más amplio e incluye las operaciones de estiba y desestiba realizadas en un puerto definido como intermediario (Rodrigue, 2010).

[12] Llamada así porque su descubridor fue Larry Page, cofundador de google, que la desarrolló para determinar la influencia de una página (Page et al., 1999).

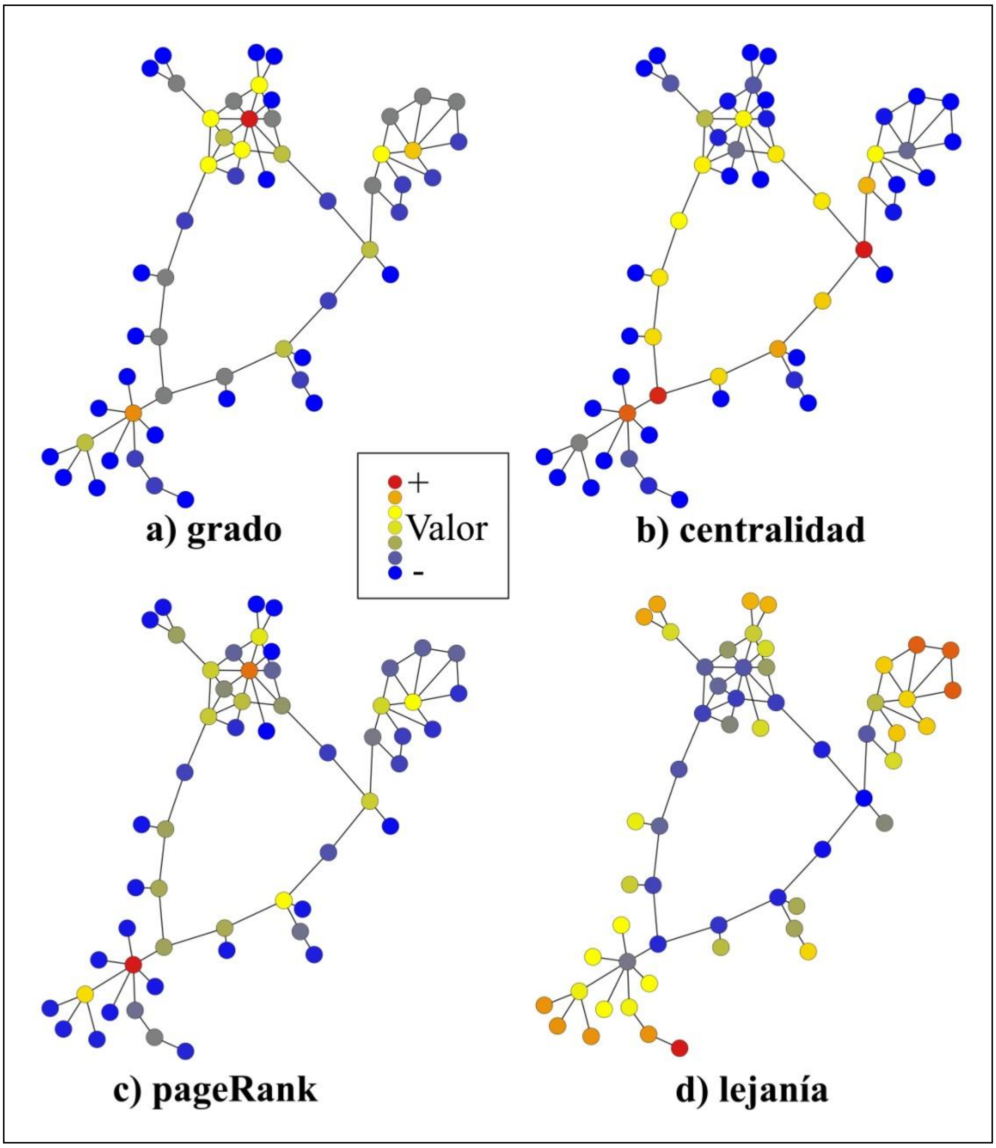
[13] No se procede a realizar computación basada en algoritmos de búsqueda en profundidad como Floyd-Warshall o dijkstra, sino que se calculan y transforman los autovalores de la matriz de adyacencia.

[14] Elemento distribuidor

podría asociarse a una medida de centralidad local, que no tiene en cuenta las rutas de navegación, sino lo compleja que es la topología de red en el entorno del puerto.

d) La característica de lejanía[15] indica qué nodos son de fácil acceso dentro de la red, y cuáles se pueden considerar periféricos en función del número de rutas disponibles para acceder a ellos. Es fácil asociar esta idea matemática al terreno del transporte marítimo. Los puertos con menor lejanía (y, por tanto, con mayor cercanía) son aquellos con una frecuencia alta de escala y son los más accesibles desde cualquier punto de la red.

Figura 1. Propiedades topológicas de las redes: algunos ejemplos gráficos



Fuente: Elaboración propia

[15] Closeness Centrality

En los tres artículos que componen esta tesis, la discusión en torno a los parámetros de red obtenidos, posterior a la transformación de la base de datos AIS en una estructura reticular, es el elemento fundamental que permite extraer conclusiones significativas sobre la evolución del tráfico marítimo de mercancías.

En el primer artículo, "Maritime degree, centrality and vulnerability: port hierarchies and emerging areas in containerized transport (2008-2010)", se realiza una exploración de la estructura de red conformada por las posiciones que la flota mundial de buques portacontenedores realiza entre los años 2008 y 2010. Se trata en este caso de un análisis de 861 posiciones (incluyendo posiciones de fondeo, estrechos y canales), 196.231 vínculos y 1.079 barcos, lo que supone de acuerdo a los datos de capacidad real de la flota mundial, considerar el 50% de la misma en actividad a lo largo de ese período temporal.

Es importante observar que una buena parte del artículo se dedica a la cumplimentación de las condiciones metodológicas para poder proceder a un análisis de Teoría de Grafos. En primer lugar, se muestra que el ajuste entre los datos reales declarados por las autoridades portuarias y el volumen de movimientos[16] estimados por el modelo reticular guarda una relación lineal con un ajuste de Pearson superior al 80%. Pero para poder hablar de una estructura reticular tipo *small-world* es preciso, además, que el grado calculado y la frecuencia acumulada de puertos con ese grado guarden una relación exponencial inversa de tipo $y=\alpha x^{-\beta}$, que se verifica con ajustes superiores al 85%.

La segunda parte de la publicación consiste en la ejecución del cálculo de las variables de red: grado y centralidad. Estos parámetros, sumados al volumen estimado de operaciones, consiguen determinar cinco áreas mundiales que han mostrado un especial desarrollo de las operaciones contenerizadas a lo largo del período considerado:

1) La emergencia de nuevos puertos de *transhipment* situados a lo largo de la línea de abastecimiento pendular que une el Este de Asia con el Northern Range Europeo (Ambarli o Tánger-Med).

2) El reforzamiento de las infraestructuras portuarias situadas en el entorno geográfico inmediato del Canal de Panamá, especialmente en el Mar Caribe

[16] *throughput*

(Kingston, Caucedo, Cristóbal-Manzanillo) y en la Costa Pacífica Mexicana (Lázaro Cárdenas), donde se está acometiendo la construcción de nuevas terminales y se está procediendo a exhaustivos programas de dragado, con la expectativa del aumento en el tráfico de buques *Post-Panamax* una vez que se pongan en funcionamiento las nuevas esclusas panameñas.

3) La Costa Este de Suramérica, impulsada, fundamentalmente, por el aumento de la demanda interna brasileña y por el aumento de exportaciones e importaciones con destino/origen a la Costa Este de Asia.

4) La Costa Oeste de África, donde una serie de países (Nigeria, Suráfrica) están procediendo a procesos exitosos de liberalización tanto en lo que respecta a la gestión portuaria como a la optimización de los corredores terrestres multimodales, lo que se traduce en importantes aumentos en los parámetros de red para puertos como Lagos o Durban.

5) Terminales emergentes de contenedores situados en Europa como Sines y Felixtowe. En algunos casos, los operadores han sido capaces de insertar determinadas áreas portuarias con un débil hinterland como eslabones fundamentales de cadenas masivas de suministro de mercancías de muy alto valor añadido, en base a una actividad de *transhipment* puro.

En conclusión, el análisis de redes complejas aplicado a una muestra que verifique determinadas propiedades de bondad de ajuste estadístico, es capaz de explicar cuantitativamente fenómenos económicos importantes de los últimos años como la emergencia de las economías del Hemisferio Sur en cadenas de suministro especializadas y la influencia que las obras del Canal de Panamá tienen en el desarrollo portuario de determinadas zonas geográficas, que albergan expectativas especiales de crecimiento en la cifra de negocio de sus puertos y de sus hinterlands.

El segundo artículo publicado, "General cargo and containership emergent routes: A complex networks description" realiza un análisis dual sobre dos muestras distintas AIS: una para buques portacontenedores y otra para buques de mercancía general. En este caso, se describió la dinámica global de los dos métodos de transporte marítimo entre los años 2008 y 2011. La hipótesis central a verificar era comprobar si la mercancía general no contenerizada había resistido mejor que la mercancía contenerizada la adversa coyuntura que el mercado global mostró a lo largo de ese período. Se trata de explicar el brusco descenso en la demanda de bienes de consumo de alto valor añadido por parte de las economías occidentales, y un momentáneo trasvase de modalidades de transporte contenerizado hacia otras formas de estiba relacionadas con el *break-bulk*[17] (paletizado, trincaje especial, modalidades mixtas de carga general/granel sólido).

Para verificar esta hipótesis, se estudió la evolución de seis redes complejas diferentes abarcando tres intervalos estacionales distintos por cada tipo de buque: [abril 2008, marzo 2009], [abril 2009, marzo 2010] y [abril 2010-marzo 2011]. Para buques de mercancía general se cubrieron 1.302 puertos, 304.604 vínculos y 1.654 barcos. Para portacontenedores se analizaron 536 puertos, 392.777 vínculos y 1.342 barcos. Metodológicamente, se comprobó que las redes construidas verificaban los requisitos de ajuste, tanto para la relación *throughput* real/*throughput* estimado como en lo que respecta al cumplimiento de la ley potencial inversa para el grado y su frecuencia acumulada. En este artículo se prestó especial atención a la definición y discusión matemática formal de los cálculos mediante los que se procede a la obtención de las numerosas variables topológicas extraídas de la red, entre las que están el grado y la centralidad. Esta cuestión es de interés debido a la controversia actual en cuanto a los diferentes procedimientos de cálculo aplicables para obtener el mismo indicador.

A nivel global se constata el drástico descenso en la capacidad de carga de los puertos de portacontenedores acontecida en el segundo período analizado, mucho más acentuado que en el caso de la mercancía general. Asimismo, la conectividad promedio desde el punto de vista del grado desciende en este mismo período (2009-2010) para la carga contenerizada, mientras que el grado promedio de la red de mercancía general asciende de manera monótona sin notar la crisis económica, lo que sin duda está relacionado con la baja elasticidad asociada a la demanda de cargas no contenerizadas (en numerosas ocasiones productos de primera necesidad). La centralidad promedio es donde la red de transporte contenerizado presenta un mayor descenso: mientras que para la carga general, la centralidad promedio de los puertos asciende ligeramente (aunque con un estancamiento en 2009-2010). La centralidad promedio de los hubs de contenedores desciende dramáticamente y retrocede en 2011 a niveles del 2008, lo que

[17] Carga general no contenerizada

está asociado no sólo a la crisis en la demanda de productos de alto valor añadido, sino también en la concentración de los movimientos de carga en cada vez menos terminales, más especializadas en *transhipment* y provistas de modernos dispositivos multimodales de intercambio y distribución de mercancías.

La segunda parte del artículo se centra en las visualizaciones de las redes complejas del transporte marítimo obtenidas mediante procedimientos informáticos denominados *force-directed*[18]. En base a la estructura obtenida se pueden delimitar tendencias económicas importantes que muestran lo importante que resulta para una autoridad portuaria mantener un buen equilibrio en lo referente a la oferta de servicios para carga general, es decir, es conveniente promover el tráfico contenerizado pero sin descuidar el hecho de que la carga general también evoluciona tecnológicamente y sigue teniendo un papel relevante en las economías de los países desarrollados. A nivel de geografía económica del transporte contenerizado, las conclusiones más relevantes señalan el importante descenso de tráfico de contenedores en algunos grandes hubs chinos. En lo referente al tráfico de carga general, el Golfo de México y el Este de Asia se configuran como las zonas más relevantes de mercado para este tipo de modalidad logística, y se observa un extraordinario aumento de la demanda de carga en varios puertos situados en el Mar Negro, alrededor de los Grandes Lagos y en ciertos puertos situados en el Golfo de Guinea.

En el tercer artículo, "Foreland determination for containership and general cargo ports in Europe (2007-2011)", se aplica la metodología de Teoría de Grafos para calcular la subred centrada en cada uno de los puertos individuales, y formada por las posiciones que están directamente relacionadas con cada uno de ellos, lo que se define como foreland de proximidad. El objetivo del artículo es visualizar la evolución de los movimientos de buques de mercancía general y contenerizada, pero esta vez, enfocándose no en los parámetros globales de red, sino en las relaciones comerciales que han sido capaces de desplegar (o inhibir) las autoridades portuarias a lo largo del período analizado.

[18] Este tipo de métodos de estudio de redes complejas consisten en transformaciones no lineales de la estructura algebraica inicial, basándose en los pesos gravitacionales de los nodos de la red, y en la carga de elasticidad (en el sentido de la Ley de Hooke) contenida en los vínculos que los unen (Hu, 2005; Burch et al., 2012; Kolaczyk y Csárdi, 2014)

Metodológicamente, el punto de partida sigue siendo la muestra global de posiciones de carga general, pero esta vez se generan tantas estructuras de red como puertos objetivo. El alcance geográfico elegido finalmente es el de los puertos del continente europeo, es decir, incluyendo Turquía y los países que circundan el Mar Negro.

En mercancía general no contenerizada, se muestra la preeminencia en volumen de operaciones de los dos grandes puertos del Northern Range (Rotterdam y Antwerp) y el papel central del puerto de Mariupol (Ucrania) en el transporte de mercancías incidente en el sistema portuario del Mar Negro. Es muy destacable la importante emergencia de la fachada del Atlantico Sur europeo, protagonizada fundamentalmente por las líneas de cabotaje Leixões-Vigo, Koper (Croacia)-Venecia, y por el foreland asociado al puerto de Batumi (Georgia).

Para las terminales de portacontenedores, se constata que los grandes hubs del Norte de Europa muestran estancamiento o decrecimiento en la intensidad y alcance de cada uno de sus forelands de proximidad. En cambio, varias terminales situadas a lo largo del Mediterráneo muestran un gran crecimiento, tanto en sus parámetros de red global (grado y centralidad) como en la intensidad y alcance de su foreland de proximidad, lo que es un dato especialmente relevante teniendo en cuenta la especial incidencia que la crisis económica ha tenido en los países a los que pertenecen esos puertos. Destacan el complejo turco de terminales situados en Ambarli, que se ha convertido en el centro de la actividad contenerizada de este país, caracterizado en los últimos años por importantes tasas de crecimiento económico. También es importante la ampliación de líneas comerciales que efectúan *transhipment* experimentado en los puertos italianos de Gioia Tauro, Taranto y La Spezia, que se han convertido en referencia para las grandes líneas de suministro procedentes de Singapur y los grandes hubs chinos. De nuevo, el puerto de Sines, con un hinterland débilmente estructurado y conectado, también se configura como hub contenerizado de referencia, tanto respecto al desarrollo de sus variables globales de red, como en lo tocante a la expansión de su foreland.

Capítulo 2. Maritime degree, centrality and vulnerability: port hierarchies and emerging areas in containerized transport (2008-2010)

Figura 2. Primera página de la publicación “Maritime degree, centrality and vulnerability: port hierarchies and emerging areas in containerized transport (2008-2010)”

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Maritime degree, centrality and vulnerability: port hierarchies and emerging areas in containerized transport (2008–2010)

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A R T I C L E I N F O

Keywords:
Complexity theory
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Port hierarchy
Scale-free network
Graph visualization

A B S T R A C T

The reaction to the financial and economic crisis has shown a new redesign of scenarios taking into account the changes made by maritime companies choosing different ports. In this research, containerized traffic evolution in 2008 and 2010 is described, both in big ports and geographic regions as from the emergent port activity areas. Database used is a sample of the world containership fleet movements that have called in some Chinese port in the years analysed. Calculus methodologies based on Graph Theory are applied to this set of data, able to give information about the global and local importance of a port given. Containerized goods transportation network have been contracted between 2008 and 2010 respect the port throughput, but there's no contraction in the distribution capacity of the main hub ports, which seem to have adopted commercial diversification strategies and foreland expansion. On the other hand, port emergent regions placed in the entrance and exit of Panama Canal will have important business opportunities.

1. Introduction

Maritime port policy should take into consideration the position of ports within the context of international logistical chains. In order to do so it needs to evaluate not only the flows of goods that take place between points of origin and destination, but also the behaviour and performance of the different actors and agents that have a role within this dynamic.

The evolution of flows of international commercial activity provides basic information as to the different capacities, infrastructures, and location of ports. Currently, however, there is not enough information to be able to carry out a simulation of the impacts that the economic and strategic decisions taken by agents have.

However, there are several pieces of research that examine the “proximity” of maritime ports (Hall and Wouters, 2010), and where the potential of maritime ports is subject to ongoing analysis (Olivier and Slack, 2006; Verhoeven, 2010). There is also a continuous stream of studies that look at the combined interaction of technological and economic developments, the influence of the internal demand areas, and the economic networks located around the ports and, the different elements and concepts related to how the ports are administered and managed (Brooks and Cullinane, 2007; Brooks and Pallis, 2010).

Globalisation has been associated with a growth in trade flows and therefore of maritime shipping. A port’s dynamics, whose perceived success depends on a context which is more commonly associated with marketing, is dealt with in this paper by looking at the level of activity of its area of influence and its position within global shipping networks.

Under this lens, it should be possible to analyse the structural changes that took place in maritime shipping networks in light of the financial crisis/recession of 2008–2010, using the China-related routes as the main criteria for sample selection.

This process gives rise to the emergence and, sometimes, the consolidation of new markets and geographical areas. In short, the development of new networks of maritime transport and the proliferation of logistical centres go to make up and encourage new forms of organisation.

The reaction to the economic and financial crisis has led to the redesigning of the maritime transport scenario. Symptomatic of these changes is the way maritime companies evaluate the selection of different ports. Aroenietis et al. (2010) provide a set of decision variables that refer to the choice of port: cost, connections, port capacity, reliability, port location, cargo base, flexibility, customer service, frequency, risk of loss/damage, and customs service. This set of variables will define the different business strategies for each agent whose aims are to minimise costs and maximise profits and, in so doing, increase the port’s market share and its positioning within the context of maritime trade routes. At this point, it is important to mention that there might be a difference between the academics’ view of how ports

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Fuente: Elaboración propia

Maritime degree, centrality and vulnerability: port hierarchies and emerging areas for container transport.

1. Introduction

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The objective of this research is to look at changes in the maritime network prior to and after the financial crisis, and to analyse the extent to which large ports have seen their position within the network change. The paper also tries to assess whether or not there are emerging areas of maritime activity that differ from those of 2009.

2. Background

The background approximation to the methodology and the results presented in this paper was made in four gradual stages. The first question taken into account, was to situate accurately in the starting moment of the analysis, using significant reference manuals able to deal with the main economic features of maritime transport at that moment. This kind of literature also often provides a valuable compendium of indicators that measure the economic climate and the temporal evolution of the main variables being studied. Chief among these are the works of Goss (1977) which provides a generic examination of some economic aspects related with maritime cost, fiscal and financial aspects, showing the influence between one specific port congestion and the global maritime transport scheme; Stopford (1997) is a fundamental reference which provides a wide view of the shipping transportation business and explains several aspects about the double direction linkage between the business cycles and the maritime transport activity; Branch (1998) contains an important overview of the main aspects of the economics of containerisation; McConville (1999) marks the limits of the methodology based in common statistical analysis for the study of the supply, demand, costs and port issues; and Freire (2009) contains an important amount of geographic data regarding supply/demand and freight distribution and a useful introduction to the current analysis of the relations existing between connectivity and port performance determinants.

A key work that led the analysis to a different stage, suggesting proper answers to the geo-logistical problem (the continuous measure of the efficiency of ports and maritime routes), was found in Rodrigue *et al.* (2009), which constitutes a comprehensive approach to the modern challenges of merchant transport, including the basis of the Graph Theory approach to the transportation networks. Some questions on the emergence of new portuary areas was already suggested in: Hayuth (1981), Slack and Wang (2002) and Notteboom and Rodrigue (2005), who emphasise the idea that the challenge of being on the periphery has been a spur to the proliferation of new ports and the consolidation of emerging port areas and regions. Also in Cullinane and Khanna (1999), showing that the concentration of goods at different points throughout the system favours an increase in the volume handled by certain loading points within a given region. Ducruet, C. (2009) has underlined the emergence of these areas within the European space. They also highlight trends towards the concentration, specialisation, and diversification in flows of traffic. Frémont and Soppe (2007) underline the fact that said concentration favours the establishment of specialist cargo centres, just as Notteboom (1997) indicated for the case of Europe. Research carried out by Hayuth and Fleming (1994), McCalla *et al.* (2005), Ng (2006), McCalla (2008) and Ducruet (2008) (1), take novel approaches from which to analyse the problem of the optimum location of hubs. Finally, it must be mentioned the solutions found to the specific problem of the maritime transport network models in the works of Fremont (2007), Kaluza and Kölzsch (2010) or Tavasszy *et al.* (2011), all of them worried about the measuring of different network parameters of connectivity and local importance.

3. Methodology

The methodology used in this research is based on the measurement instruments defined in graph theory. Thus, all of the positions or nodes, and all of the ships' trajectories from one node to another (edges) provide a system via which the measurements of maritime degree, centrality and vulnerability may be calculated. This multidisciplinary scientific area has come to the fore of late (Barabasi, A. 2009) after being successfully applied to the study of scale-free networks.

The analysis begins by using the data source to generate the adjacency matrix and from there, to calculate the aforementioned estimators. First, the degree is obtained (2), defined as the average of the incoming and outgoing connections to and from each port. The information obtained constitutes an important connectivity indicator, highly correlated to the operational capacity of each port.

Second, the centrality is calculated (3). This is defined as the estimator of a port's relative geographical importance, i.e. when considered to be at the centre of the lines of maritime transport. This article has considered a research strategy based upon the sum of the number of times that each port appears on the shortest routes whilst uniting any two ports.

Third, conventional statistical techniques are used to analyse vulnerability (Nystuen *et al.*, 1961). The vulnerability is obtained by calculating the maximum percentage of cargo that one port shares with another. Hence, those ports with lower vulnerability are those which are less dependent with respect to others located in their foreland. Establishing the links between this indicator and the throughput and a port's degree provides a novel perspective from which to view the dependency relations between the hub ports and the subsidiary ports.

However, in order for these indicators to be significant, the network must have a special structural feature, which Barabasi, A. and Albert, R. (1999) have defined in their seminal work: the power law between degree and frequency (scale free). In short, this work indicates that there are a few nodes where the concentration of connections is high in accordance with this power law.

Given that the analysis uses a measurement scale based on TEUs (and not upon geographical distance), a force based algorithm (Hu, 2007) is used for each of the samples analysed. This procedure consists of the separation of a given network by substituting the measurement for geographical distance for one that measures economic linkages (4). This method makes it possible to visualize the trade relations that exist between ports, and the possible change in the multiport regions within the area of influence, within the first period of the crisis (sample from 2008) and the last (sample from 2010)

4. Data source

The data base used is a sample of the movements of the world fleet of container ships that have docked at least once in a Chinese port in the years 2008 and 2010 (Lloyd's Shipping Register). The positional restriction of china guarantees a high degree of reliability when it comes to verifying a hypothesis regarding maritime container traffic, since China is the world's leading exporter of goods (table 1).

Table 1. China's share of world's exports and TEUs

	Millions of US$		Tons	
	Value	Share	Value	Share
China	989,283	21.9%	187,260	21.0%
Japan	432,677	9.6%	53,541	6.0%
South Korea	232,655	5.1%	44,763	5.0%
Germany	202,702	4.5%	24,184	2.7%
United States	197,914	4.4%	90,702	10.2%
Taiwan	176,168	3.9%	27,232	3.1%
Singapore	123,154	2.7%	9,951	1.1%
Thailand	114,401	2.5%	28,429	3.2%
India	100,213	2.2%	15,516	1.7%
Hong Kong	88,956	2.0%	10,816	1.2%
France	86,413	1.9%	10,780	1.2%
Malaysia	81,362	1.8%	20,120	2.3%
United Kingdom	81,183	1.8%	12,256	1.4%
Netherlands	80,538	1.8%	11,350	1.3%
Italy	77,237	1.7%	13,714	1.5%
United Arab Emirates	72,334	1.6%	5,968	0.7%
Indonesia	61,969	1.4%	24,915	2.8%
Russia	56,728	1.3%	9,000	1.0%
Brazil	50,952	1.1%	23,519	2.6%
Switzerland	49,579	1.1%	2,128	0.2%
Rest of World	1,164,887	25.8%	265,707	2980.0%

		Millions of TEUs	
Rank		Value	Share
1	China	26.2	25.2%
2	United States	10.2	9.8%
3	Japan	5.1	4.9%
4	South Korea	4.7	4.5%
5	Thailand	3.0	2.9%
6	Taiwan	2.9	2.8%
7	Germany	2.7	2.6%
8	Indonesia	2.7	2.6%
9	Brazil	2.3	2.2%
10	Malaysia	2.3	2.2%
11	India	1.8	1.7%
12	Saudi Arabia	1.8	1.7%
13	Italy	1.5	1.5%
14	Canada	1.5	1.4%
15	United Kingdom	1.4	1.4%
16	Vietnam	1.4	1.3%
17	Turkey	1.3	1.3%
18	Hong Kong	1.2	1.2%
19	Netherlands	1.2	1.2%
20	France	1.2	1.2%
	Rest of World	27.3	26.3%

Source: World Shipping Council 2009, IHS Global Insight, World Trade Service

For each cargo ship in the sample, all of the ports in which a ship docks during each voyage are taken into account. However, in the analysis, canals, straits and anchoring positions have been supressed since these might have been susceptible to information loss with respect to the points of origin and destination for certain trajectories (Ducruet, C., 2010b).

With regard to the total estimated capacity of the world's container fleet, the data base covers more than 50% of ships that exist (table 2). It is also important to observe that the study focuses on ships with an average capacity of 5,800 TEUs. This means that the analysis fundamentally refers to long range, high volume transportation services which normally have very special requirements for each stay in port, like fast and high automated transhipment facilities and cranes able to perform multiple loading and unloading operations along the vessel's deck.

Table 2. Sample break-down

		2008	2010
	Registered positions	91,832	104,399
	Docking ports or anchoring positions	584	861
	Number of vessels present in the sample	992	1,079
Annual number of positions for each vessel	Average	93	96
	Variance	38.65	39.22
Capacity in TEUs	Average per vessel	5,789	5,839
	Variance per vessel	2,061.66	2,116.80
	Maximum capacity present in the sample	14,000	14,000
	Minimum capacity present in the sample	364	364
	Total estimated throughput in the sample	5,742,924	6,299,803
	Estimated extant maximum world total*	10,925,419	12,367,723

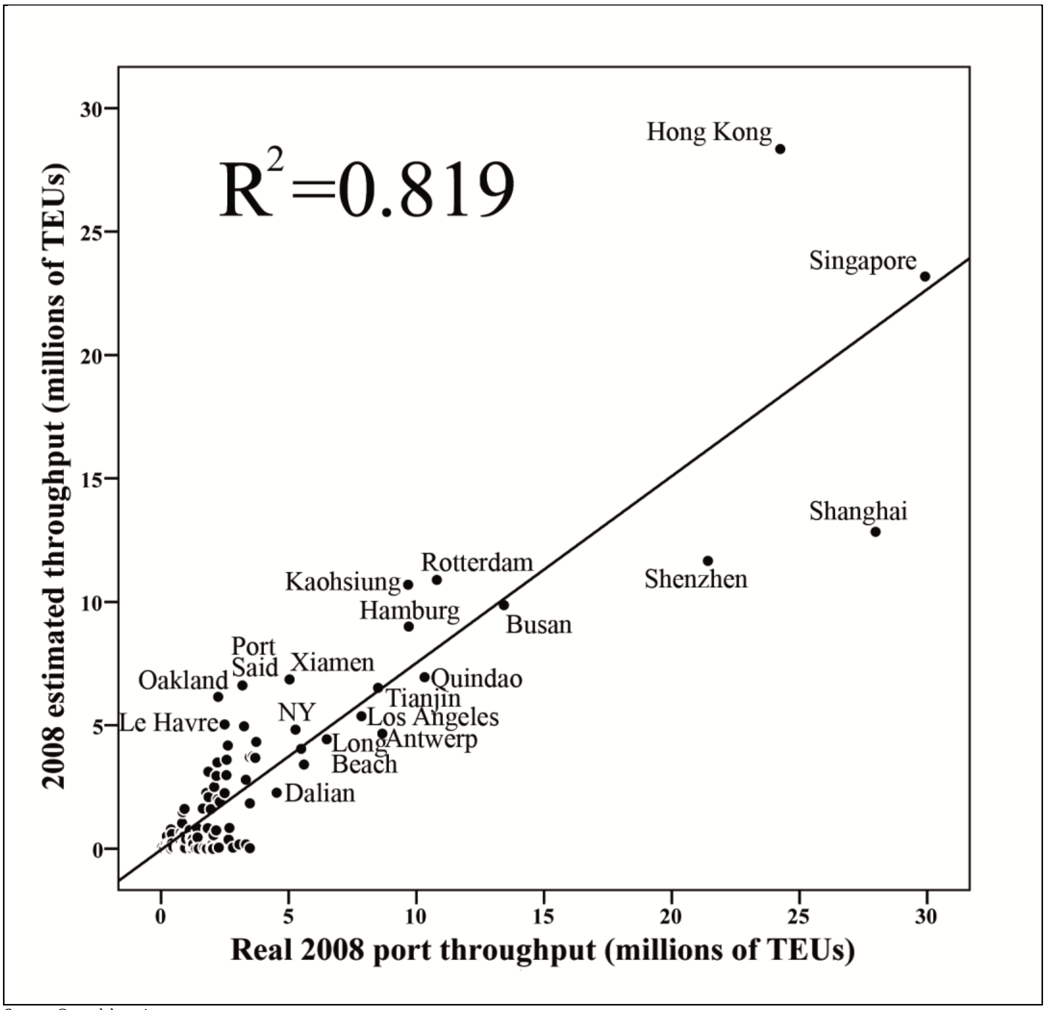
Source: Lloyd's Sea Web, own elaboration, *Barry Rogliano Sales Alphaliner

The annual number of cargo movements in each port is obtained by adding together the capacity of the vessels that have operated in each of the ports being considered. To this end, the estimated throughput of a terminal in a given period is added to the sum of TEU capacity (the size of the ship) for all vessels calling at this port during the period in question. This variable is closely related to the real TEU performance declared by each port, as can be seen in the lineal adjustment shown in figure 1.

According to Containerisation International –CI hereafter- real performance data, the estimated measure overvalues some ports, for example Oakland (2,045,211 real and 6,031,801 estimated 2008 TEUs throughput) or Le Havre (2,488,654 real and 5,039,757 estimated 2008 TEUs throughput). These differences can be explained by the special features of those routes, many of them connecting "...-Oakland-San Francisco Bay Anchorage-Oakland-San Francisco Bay Anchorage-..." or "...-Le Havre-Le Havre no.3 Anchorage-Le Havre-Le Havre no.3 Anchorage-...", and hence with an additive effect when vessels leave anchorage points. There are also residual cabotage effects in vessels of under 3,000 TEUs around these big hubs which need to be taken into account together with all of the above factors.

However, in the complete 2008 sample, which covers approximately the 50% of the estimated extant maximum world total, most positions are infra-valued, for example Antwerp (8.66 Millions of TEUs real, but 4.66 Millions of TEUs estimated), New York (5.26 real and 4.83 estimated) or Shanghai (28.00 real, but 12.83 estimated). This can be confirmed by analysing the distribution of Q=”quotient between estimated and real throughput data”, which gives an average value of 0.57, and a 80% of the sample infra-valued. A T-test designed for Q mean estimation, and executed over the entire available set of estimated and real 2008 throughput data, gives a probability of 98% that the estimated throughput of a port will be the 0.59% of its real performance. These facts, together with the 0.819 R^2 adjustment (in compliance of the precision criteria defined by Ducruet *et al.* (2010c)), and the homocedasticity of the two sources compared, define a statistically optimum environment to extract conclusions regarding the network dynamics analyzed.

Figure 1.Fit between the estimated and real data in 2008

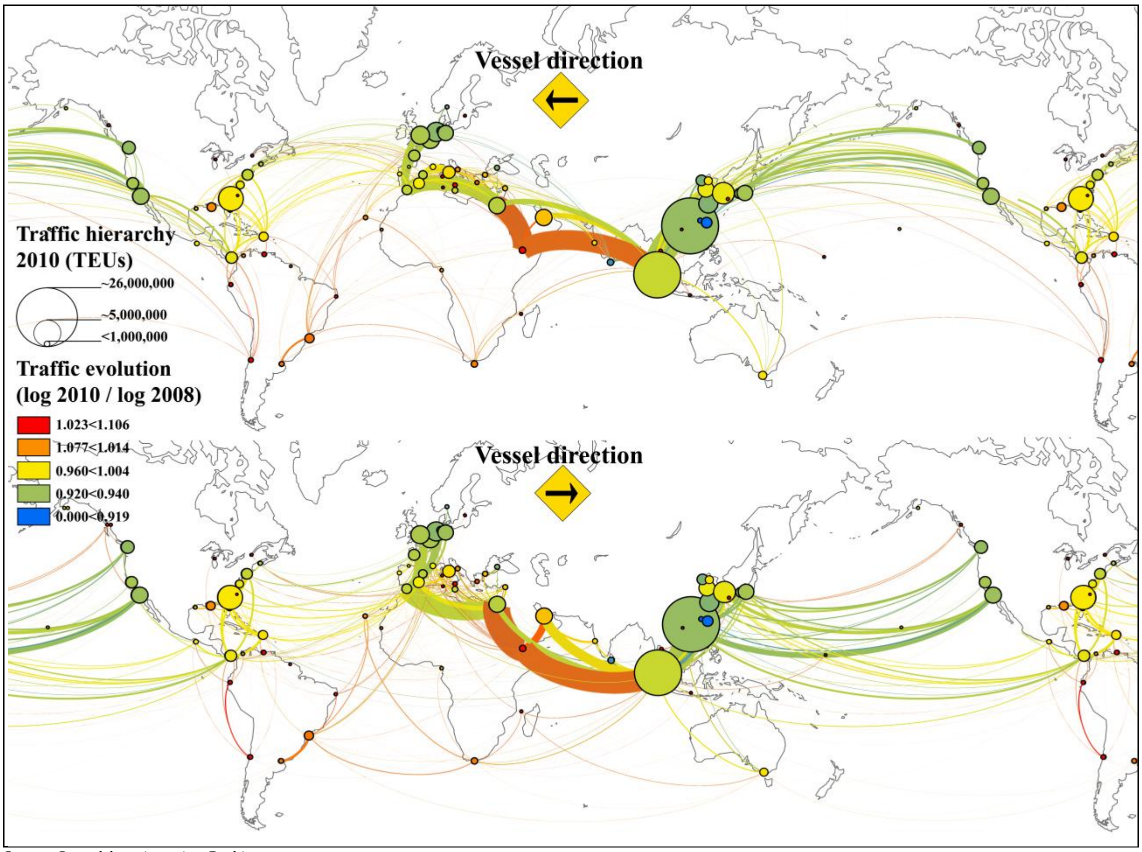


Source: Own elaboration

Figure 2 provides a cartographic representation of the sample data. This has been broken down according to the direction of the movements and by specifying the evolution of the capacity from 2008 to 2010 on each edge. One can see that there was a slight decline in the number of connections between the East coast of the United States and the European Atlantic coast. This does not mean that there was a decline in the importance of these ports however, rather that there was an easing of their connections with China. An even greater decrease occurred with respect to the transpacific connections linking East Asia with the Vancouver-Los Angeles-San Francisco line, and in the activity between the Mediterranean Sea and the Northern Range.

The only lines in which the movements of TEUs increased were the Singapore-Port Said connection and diverse low capacity services in the southern hemisphere. Some of the most prominent of these are: The Valparaíso-Guayaquil axis, located on the South American Pacific coast; the Santos-Buenos Aires connection which is an area where much activity is concentrated on the South American Atlantic coast; and finally, the supply lines that converge in Durban, the main South African port. Thus, there is evidence, which the analysis will attempt to verify, that suggests that the location of emergent port zones is logically linked to geographical regions characterised by intense economic expansion. This GDP growth during the 2008-2010 period is, according to IMF Database, focused mainly in Developing Asia (9.460%), Latin America and the Caribbean (6.083%), and Middle East and North Africa (4.408%).

Figure 2. Cartographic representation of the sample (China related maritime flows)



Source: Own elaboration using Gephi

5. Maritime degree, centrality and vulnerability

It's important to deepen into the topological structure of the transport networks considered, because of their intense double directional linkage with economical cycles. Thereby, they have a relevant role as precursors of economic development (Langdana, 2002), or as followers of the structural shifts of the economy (Rodrigue *et al.*, 1997).

Table 3 provides the results of the analysis for those ports with the highest capacities in the sample. The worldwide evolution of containerized trade reflects a general decrease in the volume of merchandise from 2008 to 2010, this being caused by a fall in the demand within the global economy which took place during the years considered.

The main indicator of this contraction is the drastic fall in the measure of operational capacity of the ports being analysed. Hence, the average volume of cargoes transported fell by 37%. With regard to the median figure, there is also a fall, in this case of 67%. This scenario also indicates that there are new ports that have gradually become incorporated within the international transport system but whose operational capacity measured in annual TEUs remains small.

Table 3. Main container ports according to TEU throughput. Statistical indicators, of degree and centrality

2008				2010			
Position*	**Estimated Throughput in TEUs**	**Degree***	**Centrality***	**Position***	**Estimated Throughput in TEUs**	**Degree***	**Centrality***
Hong Kong	28,339,881	76	4,214	Hong Kong	25,551,775	94	17,811
Singapore	23,177,455	76	4,924	Singapore	22,130,401	97	15,876
Shanghai	12,839,657	62	3,329	Shanghai	11,016,195	60	4,929
Shenzen (Chiwan)	11,661,098	46	1,267	Shenzen (Chiwan)	10,917,384	56	4,094
Rotterdam	10,888,200	51	2,451	Rotterdam	10,501,057	64	10,020
Kaohsiung	10.695.094	41	446	Busan	8.655.830	54	5.703
Busan	9.669.212	48	1.932	Hamburg	8.577.368	40	2.943
Hamburg	8.998.235	37	1.357	Qingdao	8.284.199	46	3.305
Qingdao	6.946.440	41	1.653	Port Said	7.169.764	73	7.837
Xiamen	6.857.669	34	536	Jebel Ali	6.296.650	53	5.672
Port Said	6.614.546	56	1.057	Oakland	6.031.801	36	4.643
Tianjin	6.518.506	34	910	Felixstowe	5.852.311	41	3.483
Oakland	6,151,248	24	915	Los Angeles	5,585,479	38	4,306
Los Angeles	5,372,459	20	100	Tianjin	5,443,507	29	1,349
Le Havre	5,039,757	33	817	Valencia	5,308,906	66	10,383
Felixstowe	4,959,296	29	376	New York & New Jersey	5,165,784	55	7,652
New York & New Jersey	4,826,162	47	2,208	Tanjung Pelepas	5,036,040	55	5,930
Antwerp	4,664,249	39	2,364	Le Havre	5,029,757	40	4,932
Long Beach	4,434,994	24	717	Savannah	4,884,932	28	1,514
Tokyo	4,327,513	22	293	Kaohsiung	4,803,834	42	1,768
Jebel Ali	4,304,485	46	2,118	Antwerp	4,699,815	46	5,802
Savannah	4,182,480	21	409	Kwangyang	3,927,557	25	1,108
Bremerhaven	4,049,124	33	1,464	Bremerhaven	3,775,153	37	3,614
Valencia	3,744,884	52	2,868	Long Beach	3,696,693	25	1,636
Colombo	3,685,635	42	1,234	Tokyo	3,580,735	24	1,048
Mean**	951,461	9	281	**Mean****	598,472	8	500
Median**	42,708	4	11	**Median****	13,987	2	6
Gini**	0.857	0.623	0.830	**Gini****	0.878	0.665	0.886
Correlation with estimated TEUs throughput		0.700	0.548	**Correlation with estimated TEUs throughput**		0.707	0.759

* Anchorage positions, canals and straits have been eliminated throughout the analysis

** Calculated for all of the ports within the network analysed

Source: Lloyd's Sea Web, own elaboration

What follows is an analysis of the degree and centrality of the samples. It can be observed that the average connectivity decreases by 1, from 9 to 8. However, the trend for this indicator is ascendant for certain ports, with considerable rises on the East and West US coasts (Oakland-Los Angeles and New York-Savannah axis), and in the entry and exit zones of the English Channel (Le Havre and Felixstowe, respectively).

The twin ports of Los Angeles and Long Beach, administrated by different Port Authorities but sharing quality and efficiency plans have some differences in their real TEUs throughput performance: a slight increasing in the case of Los Angeles (from 7.8 millions of TEU in 2010 to 7.9 in 2011) and a small decreasing in the case of Long Beach (from 6.2 millions of TEU in 2010 to 6.0 in 2011) (5). The behaviour shown in table 3 estimated TEUs throughput confirms this evolution for both ports. The positive variation in the L.A. degree (from 20 to 38) and the much lower evolution in L.B.'s (only from 24 to 25) indicates a possible cause for this difference between the adjoined ports: a much more successful connectivity improvement policies in the L.A. case.

Centrality tended to vary more than degree. On analysing the correlation between throughput and centrality, one can observe a positive link between the two. However, there is a group of ports which, despite handling high volumes, both in terms of trade and container transit, registers relatively low levels of centrality. There are three main reasons for this behaviour: the geographical distribution of incident routes (ports located in inland waters) or the temporary strategy adopted by lines during the recession, which consists of anchoring the oldest ships and keeping the newer, larger and more efficient ships working in a more geographically restricted set of routes.

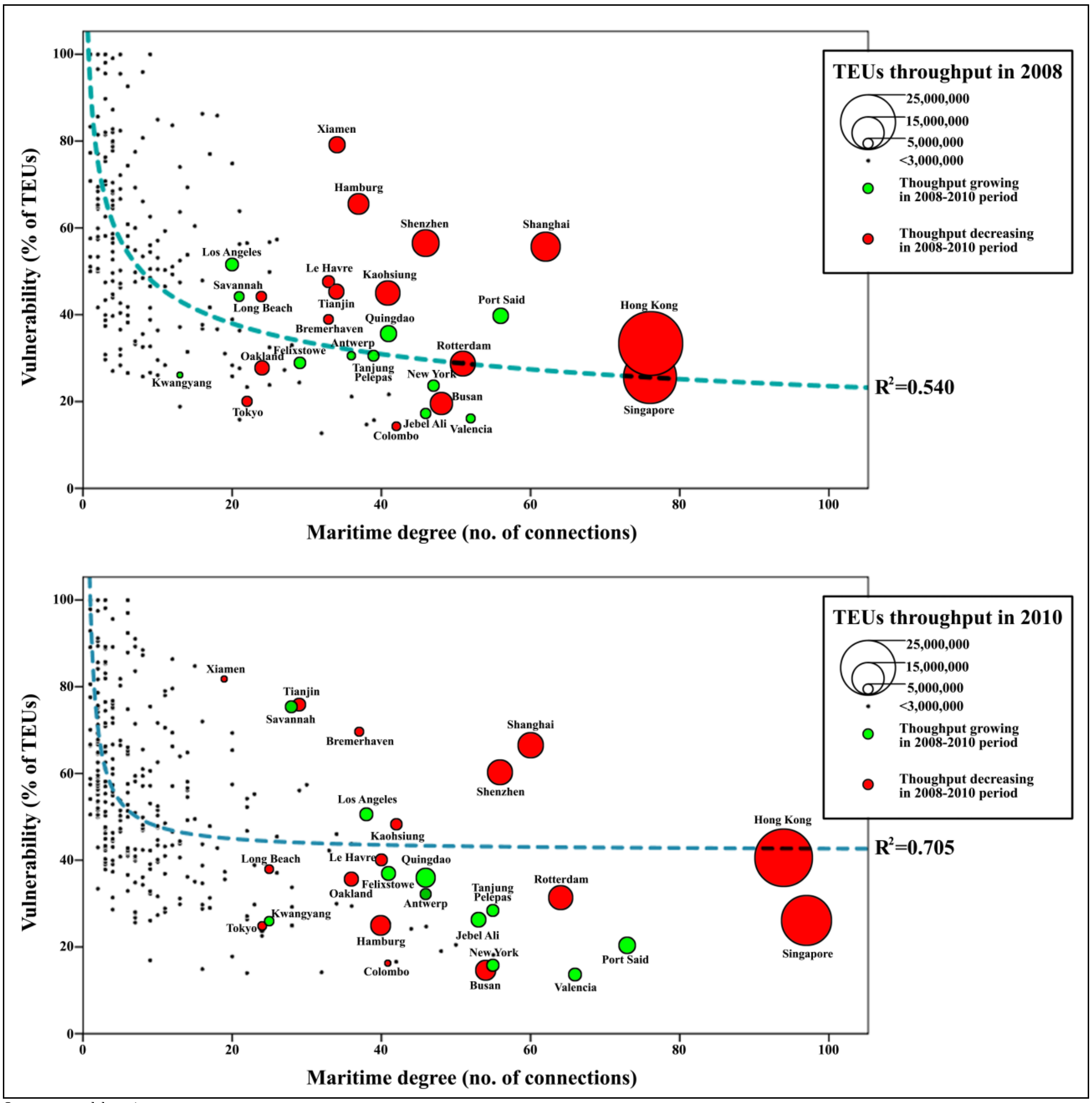
The most noteworthy cases of low centrality are those of the large Shanghai hub, whose activity appears to be focused on being a service provider for the new factory complexes along the river Yangtze rather than on the traditional activity for an international hub (Veenstra *et al.*, 2011); Shenzhen, a port complex near to Hong Kong, made up of the Chiwan, Shekou, Nansha and Yantian terminals; and Quingdao, an emergent entry port both for the Bay of Bohai and inland China (Moore, 2009; CI, 2010a). These three ports act as subsidiary distribution centres helping to create a highly central node or creating lines of restricted trade for a geographical space with special characteristics (Wang *et al.*, 2009).

With respect to the situation in Europe, the port area of Rotterdam-Hamburg is characterised by many of the features that help to explain the dynamic previously explained for the above Chinese ports. The relatively low centrality of the container terminals in Hamburg means that, on the one hand, it carries out a large proportion of its cabotage and subsidiary feeder rotations in Rotterdam (whose centrality is much greater), and, on the other, it must carry out all of these tasks upstream in the river Elba (an area in which it is logically more difficult to capture a greater variety in traffic).

Figure 3 shows the vulnerability of the ports that make up the structure being studied when compared to the degree. On looking at the world-wide structure laid out in the analysis, the volume of traffic for the two growing hubs of Valencia and Port Said in the Mediterranean really stand out: these evolved from 0.162 to 0.134 and 0.398 to 0.203 respectively. This means that there is an important opportunity with respect to the high level of diversification in the flows of transit/exports/imports originating, in the main, from Chinese-European trade, right at the departure point from the Suez Canal (Port Said) and in the entrance to the straits of Gibraltar (Valencia).

The area of Hamburg is the Northern Range port most seriously affected by the financial crisis, although it achieves an increase in degree of 3 units. It may be concluded that the port has managed to make up for this lack of throughput by increasing its levels of more geographically diversified traffic. In 2008 this dependency was 0.653, while in 2010 the score was markedly positive (0.250). What the directors of this port have partially succeeded in doing is severing the dependency on cabotage traffic with Rotterdam, by increasing the numbers of international supply lines.

Figure 3. Vulnerability and maritime degree2008 and 2010

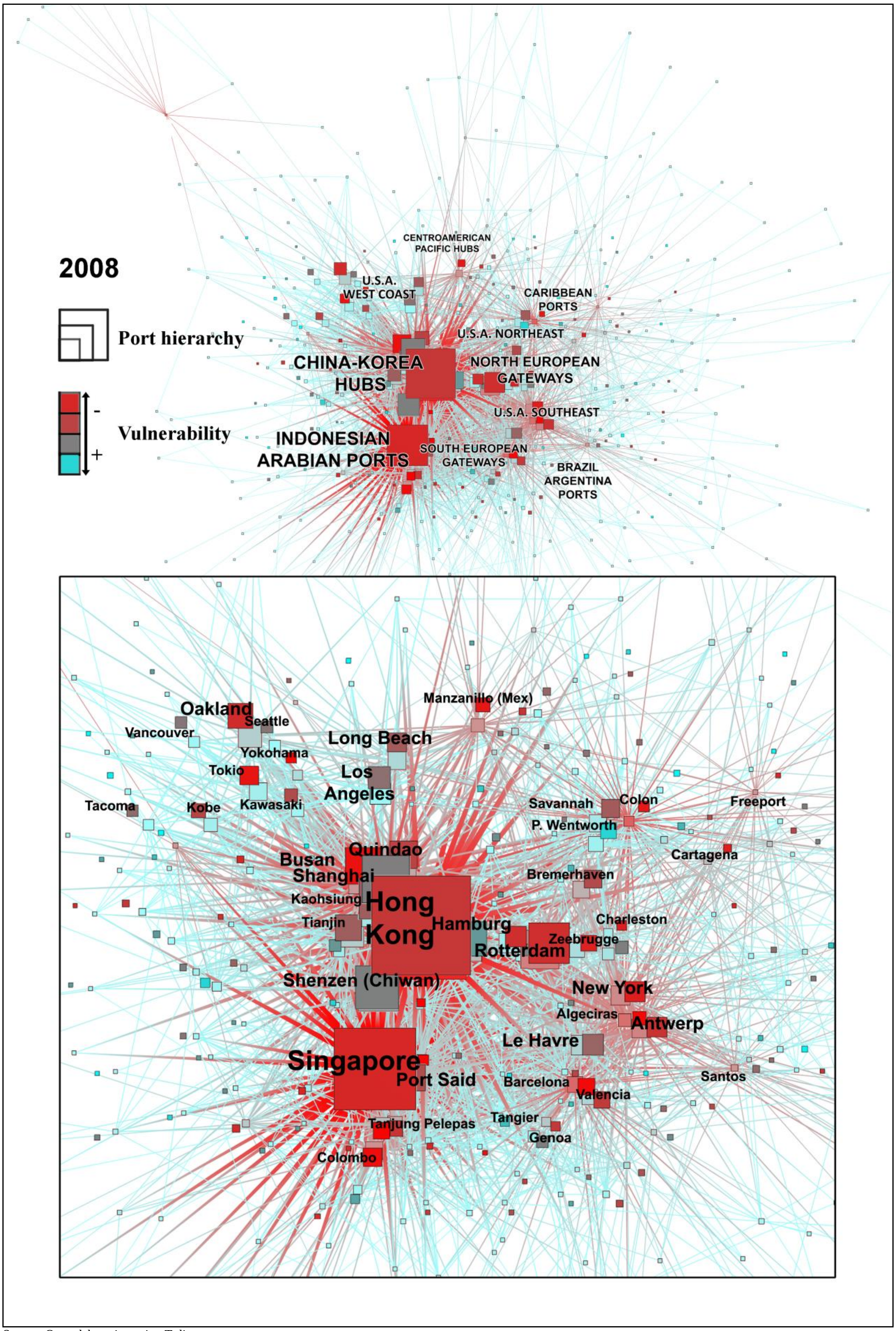


Source: own elaboration

6. Network separation structure

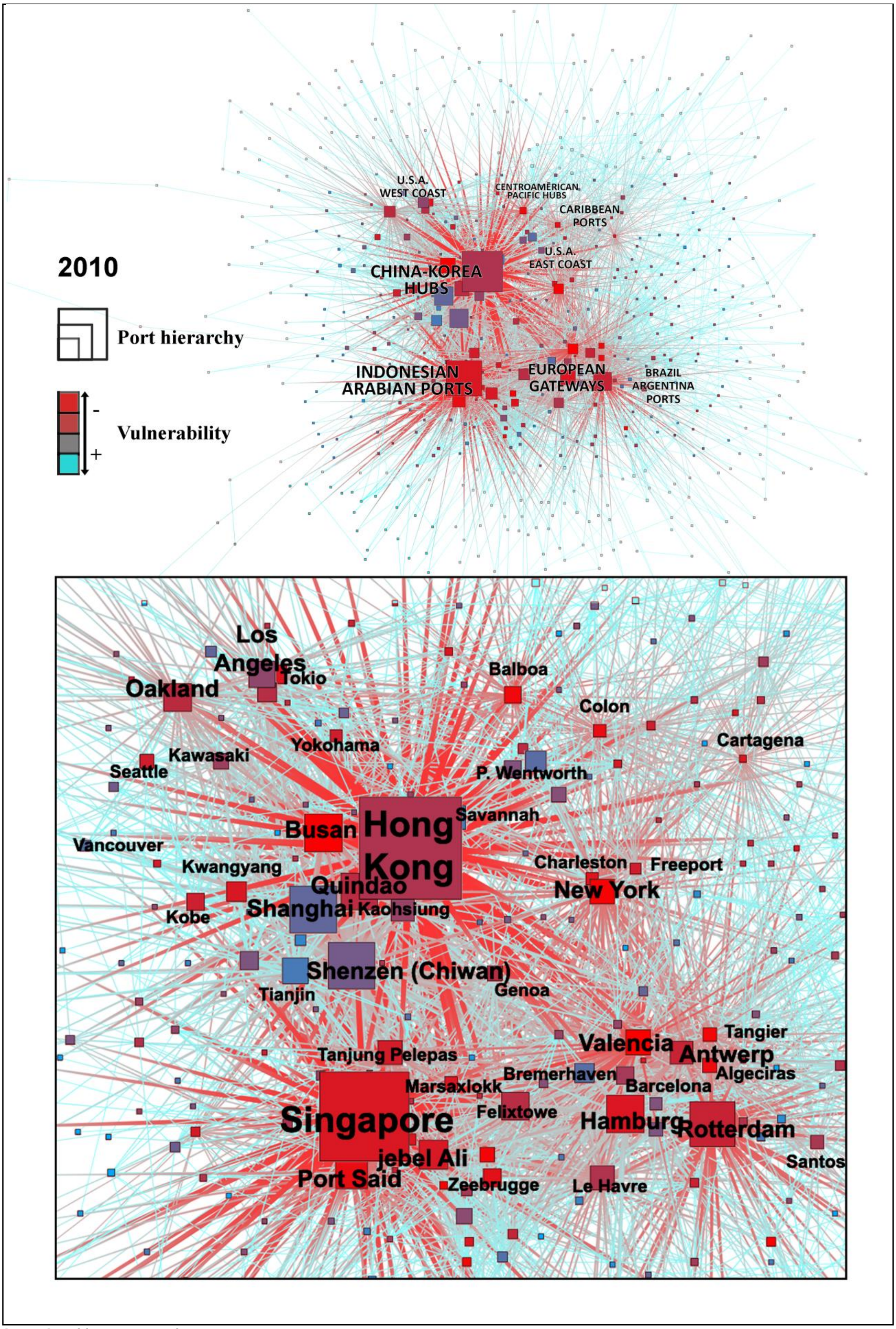
By using the Tulip software (Ducruet, 2010c), one can represent the graph being studied by defining a measurement system based on trade links, that is, the total quantity of TEUs shared between the two nodes. The application of the separation algorithm (Figures 4a and 4b), facilitates a vision of the commercially proximate regions, even when these are geographically distant.

Figure 4a. Separation structure using the centrality measure for 2008



Source: Own elaboration using Tulip

Figure 4b. Separation structure using the centrality measure for 2010



Source: Own elaboration using Tulip

Firstly, the above map illustrates that, during the crisis years, the Indonesian-Arabic hubs became firmly consolidated as priority ports for Europe, on par with the Chinese hubs in terms of connectivity and centrality.

Secondly, there have been changes in the patterns of supply of Chinese products on the east coast of the USA. In 2008 it was possible to observe a heavy flow of cargo coming from the European hubs. However, the exceptional evolution of the intermodal cargo transport network crossing North American soil has meant that the supply routes in 2010 have been organised via the Pacific, and this is reflected in the extraordinary development of the Oakland and Los Angeles hubs. These ports also share high levels of vulnerability, which indicates almost exclusive relations with the East coast of Asia, a connection which involves using the North American transcontinental rail crossing.

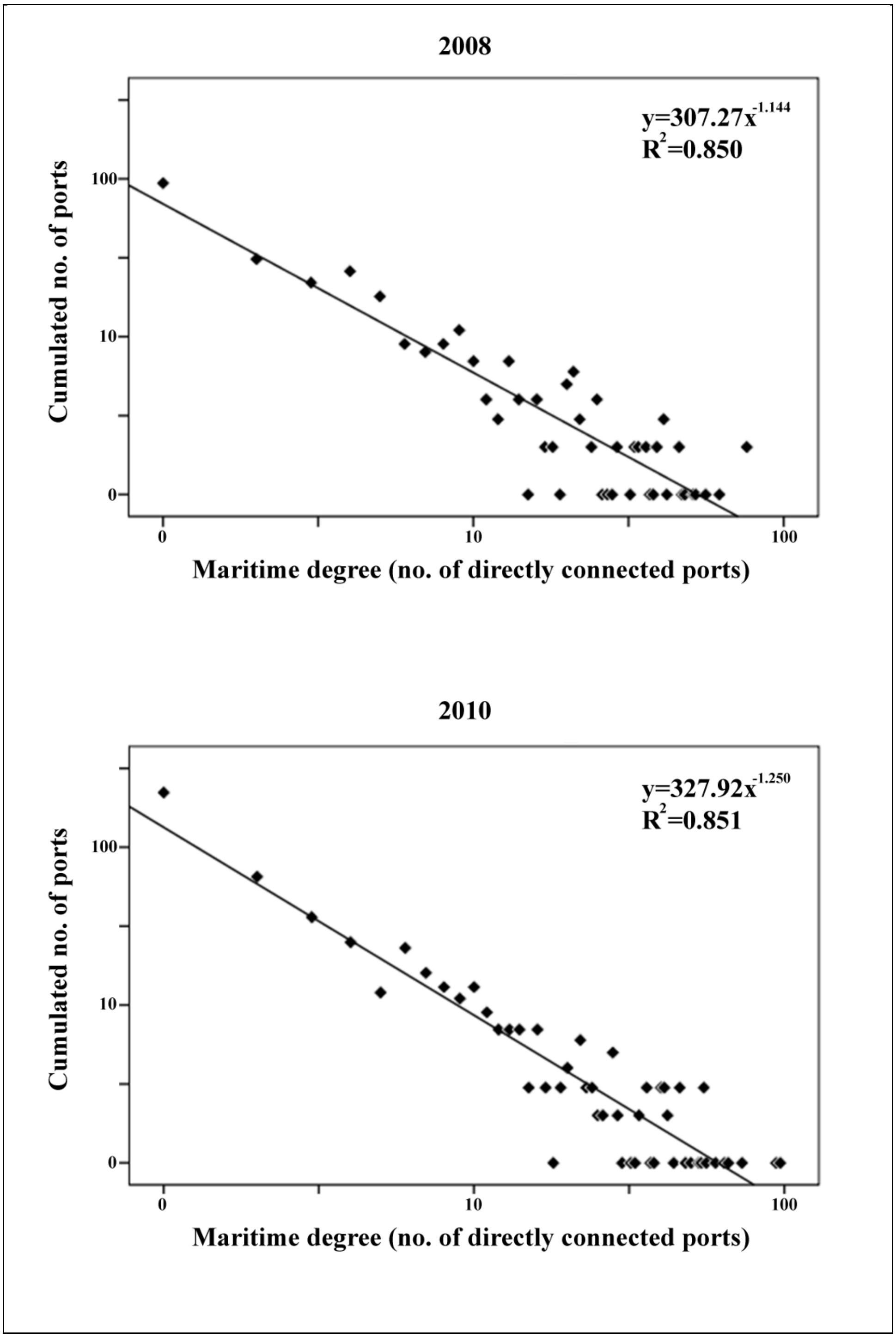
7. Structure of scale-free network

The degree calculated for each of the ports demonstrates a precise fit with the potentials law (figure 5). This confirms that the world wide containerized transport network is a scale-free structure composed of just a few highly connected ports, many of which have a connectivity which is close to 1.

The exponential of the regression obtained represents the magnitude of the integration of the nodes that go to make up the network. This means that the lower the value of the indicator, the greater the number of ports with a high level of degree. In this case, probably as a consequence of the new time/space divergences (Knowles, 2006) derived from the crisis, the coefficient has fallen from -1.144 to -1.250 (a repositioning of the world market), giving rise to a network in which the connections are concentrated in ever fewer ports. This implies that the crisis has led to an especially difficult period for those ports intent on increasing the number of operations involving container movements.

Currently, in numerous port installations, and, within the framework of the infrastructure investment stimulus plans carried out by the various states, numerous port operators have staked a great deal on a prompt recovery and a return to the dynamic that existed in times when there appeared to be an economic bonanza, when the exponentials demonstrated a positive trend (Ducruet 2010a), indicating an increase in the capacity of the ports to function as regional or international hubs.

Figure 5. Structure of the scale free network



Source: Own elaboration

8. Emergent ports

This section looks at the growing importance of certain ports within the framework of the main lines of containerized transport. There are, therefore, a whole series of port regions which, despite the contraction in demand, have managed to improve their operating capacity both with respect to the growth in connectivity with the other ports and in terms of their accessibility for the main lines of transport. In order to ensure the precision of the ranking shown, only ports were chosen whose throughput indicators, degree and centrality were above their respective medians (this means outliers filtering, i.e. ports possibly affected by calculus bias). The mean position in the Centrality and Degree ranking will give a measure of port emergency. The results can be seen in Table 4.

Table 4. Emergent ports in terms of centrality and maritime degree

Centrality and Degree growth - average ranking position	Position	Country	2010			2008-2010 Compound average growth rate	
			Estimated Throughput in TEUs	Centrality	Degree	Centrality variation	Degree variation
1.5	Salalah	Oman	939,614	1,817.4888	28	9.608	0.871
5.5	Lazaro Cardenas	Mexico	309,137	288.1131	13	4.730	0.612
7.0	Valparaiso	Chile	345,332	750.1363	14	3.411	0.871
7.0	Ambarli	Turkey	541,718	147.8270	16	3.711	0.789
10.5	Los Angeles	U.S.A.	5,585,479	4,306.3192	38	5.572	0.378
12.0	Sines	Portugal	760,871	405.1283	14	3.377	0.414
13.5	Dakar	Senegal	75,759	555.0362	13	1.939	0.612
13.5	Keelung	South Korea	539,306	447.7434	15	4.599	0.369
15.0	Buenos Aires	Argentina	1,067,017	981.8722	16	2.192	0.414
15.0	Ashdod	Israel	289,273	229.5009	9	3.901	0.342
17.0	Kwangyang	Taiwan	3,927,557	1,107.6425	25	2.476	0.387
17.5	Lagos	Nigeria	181,687	751.6019	12	1.928	0.414
19.0	Kawasaki	Japan	2,736,154	2,779.9354	34	3.380	0.304
19.5	Karachi	Pakistan	507,949	23.8019	7	3.328	0.323
19.5	Miami	U.S.A.	1,285,856	203.3093	14	7.933	0.247
23.0	Altamira	Mexico	473,966	202.7315	6	4.831	0.225
24.5	Durban	South Africa	1,063,138	1,446.6834	20	1.945	0.291
27.5	Sepetiba/R. de Janeiro	Brazil	542,166	1,508.7054	23	1.046	0.446
30.5	Kingston	Jamaica	905,241	3,426.1806	34	1.439	0.304
30.5	Tangier-Med	Morocco	2,286,878	5,969.7387	42	1.452	0.296

34.0	Cristóbal-Manzanillo	Panama	672,704	882.2958	22	0.818	0.563
34.5	Felixstowe	Great Britain	5,852,311	3,483.4143	41	2.043	0.189
40.5	Port Said	Egypt	7,169,764	7,837.0923	73	1.723	0.142
44.5	TanjungPelepas	Singapore	5,036,040	5,930.0340	55	0.976	0.236
47.0	Paranagua	Brasil	311,000	23.2758	8	0.802	0.265

Source: Own elaboration

According to the data obtained, and within the context of worldwide maritime container transport activity, there are 5 port development regions:

- Positions located along the pendulum services that link the coast of China with the European Northern Range: Salalah, which has set up a working APL terminal; Ambarli, which is already the leading container port in Turkey; Ashod (together with Haifa, the main Israeli port); Karachi, which has a recently-finished deep sea container terminal run by Hutchinson Ports Holdings; and Tanger-Med, a terminal located in the entrance to the straits of Gibraltar, which has succeeded in establishing itself as an important alternative to the competing port of Algeciras (Fossey, 2009).

- Positions located on the west coast of America and the Caribbean. There is evidence that the work being carried out on the enlargement of the Panama Canal will have repercussions for the port policies of certain hubs located in the Caribbean Sea or on the Pacific side of Central America (Ashar, 2010). Hence, the opening up of this channel for the passage of ships of over 5,000 TEUs will not only lead to the strengthening of round-the-world services, but will also reinforce the transhipment operations carried out by the hubs within the region. These hubs are strategically located in order to be able to distribute goods from both the East and West Coast of the USA towards the emerging economies of South America and even towards the ports on the European and African Atlantic.

  The ports in this area which have experienced the greatest increases, both in connectivity and centrality, are:

  - In the Gulf of Mexico/Caribbean Sea: Miami, Altamira (a serious competitor for what has been the main Mexican area of operations for container traffic in the Caribbean: Veracruz), Kingston (which is growing in importance as a regional hub at the expense of the more traditional terminals of Tampa, Mobile and Houston (CI,2009a)) and Cristóbal-Manzanillo (Colón, Panama) (CI,2009b).

  - On the West coast of America: Lázaro Cárdenas (a terminal which has become a serious competitor for its Mexican rival in the Pacific, Manzanillo (Fossey, 2010)), Valparaíso (which has major problems with traffic congestion (CI, 2009c) and Los Angeles (Dixon, 2009).

  - The two sides of the Panama Canal: the Caribbean Cristobal (position 23) and the Pacific Balboa (position 25) appear in this ranking as great growing nodes, improving their degree from 9 (in 2008) to 22 (in 2010) and from 36 to 55, respectively. The centrality in both ports also grows significantly, from 267 to 882 and from 2,058 to 7,170. This means that the strategy of the Panama Government regarding the Canal includes two strong Pure Transhipment Ports (PTP) just at the two entrances (Ashar, 2006), in order to compete with: relevant surrounding terminals (Mainly Buenaventura and Cartagena in Colombia, Puerto Limon in Costa Rica, and above all the big hub at Kingston); with the landbridge or minibridge activity joining East Asia with Europe or U.S. East Coast, respectively, via railway; or even with some future but real alternatives, like the Nicaraguan dry canal joining both sides of Centroamerica (Rogers, 2012) or the Artic Bridge (Rodrigue *et al.*, 2009).

- The East Coast of South America: the Argentinean port of Buenos Aires and the Brazilian ports of Sepetiba/Río de Janeiro and Paranagua appear to be emergent ports in terms of connectivity and accessibility, which makes up an important focus of development for container traffic in this area (Ward, 2009; CI, 2009d).

- Africa: The Senegalese port of Dakar, Lagos in Nigeria and Durban in South Africa, have, without a doubt, managed to take advantage of the circumstantial rerouting of many of the commercial lines which traditionally used the Suez Canal (Notteboom, 2012). These have come to form part of the new rotations with Asia for important shipping companies such as K-Line, thus searching for greater benefits from the emerging economies of scale in the internal demand areas associated with these ports (CI, 2010b; CI, 2009e). However, this means that the port installations must be adapted to these growing volumes of traffic in order to avoid increased congestion similar to that in the port of Lagos (CI, 2009f).

- There are two European ports that stand out from the rest, because of improvements in terms of degree and centrality and because of an annual increase in TEU capacity. The first of these is the recently-built Portuguese deep sea port at Sines, which was initially small but expanded significantly in 2010. This port might constitute an important node of high volume shipping, forming a connection with the East coast of Asia. The second is the port of Felixstowe, which is gradually becoming established as the main entry port for the area of demand dominated by London and its area of influence.

9. Relationship between principal and emergent ports

Figure 6 shows the evolution of the relationships that have been established between the main container ports and some of the emergent ports. This diagram only takes into consideration those routes that carry more than 8,000,000 TEUs. Subsequently, a FM^3 separation algorithm was applied using the Tulip programme.

It can be observed that the increase in the connectivity of the large ports, between 2010 and 2008, has fomented their interconnectedness. This reflects a change in global cargo distribution strategies to the rest of the world's ports.

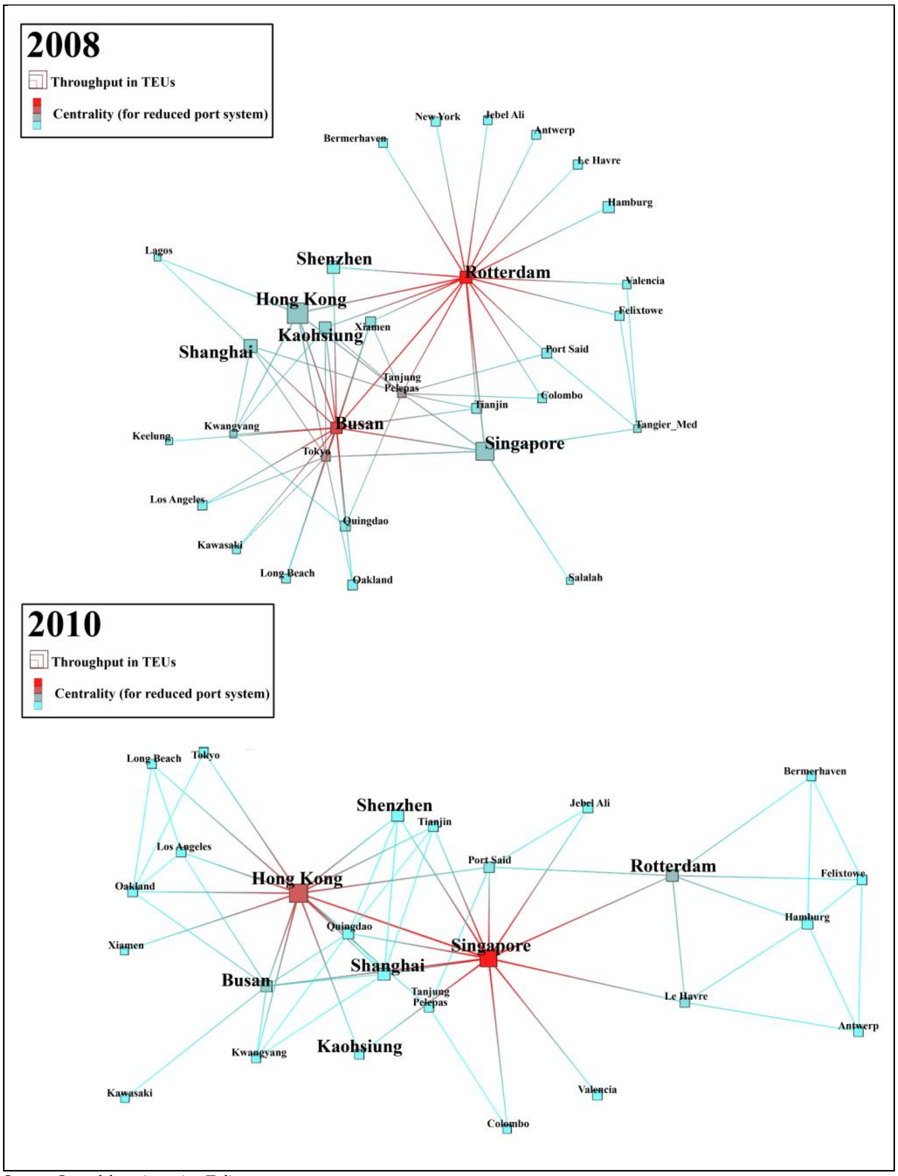
From the separation of degree obtained, the following may be highlighted:

- In 2008 the two most connective hubs were observed to be Rotterdam and Busan. However, in 2010, Hong Kong and Singapore had regained their primacy as mega-hubs.
- In 2008, the European ports appeared to have been subordinate to the transit originating from multiple terminals in the huge Dutch mega-hub. However, by 2010 the channels of communication with the Hong-Kong and Singapore axis

had diversified, leading to an increase in the prominence of Le Havre and Valencia.

In the diagram representing the global distribution of containerized traffic in 2008, the emergent ports still had a certain presence with respect to the interchange of goods in the big hubs: Lagos, Tangier-Med and Salalah appeared (although they did not play a central role).In 2010, at the mercy of the repositioning of trade activity analysed above, the emergent ports now focus on the distribution of transit and import/export container operations to other ports of similar or lesser capacity, which is why they have completely disappeared from the framework shown.

Figure 6. Dependency relations among big ports



Source: Own elaboration using Tulip

10. Conclusions

The most significant conclusions from the analysis carried out impinge upon two different areas: the methodology utilized and the results themselves.

Firstly, it may be observed that the combination of maritime degree and centrality allows the analysis to precisely determine the port hierarchy and the dynamic underlying how this evolves. Above all, if there is a detectable concentration of these parameters in certain port areas, this might condition the location of traffic within the global routes analysed. Hence, the maritime world of containerized traffic would become polarized within reduced areas and dominant hubs.

Secondly, in the phase of the crisis between 2008 and 2010, the throughput for the transport network of cargo container ships has contracted. However, there has not been a contraction in the main hub ports` distribution capacity. These entities appear to have adopted strategies that entail commercial diversification and the expansion of their forelands, in order to offset the fall in demand.

Thirdly, within this global logistical scenario, the mediation carried out by the Indonesian ports with respect to the movement of containers throughout the pendulum line of the East of Asia-Northern Range would seem to have been consolidated. This is probably linked to the low levels of activity that the container ships of over 10.000 TEUs demonstrate within the sample when compared to the movement undertaken by the Panamax and Post-Panamax feeder fleets.

Finally, the relative weight of emergent port regions located at the entrance and exit to the Panama Canal, reflects how logistical operators and those involved in port management positively evaluate the widening perspectives that will undoubtedly accompany the enlargement of this channel.

On the Atlantic side of South America and Africa, there are important indicators of economic recovery which are geographically interlinked. In the case of South America, the economic impetus of Brazil and Argentina has meant that the Río de Janeiro-Santos-Río de la Plata axis is an area which has seen notable increases in demand. With respect to Africa (Durban-Lagos port line), this emergence has been due as much to the rerouting of the China-Europe lines via the Cape of Good Hope, as to the growth currently characterising these countries. These ports might be benefitting from decisions related to slow steaming and policies that aim to minimize the effects of piracy and thus avoid the Suez, but this remains uncertain.

Footnotes

(1) The work of the team coordinated by C. Ducruet must be highlighted here, both with respect to obtaining relevant solutions to the problem of complex transport networks and for the care applied in the econometric analysis.

(2) Given the adjacency matrix (a_{ij}) of the graph made up of the positions p_i, the degree is defined as (p_i)= $\frac{\sum_j a_{ij}+a_{ji}}{2}$

(3) Given the adjacency matrix (a_{ij}) of the graph made up of the positions p_i, the centrality may be defined from various points of view, two of which are highly important, and give results that are very similar: a) On using the adjacency matrix: centrality (p_i)= $\max_{\lambda}\left\{\lambda \in \Re / x_i = \frac{1}{\lambda}\sum_j a_{ij}x_j\right\}$; and b) using the definition (calculation method used for this article): centrality(p_i)= $\sum_{s \neq v \neq j \in \{p_i\}} \frac{\sigma_{st}(v)}{\sigma_{st}}$, where $\sigma_{st}(v)$ is the number of the shortest trajectories that join ‘s’ and ‘t’ via ‘v’; and σ_{st} is the number of the shortest trajectories linking s and t

(4) The software used in the computation and graphical representation of the force-based algorithm was Tulip, the tool for the analysis of complex networks designed by Laboratoire Bordelais de Recherche en Informatique

(5) According to yearly TEUs evolution shown in L.A. and L.B. webpage statistical reports

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Capítulo 3. General cargo and containership emergent routes: A complex networks description

Figura 3. Primera página de la publicación “General cargo and containership emergent routes: A complex networks description”

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General cargo and containership emergent routes: A complex networks description

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A B S T R A C T

The paper aims to explain the evolution of the containerized and general cargo maritime routes in the last 3 years using complex networks analysis. Several particular results are searched: which ports are currently rising or dwindling in throughput; how is the structure of their network dynamics; and how to describe the resemblances and differences between these two transport patterns.

In a densely connected logistic scheme, like the current maritime transport network, classic statistical techniques cannot show an accurate measure of the regional and global importance of a port or a route, within the deeply interrelated global market. The influence of a given harbor must be put in relation with the whole set of the network nodes. Standard statistic tools also cannot explain the chronological evolution of a complex system such this, needed of an importance metric and a proper visualization treatment.

Graph theory provides powerful mathematical tools in order to achieve such requirements. Several calculations (degree and centrality) can be performed on each node, in order to describe clearly the structure and evolution of the complex system formed by ports of call and routes performed between them. Besides this, new software representation tools, like Gephi and Tulip, allow the immediate and deep comprehension of the relations between all the elements of the graph computed, and the temporal evolution of the whole network.

In this paper we will apply these methodologies to the entire database of containership and general cargo vessel positions in three periods: March 2008–February 2009, March 2009–February 2010 and March 2010–February 2011. The relevance of the time intervals for this analysis, in terms of length and immediacy, will lead us to an accurate and dynamic diagnostic for the evolution during the crisis years in the transport patterns of the two traffics considered.

1. Introduction

Precisely how, when, and the state in which developed countries emerge from the current economic crisis is the subject of intense debate. This controversy is reflected in the divergent macroeconomic data series forecasts obtained by different financial institutions with respect to trends in commercial trade. This data is being constantly updated and revised in consonance with the volatility currently buffeting economic scenarios.

The goal of this research is to provide evidence as to the way in which both general and containerized traffic has evolved between 2008 and 2011. According to data from UNCTAD (2010), containership transport has increased significantly since the 1960s when it first came to be an integral part of maritime trade. By the year 2005 the containership fleet already had a larger capacity than that of the general cargo class. Since then, this difference has increased until the present day when 8.48% of global deadweight tonnage (henceforth d.w.t.) is carried using general cargo vessels, while 13.26% is transported by containership. However, between 2007 and 2009 (UNCTAD, 2011) variations in the volume of orders for the building of the two types of vessels have been quite different. The number of orders for the former has increased by 13.91%, while, for the latter there has been a decrease of 43.34%. This information forms the basis for the hypothesis formulated in this analysis, namely that the crisis in demand has affected these two modes of maritime transport differently.

It would have been possible to verify this hypothesis by using statistical analysis techniques to express the features of each unit and then to carry out quantitative comparisons. It was decided instead, however, to use a technique that looks at complex networks. The main goal was to set out the interrelations that exist between a given port and the global set of nodes that exist

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Fuente: Elaboración propia

General cargo and containership emergent routes: A complex networks description

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It would have been possible to verify this hypothesis by using statistical analysis techniques to express the features of each unit and then to carry out quantitative comparisons. It was decided instead, however, to use a technique that looks at complex networks. The main goal was to set out the interrelations that exist between a given port and the global set of nodes that exist within the network. In order to do this it was first necessary to obtain a measure of the local importance of each port and a suitable visual representation of the complex network. The main thrust of the work carried out here is closely connected to the ideas of degree and centrality. These concepts allow the analysis to build a measurement framework which is capable of explaining a large proportion of both global and local activity for a certain position or geographical region.

2. Antecedents

There are various key contributions to the study of transport and complex networks. There are four complementary areas of knowledge used as the cornerstones of this work.

First, there is the economic theory that underlies marine and maritime analysis. There are many important contributions within this area, studies that often include swathes of economic estimators and temporal series and which provide accurate knowledge with respect to certain concepts such as the market for the sale of ships, freight indexes and the size of the active world fleet. So comprehensive are these sources, that it is sometimes rather difficult to isolate the main pool of information (UNCTAD, IMO, IMF, World Bank). Key works in this area include those of Goss (1977), Stopford (1997), Branch (1998), McConville (1999) and Freire (2009). A special mention should also be given to the approach undertaken by Rodrigue(2009) which is both encyclopedic and methodological and addresses the geo-logistical problems that are part and parcel of the modern challenges posed by multimodal goods transport. Hayuth (1981) and Slack (2002) on the other hand, look at new ports and emergent regions.

Second, the analysis also rests upon more specific works that look at the dynamics of port regionalization processes (hinterland-foreland interaction phenomena).These are important for the accurate economic interpretation of the market relations that exist in a given geographical area. Notteboom (2005) explains the working structure of ports clusters, and conceives of the current phase of activity as the extension of inter-port commercial relations beyond close-range geographical influence towards the foreland. The work of Fremont (2007) contains answers to questions thrown up by the polarization of the specialized Northern Range trade centers. Along similar lines, De Langen (2002) identifies port clusters as the main unit of analysis, while Hayuth (1994), McCalla (2005), Ng (2006) and Ducruet (2008) provide new perspectives from which to study the optimal localization of hubs.

Third, it is important to cite the works that deal with complex maritime networks. Ducruet *et al*. (2010a, 2010b, 2010c) and Kaluza *et al*. (2010) establish the basis of this methodology, both in terms of the definition of key concepts, the correct procedures for analysis and, the levels of rigor and precision of the quantitative techniques themselves.

Fourth, graph theory has also played an important role in clarifying some of the questions arising from the complex systems analyzed in other academic, theoretical and practical levels. The study of scale free networks, such as those analyzed in this research, constitutes a novel, innovative area of scientific knowledge. This discipline came into its own with the work of Barabasi (1999) and has recently become an important focus of multidisciplinary development. Different perspectives have included work on internet technologies (Franceschet, 2011), human mobility patterns (Gonzalez et al., 2008), social sciences (Eagle and Pentland, 2005; Pentland, 2006; Lazer *et al*., 2009), public health (Dey and Estrin, 2011), neuroanatomy (Joyce *et al*., 2010), information technologies security (Altshuler *et al*., 2010; Wang, *et al*., 2009) and economy (Hausmann *et al*., 2011).

3. Sample composition

The sample used in this analysis was obtained from the Lloyd's Register database for the geographical location of vessels and is known simply as the Automatic Identification System[1] (henceforth AIS). This database has been used by many authors to describe maritime transport trade networks for several different classes of vessel (Kaluza *et al*., 2010, Ducruet *et al*., 2010a, 2010b).

Table 1 provides the main features of the positions set used in the network analysis. Inclusion in the sample depended on criteria that looked at; the construction of vessels (from 1967 to 2009), whether or not a vessel was "in service", and a minimum size of vessel – a measure that aimed to eliminate coastal navigation and short-range maritime transport activity which would not be relevant for a global maritime analysis. Hence, only general cargo vessels over the average capacities (38,622 Gross Tonnage -

GT hereafter), and containerships of over 6,176GT were selected.

Table 1: Sample composition

Type of Vessel analysed	General Cargo			Containerships		
Time scope sample	April 2008 - March 2009	April 2009 - March 2010	April 2010 - March 2011	April 2008 - March 2009	April 2009 - March 2010	April 2010 - March 2011
Number of vessels analysed	1,515	1,578	1,654	1,164	1,231	1,342
Number of positions analysed	83,057	102,330	119,217	113,125	128,230	151,422
Average number of calls per year	54	64	71	97	103	112
Maximum vessel capacity	49,370 dwt	49,370 dwt	51,624 dwt	15,550 TEU	15,550 TEU	15,550 TEU
Minimum vessel capacity	6,179 dwt	6,179 dwt	6,179 dwt	1,104 TEU	1,104 TEU	1,104 TEU
Total fleet capacity present in sample	23,284,510 dwt	24,360,830 dwt	25,946,904 dwt	6,434,923 TEU	7,000,233 TEU	7,946,910 TEUs
Total world fleet capacity estimated*	105,492,000 dwt	108,881,000 dwt	n/a	10,760,173 TEU	12,142,444 TEU	n/a
Number of different ports of call (nodes)	938	1,232	1,302	330	536	390
Number of links between ports (edges)	8,857	12,487	14,181	2,511	3,355	3,057

Source: Lloyd's Shipping Register. Own elaboration. Review of Maritime Transport 2010, 2011 (*)

The sample was divided into three time periods. The first takes in April 2008 to March 2009 (08_09 henceforth). According to UNCTAD data, In terms of capacity, this period covers 22.07% of total extant general cargo vessels and 59.80% of the total current containership fleet. The second period from April 2009 to March 2010 (09_10 hereafter), saw similar proportions of the two types of vessels: 33.37% and 57.65% respectively. For the third period from April 2010 to March 2011 (henceforth 10_11), there is, as yet, no conclusive data. However, similar percentages are expected, in consonance with statistical accuracy.

The total number of general cargo vessels considered varied between 1,515 and 1,654 (08_09 and 10_11 respectively) while the numbers of container ships were 1,164 and 1,342 (08_09 and 10_11 respectively).

The increasing number of ports available for the general cargo class (938 in 08_09, 1,232 in 09_10 and 1,302 in 10_11) indicates that, even during a pervasive economic crisis, there have been a growing number of geographical positions that have begun to use general cargo transport. The scenario with respect to container-shipping is quite different; 330 in 08_09, 536 in 09_10 and 390 in 10_11 in which there was an important decrease in the number of ports of call registered. This does not necessarily imply that there was a decrease in activity for container shipping but a possible contraction in the location of containerized activity, as will be shown over the course of this article.

Each of the periods analyzed was subject to four refinement processes, or filters. The first of these involved removing all of the AIS positions for straits, channels and anchorages. While these data might be extremely useful for other kinds of study, they are useless for measuring the relevancy of ports in a given region. It is evident that the Strait of Malaca, and the Suez and Panama Canals are the main AIS positions for both maritime networks. However, these registered positions do not operate as commercial ports (Ducruet, 2010c) and are irrelevant, since the object of this analysis is to uncover economic and geographic explanations for maritime traffic. The most significant example of this, is the Hong Kong-Malaca Strait-Jebel Ali route, which we have termed Hong Kong-Jebel Ali, with the aim of expressing the relative real weight of the link between the two ports.

A second refinement consisted of eliminating all of the distortions that might have arisen due to the geographical proximity of terminals, as was the case of the sequence“…-Apapa-Lagos-Apapa-Lagos-Apapa-…” and “…-Pernis-…-Rotterdam-…-Pernis-…-…-Rotterdam-…”. These positions represent different locations within the same terminal; hence, presenting them as different ports would constitute a significant source of error. Therefore, the first sequence mentions only the "Lagos" positions, while the second contains only those of "Rotterdam".

A third refinement involved eliminating the ports that would have been repeated in different sequences. This measure aimed to avoid distortions with respect to the maximum capacity measured for each of the ports.

Lastly, connections were considered to be “undirected”. For example, this means that no distinction was drawn between the "GioiaTauro-La Spezia" edge and "La Spezia-Gioia Tauro" for example. This is essentially a methodological refinement linked to the lack of information in the AIS registries with regard to the real quantity of goods transported via the given route, since this is a datum which is highly illusive. This fine-tuning means that the maximum capacity of the vessel may be taken to be the most accurate measure of the quantity of goods transported.

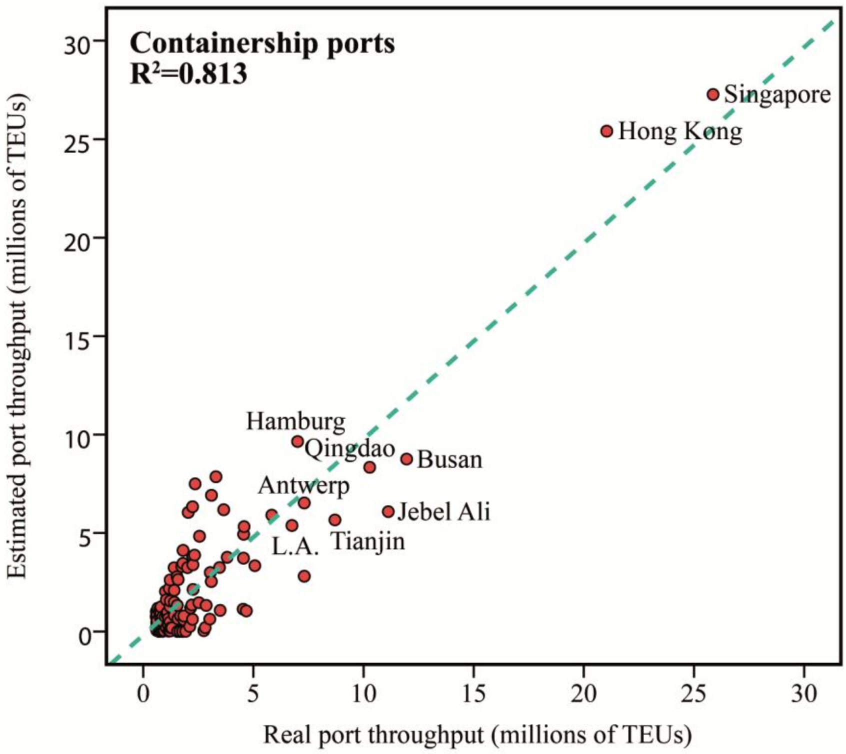
Once refined the initial dataset, graph theory is used in order to assess the behavior of each sample. It should be stressed that the relative weight of the traffic for a given port is computed by adding its total inbound and outbound capacities. In table 2 (figure 1) it can be observed that the lineal concordance between the estimated capacity in the 09_10 period and real throughput data for the same time period is relevant. The values obtained for R2 are 0.813 for containerized operations and 0.713 for general cargo.

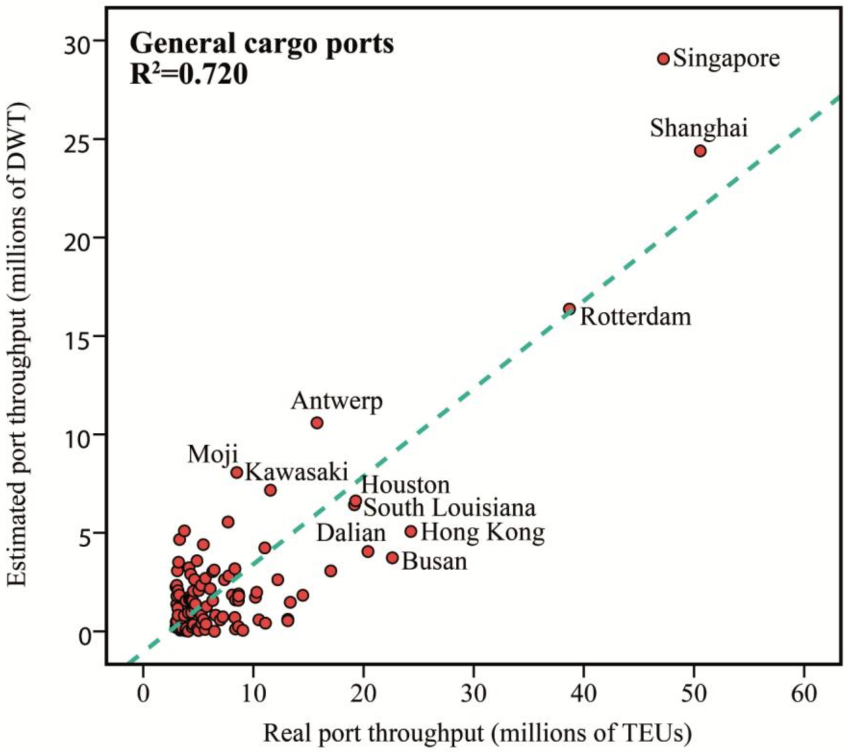
Table 2. Adjustment with real cargo data for the 25 main ports

	Main Containership ports			Main General cargo ports	
Position	**TEUs throughput estimated**	**Real TEUs throughput**	**Position**	**DWT throughput estimated**	**Real TEUs throughput**
Singapore	27,946,876	25,866,600	Singapore	30,917,648	47,230,000
Hong Kong	26,059,836	21,040,096	Shanghai	26,009,416	50,571,500
Rotterdam	17,063,396	9,743,290	Rotterdam	16,918,724	38,695,700
Hamburg	9,780,812	7,007,704	Antwerp	10,811,577	15,780,700
Chiwan	9,178,402	18,250,100	Tianjin	9,613,896	38,111,000
Shanghai	9,132,470	25,002,000	Moji	8,246,797	8,494,100
Busan	8,982,646	11,954,861	Yokohama	7,301,245	11,552,900
Qingdao	8,496,203	10,280,000	South Louisiana	6,956,156	19,285,300
Port Said	8,034,112	3,300,951	Houston	6,755,829	19,172,900
Savannah	7,527,376	2,356,511	Guangzhou	5,723,339	36,400,000
Felixstowe	7,054,050	3,100,000	Kobe	5,712,788	7,702,700
Antwerp	6,586,094	7,309,639	Durban	5,454,395	3,741,900
Le Havre	6,413,686	2,240,714	Hong Kong	5,378,904	24,296,700
Valencia	6,275,818	3,653,890	Saigon	5,085,851	3,300,000
Jebel Ali	6,266,933	11,124,082	Qingdao	4,667,818	27,430,400
Oakland	6,120,964	2,045,211	Mumbai	4,642,591	5,454,000
Tanjung Pelepas	6,025,101	5,835,085	Hamburg	4,274,736	11,038,100
Tianjin	5,827,235	8,700,000	Dalian	4,204,135	20,400,000
Los Angeles	5,563,492	6,748,994	Busan	3,893,833	22,618,200
Bremerhaven	5,356,191	4,578,642	Philadelphia	3,705,570	4,876,300
New York	5,028,793	4,561,528	Brisbane	3,597,662	3,211,900
Yokohama	4,943,881	2,555,000	Santos	3,343,201	8,319,400
Kwangyang	4,175,502	1,810,438	Tanjung Priok	3,298,679	4,154,600
Zeebrugge	3,907,294	2,328,198	Port Kembla	3,194,912	3,104,500
Kobe	3,881,413	2,247,024	Ulsan	3,130,577	17,031,400

Source: American Association of Port Authorities, own elaboration

Figure 1. Lineal adjustment with real cargo data





Source: American Association of Port Authorities, own elaboration

4. Methodology

The methodology used starts from the mathematical concept of networks understood as an ordered pair of two sets: one of nodes, and another of the relations between those nodes (edges).

Once the database has been cleaned and filtered, and the AIS positions (nodes) for each vessel class refined, the network structure is built up using a postgresql server. This platform allows the analyst to perform the procedures needed in order to define the adjacency matrix, a mathematical construct that contains information relative to the connected nodes and the weight of their links. In order to calculate the different indicators, the Gephi network analysis tool was used (Bastian *et al*., 2009).

Firstly, it should be underlined that the concept of density may be used as an accurate measure of the global interconnectedness of the nodes within the network structure. A graph has density 1 if all its nodes are connected to one another. However, in the case of maritime transport networks some nodes tend to act as regional distribution centers and, as such, display high levels of connectivity, while others act as mere stop-over ports and have relatively few destinations for their foreland (Fremont, 2007). Given a graph (V,E), where V is the set of nodes and E the set of edges, the density is calculated using the following formula:

$$\mathrm{Density} = \frac{2|E|}{|V|(|V|-1)}$$

Another robust, yet simple approach to network topology can be obtained using the concept of the average path length (henceforth APL). This indicator expresses the mean number of nodes needed in order to join any given pair of positions. When the APL decreases this means that there are more peripheral ports forming part of the kernel of the global supply chain and hence it is easier for clients to reach any position. The distance between two nodes v_i and v_j defined as $d(v_i, v_j)$ and the total number of nodes $|V|$ allow us to compute the APL:

$$\mathrm{APL} = \frac{1}{|V|\cdot(|V|-1)}\sum_{i,j} d(v_i, v_j)$$

An indicator which is widely used in this study is that of degree which is crucial to the computation of the network's centrality coefficients, and affords access to the main topological properties. Given the network (V,E) and $v_i \in V$, the neighborhood of v_i is defined as $N_i=\{v_j / e_{ij} \in E \text{ o } e_{ji} \in E\}$ where $e_{ij}=\overrightarrow{v_i v_j}$. Under these conditions the degree (or degree of centrality) of a node is the total number of connections that it has with the other nodes in its neighborhood, hence $degree(v_i)=|N_i|$.

In a random network, in which all the nodes have approximately the same number of connections, erasing one of the positions significantly increases the APL, and it is said that the graph is vulnerable to random perturbations. However, in the maritime transport graph which is a connected graph, there are many nodes that are not relevant, and their suppression has no effect on the apparent structure of global trade. There is a small set of central nodes that exist within these networks which is critical in maintaining the topology. These types of network constitute an emergent field of research in graph theory and are normally termed "small world networks". They can be detected by using the average clustering coefficient or ACC. Under these circumstances, given a node v_i and its neighborhood N_i (which is directly linked to the nodes v_j), the calculation of the ACC is carried out as follows (Watts and Strogatz, 1998):

$$ACC = \frac{1}{|V|}\sum_{i=1}^{|V|}\frac{2|\{e_{jk}\}|}{k_i \cdot (k_i - 1)} \text{ with } e_{jk} \in \{\overrightarrow{v_j v_k} \in E / \{v_j, v_k\} \subset N_i\}$$

The ACC is an indicator that reveals the presence of groups of self-differentiated (clusters) within the graph. If this value is computed for a random network made up of the same nodes, the resulting figure is much lower than that obtained for the (V,E) network calculation. This means that there exists a "small world network" for the graph being considered.

The other key indicator for this study is centrality, which, unlike degree, relates to the importance that the connections can have within the global scheme of paths and weights defined by the network, using this information as weighting criteria (Newman, 2008). Hence, a port with a high-level of centrality will be situated at the intersection of a large number of routes within the network, acting as a hub to the ports situated within its hinterland. When there are low values of centrality however, this does not necessarily mean that the market position is any worse (Ducruet, 2010a) but rather that the port has a special geographical location, located within an inner area of continental waters for example, or closer to positions which are much more important in terms of capacity.

Methods for calculating centrality are a branch of discrete mathematics, and one of the reasons for the entrepreneurial success of internet search engines which depend on algorithms to identify the most relevant pages for a requested search (Brin and Page, 1998). There are two main approaches to the calculation of the centrality of a given node. The first consists of performing algebraic transformations in the set of eigenvalues and eigenvectors for the adjacency matrix. This technique has been shown to be efficient in the resolution of problems related to networks that accept states of connectedness that may be more than simply binary relations (Bonacich, 2007).

The second approach, used in this research, is the idea of betweenness centrality (henceforth BC) (Freeman, 1997). This indicator counts the number of occurrences of a given port within the set of all the shorter trajectories connecting any two nodes. It is therefore, a "crude measure of the control that exerts over the flow of information (or any other commodity) between others" (Newman, 2008). It must be highlighted the recent works published by Puzis *et al.* on the algorithm methods for the optimal calculation of this indicator (Puzis *et al.*, 2010) or for to solve sensitive issues like the measuring of road traffic flow using mobile phones GPS data (Puzis *et al.*, 2012). The formula used in this article (Brandes, 2001) is as follows:

$BC(v)=\sum_{s\neq v\neq t\in V}\frac{\sigma_{st}(v)}{\sigma_{st}}$ where σ_{st} is the set of shortest paths from the node s to the node t, and $\sigma_{st}(v)$ the number of shortest paths from the node s to the node t passing through node v. In order to calculate these paths the Dijkstra algorithm is used (Dijkstra, 1959).

This indicator is utilized for environments in which there are problems of geographical or informational flux, where it is important to consider the question of the shorter trajectories visiting a given node and where there can be nonegative weights (Ducruet, 2010a, 2010b, 2011; Kaluza *et al*. 2010).

5. Topology of the general cargo and containerized networks

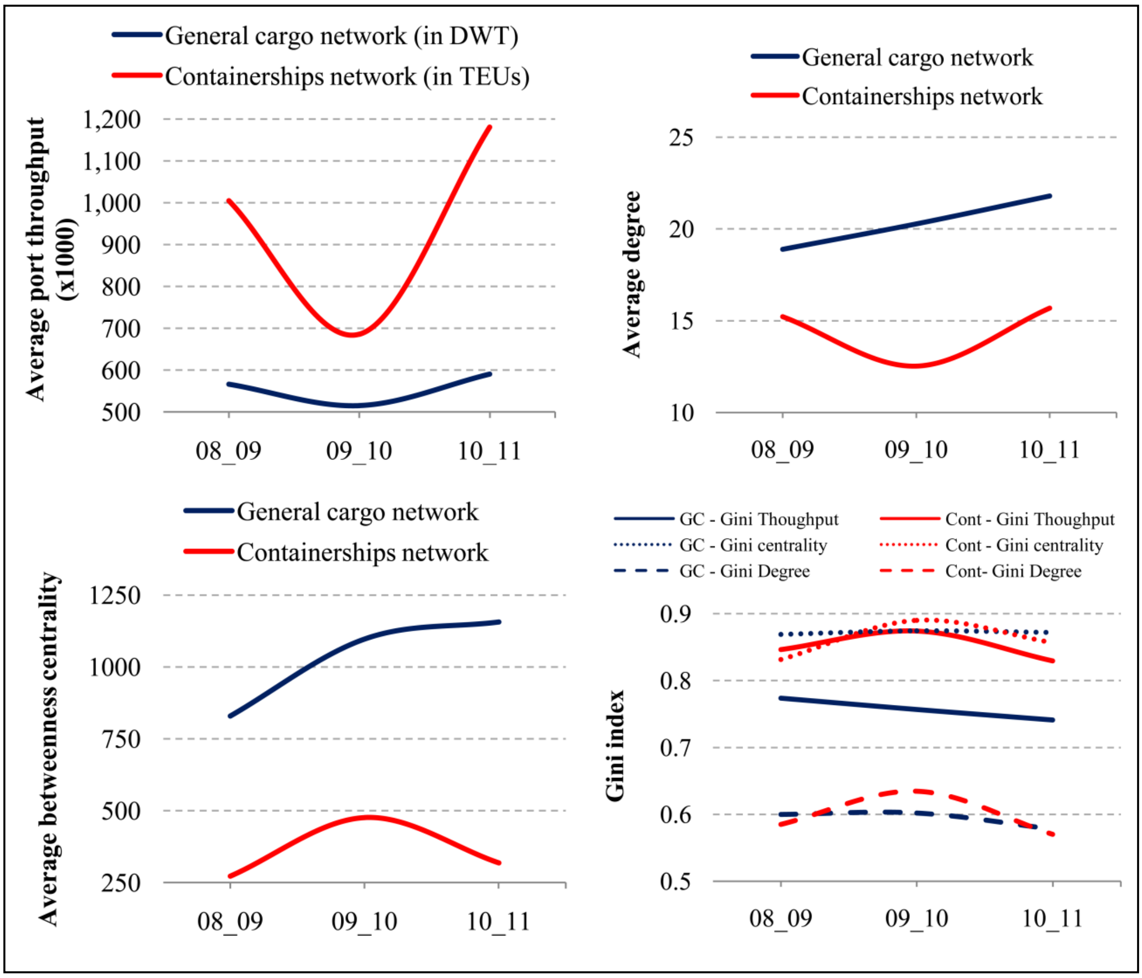
In table 3 (figure 2) the main topological features of the network are presented. First, the mean capacity of each port is analyzed. The variable reflects a recovery in both types of mode of transport. This increase was lower in standard cargo transport which rose by 4.2% during the period studied while the comparative increase relative to containerships was 17.48%. This difference suggests that containerized traffic operators reacted with greater impetus to the decrease in demand[2].

Table 3. Topological parameters of the networks analyzed

Type of Vessel analysed	General Cargo vessels						Containerships					
Sample	08_09		09_10		10_11		08_09		09_10		10_11	
	Mean	Gini	Mean	Gini	Mean	Gini	Mean	Gini	Mean	Gini	Mean	Gini
Throughput	566,594	0.7736	515,111	0.7567	590,430	0.7409	1,004,910	0.8464	685,875	0.8738	1,180,623	0.8293
Degree	19	0.5998	20	0.6020	22	0.5780	15	0.5848	13	0.6344	16	0.5701
Betweenness centrality	828.797	0.8691	1,097.291	0.8745	1,155.782	0.8719	272.552	0.8314	475.873	0.8900	318.980	0.8567
Maximum Degree	Rotterdam (302)		Singapore (376)		Singapore (416)		Singapore (128)		Singapore (171)		Singapore (152)	
Maximum Bet. centrality	Singapore (83,780)		Singapore (133,899)		Singapore (181,898)		Singapore (9,557)		Singapore (24,466)		Singapore (13,725)	
Normalized Bet. centrality	0.0098		0.0081		0.0063		0.0508		0.0194		0.0232	
Graph density	0.0200		0.0160		0.0170		0.0460		0.0230		0.0400	
Average Path length	2.7690		2.7827		2.7767		2.6568		2.7856		2.6399	
Clustering coefficient	0.425		0.426		0.418		0.581		0.629		0.593	
Diameter	7		6		6		6		7		6	
Radius	4		3		3		3		1		3	
Number of shortest paths	878,906		1,516,592		1,693,902		108,570		285,690		151,710	

Source: Own elaboration

Figure 2. Main topological parameters of the networks analyzed



Source: Own elaboration

Second, the analysis now looks at the way in which the mean degree changes. With respect to general cargo the indicator evolves positively throughout the period analyzed, indicating an enlargement of the foreland associated with each port. The scenario with respect to containerships was somewhat different. The foreland for these vessels contracted during the 09_10 period, but recovered and surpassed previous levels during the 10_11 period.

The centrality of general cargo ports has increased over the period analyzed, and the recession seems to have had only a mild impact on these firms. However, the sectoral crisis has affected a variety of processed products transported via containerships and this has meant that there has been a significant loss of mean centrality for the 10_11 sample ports when compared to the 09_10 period. In short, the general cargo terminals have had few strategic losses with respect to their forelands, while the containership terminals registered a local maximum in 09_10, which indicates that there are nodes whose growth has been significantly curtailed.

There is also an analysis of the betweenness centrality normalized with respect to its maximum value. This indicator facilitates a comparison between the two modes of transportation. The data for general cargo reflects decreases for the two periods considered of -17.34% and -22.46%. The decrease for containerized traffic, however, was of a magnitude of -61.81% in the first period with a slight recovery of 19.58% in the second. Therefore, the data clearly points to the fact that containership transport has been much more severely affected by the crisis in world demand.

Next, the graph density is analyzed in order to obtain the magnitude of the interconnection for each of the network nodes. The intermediate period 09_10 reflects a relative minimum for both modes of transport, and this corresponds to a key period in which there was a loss in the number of commercial links between ports. The situation improved during the last of the periods considered, thanks to an increase in the activity of the busiest routes.

Finally, the evolution of the Gini index provides a further perspective from which to view the network topology. This indicator reflects an increasing dispersion in the amount of goods transported (throughput) and in the scope of the foreland (degree), a tendency which is diametrically opposed to the proliferation of hubs (Ducruet, 2010a). It is always the containerships that glean the highest Gini values, which is consistent with the hub&spoke structure of this mode of transportation.

6. Geography of the network

An initial approach to a significant visualization of the networks studied can be adopted by using the geographical coordinates of each node. With the aim of reflecting any increase or decrease in the maximum capacity of the routes over the three periods analyzed, the logarithmic rates of variation (LRV) for the weight of each edge of the graph are computed. Figures 3 and 4 (table 4) represent the set of raw data corresponding to percentile 0.9, and aim to highlight the main trade flows. If we analyze the variation in the capacity of the routes it can be shown that, despite the stagnation (logarithmic rate of variation close to one), there are several lines in which traffic is increasing in both modes of transport.

The graphs show that, on the one hand, traffic across the Pacific Ocean is, in the main, containerized. This is due to the important weight of value added goods traded between both sides of this ocean. This contrasts markedly with general cargo transport, which is much more diversified and complex when it comes to loading, unloading and trans-shipment.

In contrast, trade via general cargo proliferates between the African and South American Coasts. The big hubs of the African West Coast (Lagos, Dakar, San Pedro, Douala, etc.) have not, as yet, become part of the globalized chain of container routes. Rather, their route takes them past the Cape of Good Hope, an alternative which has become increasingly important due to congestion and problems of piracy in the Gulf of Aden.

In the graph representing general cargo, one can visualize other areas in which traffic has increased significantly. The routes that stand out are the lines joining Valparaíso (Chile) with Callao (Perú) and the Panama port of Balboa; the Durban-East Asia connection; the entry to the Straits of Hormuz; and the New Orleans-Freeport (Bahamas)-Savannah line. The growth in America is closely linked to the forthcoming opening of new channels in the Panama Canal, which is promoting considerable improvements in the installations and draughts of several American ports[3].

7. Visualization of the Gravity model

There is a further method via which these logistical chains may be analyzed besides simply using geographical distances (Kaluza, 2010). The gravitational model applied to the vessel positions sample is based on the calculation of the force of attraction joining two given ports when the following variables from the graph are taken into consideration: capacity and the "weight" of the edge. The former represents the "mass" in the Newtonian model (which means that large mass exerts a greater gravitational force than a small one). The second variable measures the distance travelled between the two positions measured in terms of units of capacity transported; "distance" between masses in the Newtonian model. If the geographical network is allowed to evolve via algorithmic separation (Hu, 2005), the nodes and the edges become relocated in a state of equilibrium which is represented in graphs 5, 6, 7 and 8.

The dynamics of the evolution of general cargo from 2008 to 2011 (figures 5 and 6) are characterized by several significant changes. The most important of these is a perceptible de-clusterization or redeployment, the effects of which can be observed, for example, in the expansion of the Central-American region, where there are several strongly emergent areas of activity, and in the reinforced link between the East Coast of the USA and the Caribbean, South America and the African Atlantic coasts.

The two key axes of general cargo transport, Rotterdam-Antwerp and Singapore-Shanghai, have experienced an increase in the volume of their regional trade relations, characterized by links to a growing number of subsidiary ports. This suggests that current internal demand stimulus policies may have led the new big clusters to channel more port resources towards importation rather than exportation.

With respect to the connections between the former meta-hubs, there has been an observable reinforcement in supply routes via the Cape of Good Hope. The graphs also register the emergence of wide channels of communication via the Saudi port of Jeddah, and a strengthening of the connection between the East and West Atlantic coasts. Communications between East Asia and America have fallen off dramatically however (Singapore-Houston line), and only the line that joins Guayaquil-Valparaíso to the Asian side of the Pacific Ocean remains.

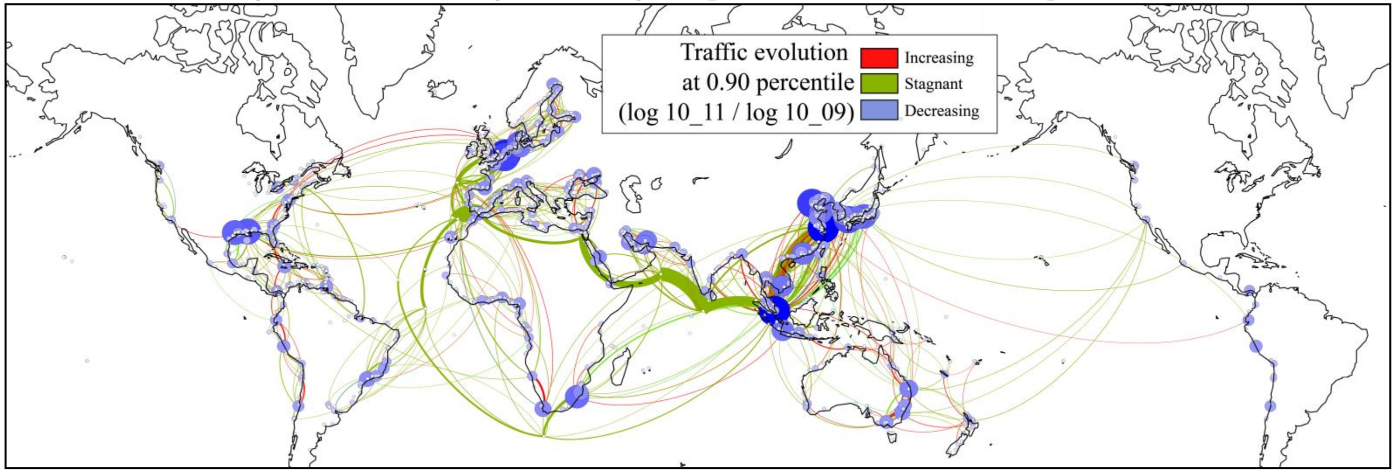
The issues concerning graph density and the clustering coefficient mentioned above are clearly observable in the comparison established between the containership graphs (figures 7 and 8) and general cargo. The containerized trade network is demonstrably denser, due not only to the lower number of ports required for this mode of traffic, but also because of the intensity of the clusterization.

In the graph showing general cargo, three large clusters can be distinguished. This contrasts with the structure for containerized transport in which there is a clearly ring-like configuration with only a single entity exerting a powerful force of attraction: Hong Kong, Singapore, Rotterdam and all its dependent ports. The US East Coast appears to try to use its economic potential to attain the status of an independent hub, but the link between East Asia and North Europe remains the principal conglomerate for the whole of the containership structure. This said, there does exist a powerful link between the port line of Vancouver-Los Angeles-San Francisco (West Coast of North America) and the East Asian hubs. This data suggests that the main supply routes for the US East Coast are the intermodal lines that transversally cross the country. This result reveals an area of potential future research which would aim to clarify how this railway transport structure will be affected when the new locks for the Panama Canal are opened. By referring to the separation graph it may be conjectured that the change will be both profound and global in nature, strengthening trans-world services and augmenting new clusters which are currently emerging. The most significant routes within this context are the supply line between the Caribbean and Santos-Buenos Aires, the West Coast of South America, and the new containerized trade area in the Middle East.

Using the information available it may be observed that containerships always sail from the East Asia hubs to the Northern Range, using the Singapore area as a trans-shipment service. What also stands out is how important the Middle Eastern ports of (Jeddah, Jebel Ali, Port Said, etc.) have become over the previous year. During the crisis they have been transformed into wealthy commercial intermediaries, generating their own demand structure and supplying a growing volume of goods to the Mediterranean and Black Sea ports, which are, in turn, immersed in their own intense regionalization processes.

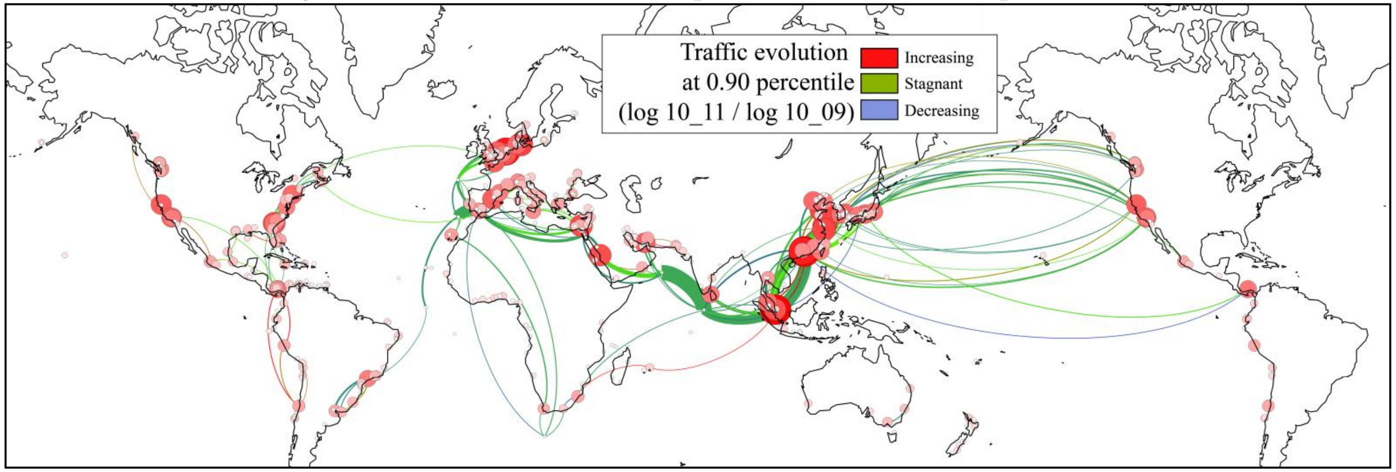
Each of the network diagrams includes the relationship between each nodal degree and its aggregate frequency. In the four graphs, it can be observed that there are high frequencies for nodes where the level of degree is low and low frequencies for positions with high levels of connectivity. If the relationship between these two variables is consistent with a power law, then the networks are referred to as "scale free" networks. The exponent of each of the resultant power laws is a measure of the polarization within the system, that is, between the higher connectivity ports and subsidiary positions (Ducruet, 2010c). The precision of the “fit””’obtained in the cases analyzed in this article is very high. For general cargo, the evolution of this exponent is from -1.301 to -1.344, which means that there is an increase in the level of integration between each of the port regions analyzed. In contrast, in containerized networks, the exponent evolves from -1.183 indicating the emergence of new alternative hubs.

Figure 3. Routes for general cargo ships in 10_11 from the 0.90 percentile



Source: Own elaboration

Figure 4. Routes for containerships 10_11 from the 0.90 percentile



Source: Own elaboration

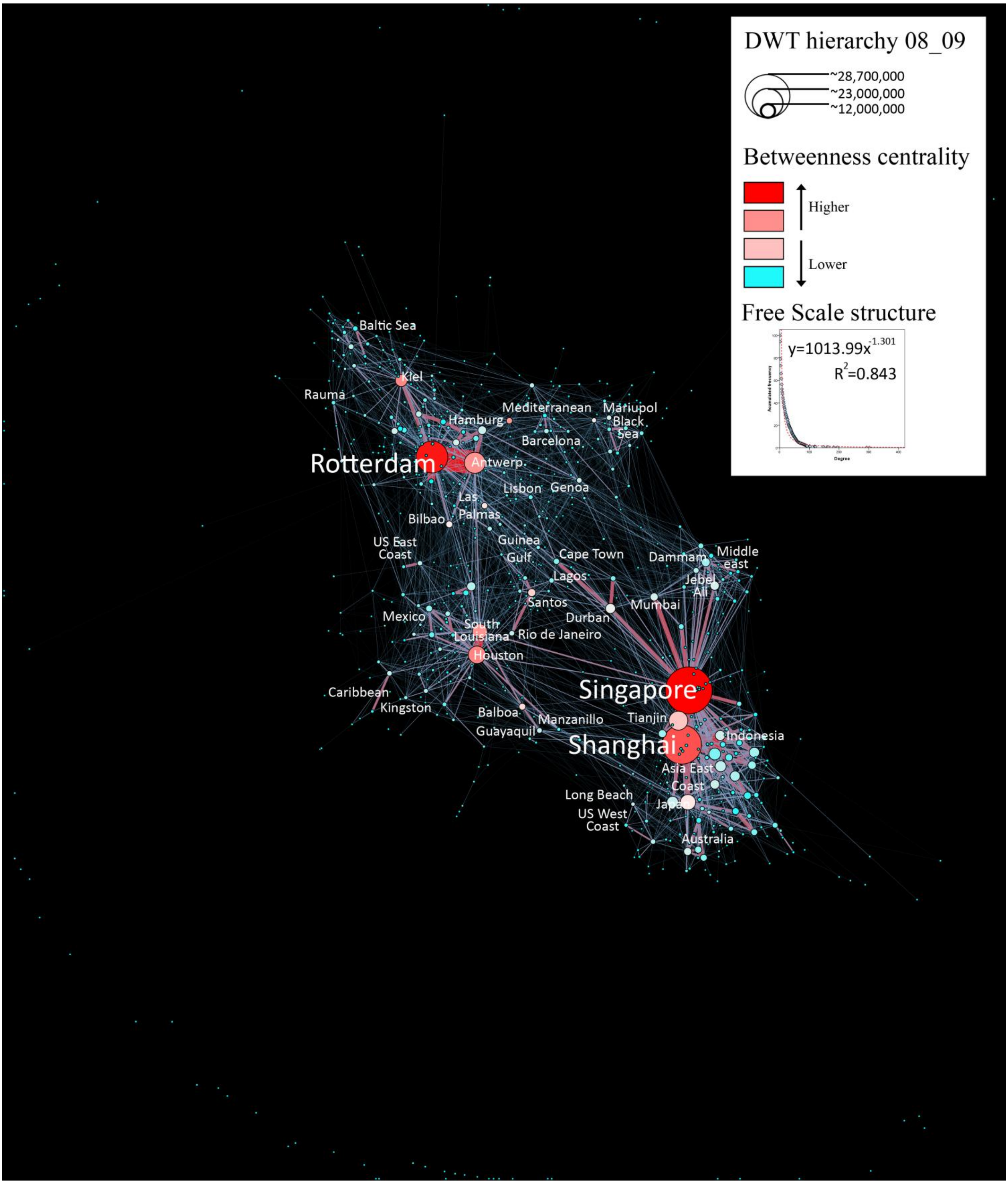
Table 4. Top 25 Routes (edges) with more logarithmic rate of variation (LRV*)

General Cargo routes				Containership routes			
Position 1	Position 2	Edge weight (TEUsx1000)	LRV	Position 1	Position 2	Edge weight (TEUsx1000)	LRV
Singapore	Laem Chabang	1,110	1.2816	Cristobal	Balboa	956	1.2406
Bangkok	Saigon	449	1.2173	Yokohama	L. Cardenas	210	1.2286
Bangkok	Singapore	491	1.2153	Barbours Cut	Savannah	188	1.2175
Tanjung Priok	Belawan	616	1.2048	Napier	Otago	100	1.2170
Taranto	Mariupol	367	1.1994	Otago	Timaru	95	1.2137
Wakamatsu	Hibikinada	190	1.1717	Las Palmas	San Pedro (Iv. Coast)	74	1.2074
St Petersburg	Kronshtadt	1,174	1.1710	Rotterdam	Caucedo	97	1.2053
Durban	Beira	340	1.1652	Ambarli	Port Said	168	1.2026
Varna	Kerch	493	1.1555	Lagos	Lome	76	1.2024
Hirohata	Himeji	1,143	1.1549	Karachi	B. Abbas	436	1.2019
Map Ta Phut	Saigon	228	1.1495	Durban	Port Louis	322	1.2015
Tianjin	Kwangyang	288	1.1492	Miami	NY & NJ	161	1.1978
Qingdao	Sungai Paking	108	1.1486	Jebel Ali	Sharjah	55	1.1923
Kobe	Ulsan	139	1.1462	Cartagena	Cristobal	29	1.1905
Qasr Ahmed	Homs	148	1.1461	San Pedro (Iv. Coast)	Douala	55	1.1887
Guayaquil	Callao	939	1.1442	Dakar	Abidjan	63	1.1881
Ube	Moji	112	1.1431	Klaipeda	Gdynia	66	1.1876
Napier	Tauranga	389	1.1421	Tanjung Pelepas	Johor	57	1.1875
Onne	Malabo	204	1.1415	Shimizu	Kobe	362	1.1867
Varna	Mariupol	705	1.1397	Chiwan	Kwangyang	147	1.1864
Cote-Sainte-Catherine	Hamilton (Canada)	145	1.1397	Westport	Tanjung Pelepas	714	1.1825
Belawan	Tanjung Perak	103	1.1365	Philadelphia	Colon	56	1.1818
Siam Seaport	Kashima	147	1.1359	Iquique	Arica	50	1.1796
Kingston	Paramaribo	205	1.1346	Montreal	Liverpool	233	1.1780
Walvis Bay	Cape Town	1,487	1.1344	Shimizu	Nagoya	370	1.1746
	Average for all edges	76	1.0020		Average for all edges	265	1.0109

*Given the capacity of one route in 08_09, c_{08_09}, and the capacity of the same route in 10_11, c_{10_11}, the Logarithmic Rate of Variation is $\ln(c_{10\_11})/\ln(c_{08\_09})$

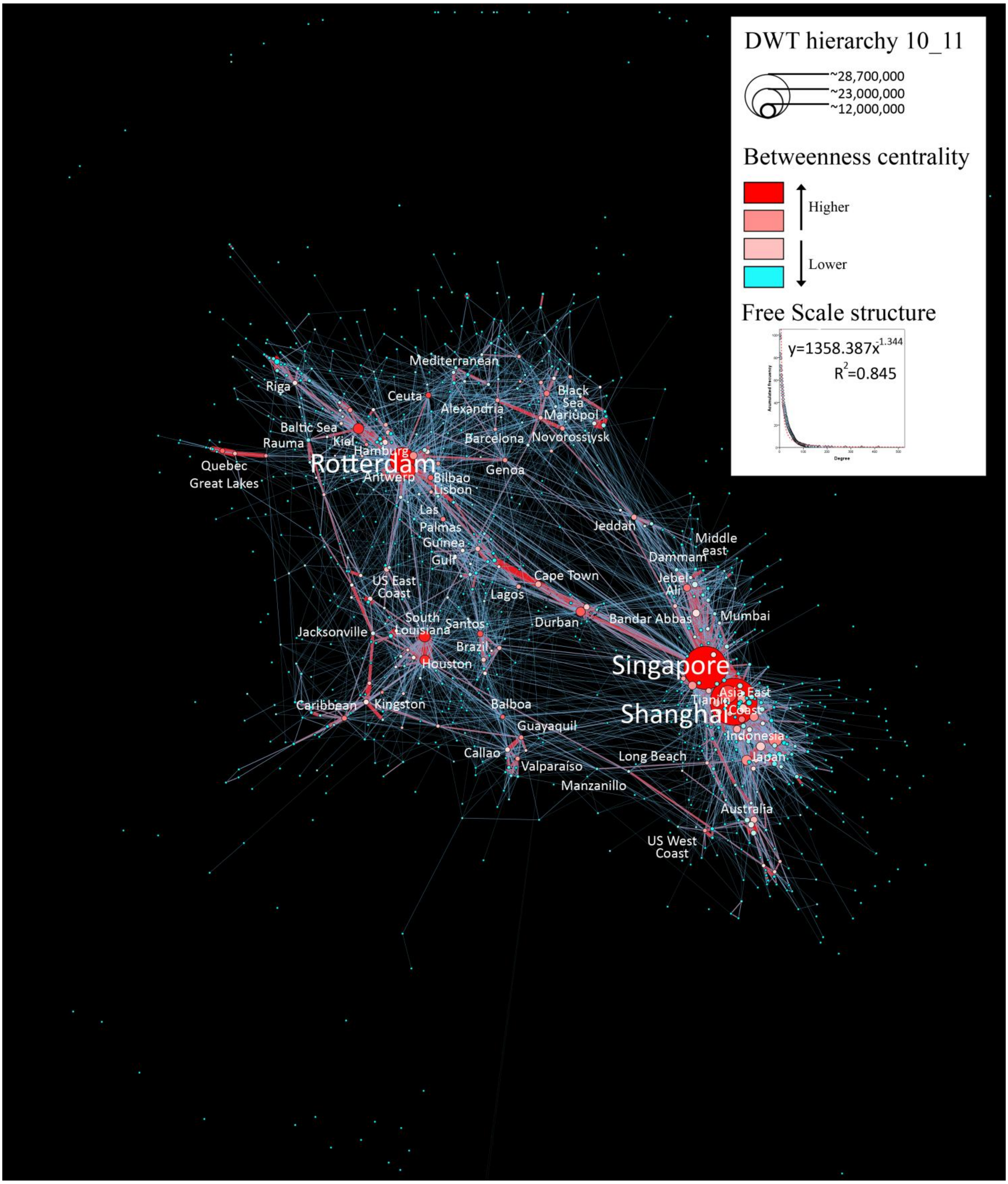
Source: Own elaboration

Figure 5. Separation of 08_09 general cargo graph



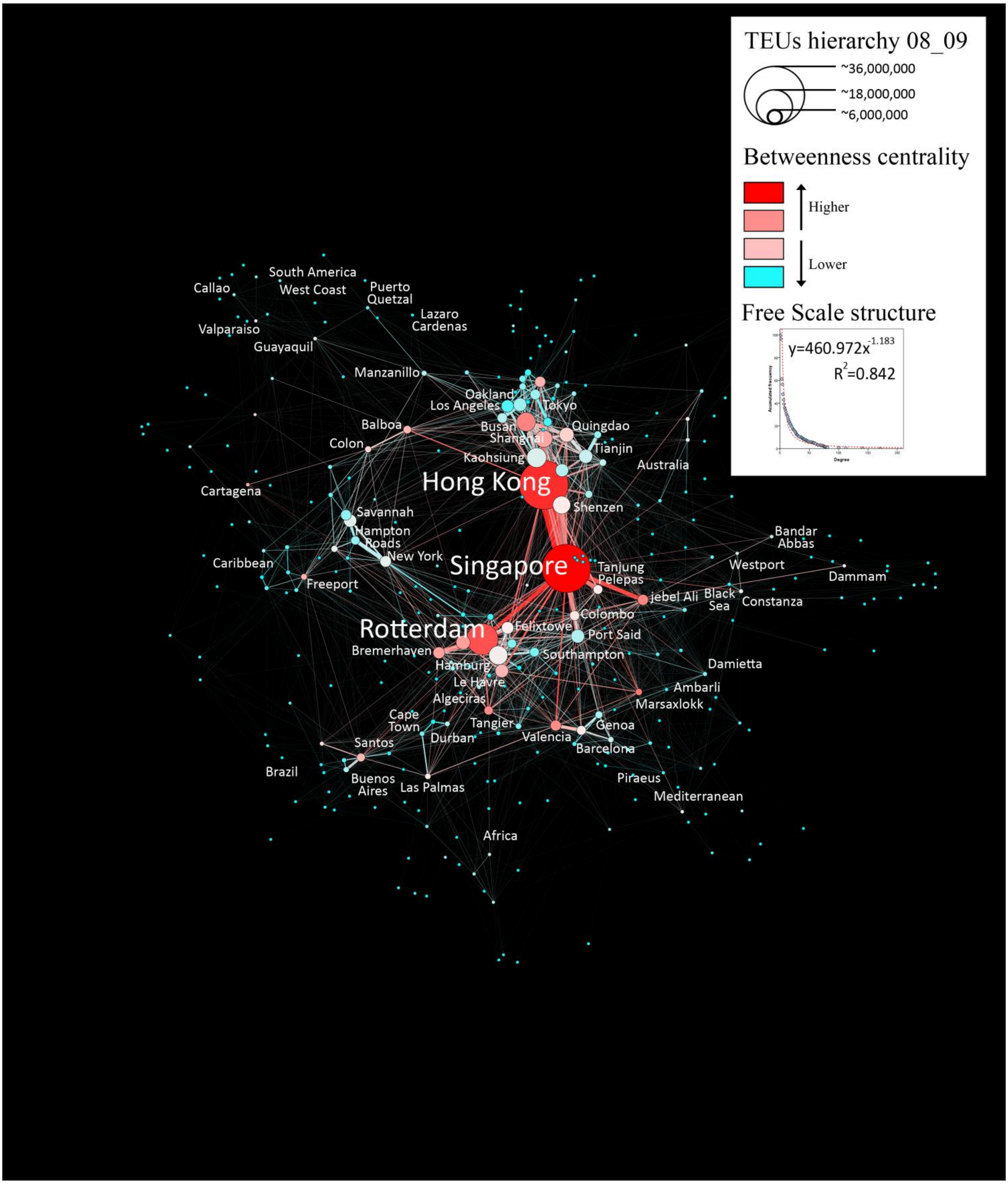
Source: Own elaboration

Figure 6. Separation of 10_11 general cargo graph



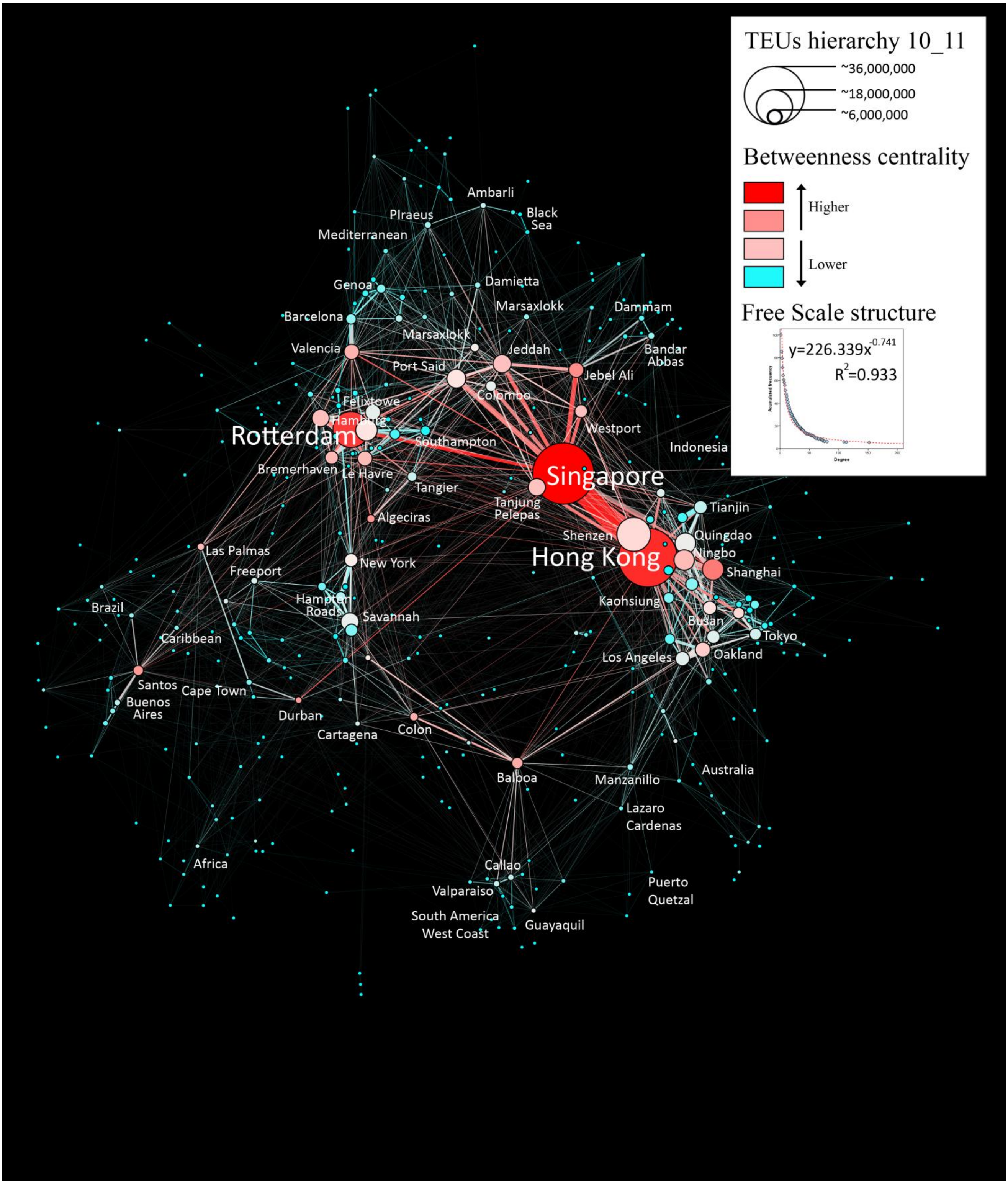
Source: Own elaboration

Figure 7. Separation of 08_09 containership graph



Source: Own elaboration

Figure 8. Separation of 10_11 containership graph



Source: Own elaboration

8. Main and emergent ports

This section looks at which of the ports within the complex network are growing in terms of both regional and global relevancy. The analysis shows that there was an important recovery last year while, at the same time, there is evidence of a new configuration in the supply chain and the appearance of emerging clusters and regions of port coordination regions.

Table 5 provides a ranking of the most important ports in terms of their capacity. The table gives the rates of variation in capacity, and the degree and centrality over the period being considered.

On looking at the detailed study of each of the containership port variables, one sees that the variation in capacity for the big hubs almost always falls below the average rate of growth for the entire sample (72.3%), the exceptions being Shenzhen 104.1% growth, Ningbo 411.3%, Jeddah 238.6% and Westport 92.2%. Several ports exhibit negative growth rates i.e. Felixtowe (-0.8%), Busan (-33.8%) and Tianjin (-2.9%). The relative performance of the general cargo ports is much better and almost all of them find themselves above the mean variation rate (1.1%). However, there are negative growth rates for the ports of Yokohama (-7.3%), Jebel Ali (-5.3%) and Lianyungang (-13.1%).

The scenario contrasts sharply with the key indicator, rate of variation in degree, for which almost all of the ports exhibit declining rates. The only containership ports whose foreland increases are Shenzhen (5.9%), Shanghai (8.1%), Ningbo (46.8%), Jeddah (21.7%), and Tianjin (2.2%). This development clearly reflects port authority efforts to make up for a fall in demand by becoming the main suppliers for their growing internal markets[4]. With regard to the most important general cargo ports, in the main, the evolution of the degree has been much better than that for containerized cargo. However, all of these fall a long way short of the mean growth rate of 50.3%. The three that exhibit the most significant levels of growth are Dalian (23.6%), Tanjung Priok (25.9%) and Busan (24.0%).

The evolution of the rate of centrality clearly reveals a contraction in the level of containerized traffic in all the important ports, despite the fact that the mean variation in the rate of centrality increases by 153.5%. The ports in which decreases are most pronounced are Yokohama (-83.3%), Busan (-75.3%) and Los Angeles (-74.0%). This decline in the centrality of the ports belonging to the Transpacific routes suggests that secondary supply lines have been sacrificed, i.e. those that were less profitable and which could not be maintained over the period studied due to problems of congestion in the port of Los Angeles[5], and to a general decline in Trans-Pacific transit[6]. The port of Ningbo is particularly noteworthy since it registered a remarkable rise in centrality of 201.9%, much higher than average. This set of terminals emerges from the Shanghai subsidiary hub and plays a very important role as a complementary trans-shipment node and helps to free up Shanghai. This development falls within the framework of Chinese governmental strategies to improve the production centre located along the Yangtze river[7]. The evolution of the centrality in general cargo ports reveals a highly significant increase for almost all of the most important ports. There are, however, several exceptions: Yokohama (-45%), Durban (-13%), Kobe (-51.7%), Hong Kong (-15.2%), Hamburg (-2%) and Bandar Abbas (-48%).

Despite the more favourable results for the evolution of general cargo transport, most of the important ports have not performed well in terms of growth. This suggests that emergent nodes are located in areas with discreet annual throughput. Hence, currently, there are ports with moderate or low operational capacities which are in the process of carrying out improvements in their infrastructures or in their draft, and these ports aim to be key players in the reconfigured network of international maritime transport. The emergent ports have been selected from those that exhibit the most relevant rates of degree and centrality, the chosen ports being the ones that are ranked highest when the combined variables of degree and centrality are taken into account when compared to position (tables 6, 7 and figure 9).

Table 5. Top 25 ranking of ports with higher throughput in 10_11. Variation rate of throughput, degree and centrality respect 09_10 and 08_09 (TEUs for containerships and DWT in General Cargo)

Throughput ranking position	Containership				General Cargo			
	Port	TEUs variation rate	Degree variation rate	Centrality variation rate	Port	TEUs variation rate	Degree variation rate	Centrality variation rate
1	Singapore	29.0%	-11.1%	-43.9%	Shanghai	50.3%	14.5%	43.8%
2	Hong Kong	32.2%	-19.9%	-56.0%	Singapore	15.6%	10.6%	35.8%
3	Rotterdam	18.1%	-2.7%	-44.7%	Rotterdam	16.9%	4.9%	10.2%
4	Chiwan (Shenzhen)	104.1%	5.9%	-33.0%	Tianjin	37.7%	18.6%	45.9%
5	Hamburg	12.4%	-5.6%	-18.8%	Antwerp	9.3%	0.5%	18.1%
6	Shanghai	18.8%	8.1%	-10.3%	Moji	15.0%	17.6%	45.1%
7	Qingdao	23.1%	-7.8%	-60.8%	Port of S. Louisiana	12.7%	14.9%	23.5%
8	Ningbo	411.3%	46.8%	201.9%	Kiel	14.1%	-1.2%	41.0%
9	Port Said	16.7%	-25.0%	-79.0%	Houston	3.7%	5.7%	6.7%
10	Jeddah	238.6%	21.7%	-3.8%	Yokohama	-7.3%	-11.2%	-45.0%
11	Savannah	16.0%	-17.2%	-70.5%	Durban	10.9%	-2.4%	-13.0%
12	Antwerp	26.7%	-3.9%	-58.1%	Dalian	39.7%	23.6%	39.1%
13	Tanjung Pelepas	38.5%	-6.2%	-42.2%	Qingdao	25.4%	9.2%	-0.8%
14	Felixstowe	-0.8%	-25.0%	-26.9%	Kobe	1.9%	-9.0%	-51.7%
15	Valencia	10.9%	-5.3%	-55.0%	Hong Kong	4.6%	10.9%	-15.2%
16	Oakland	12.6%	-22.8%	-57.6%	Tanjung Priok	59.0%	25.9%	20.3%
17	Jebel Ali	9.2%	-15.4%	-36.5%	Saigon	2.3%	-4.3%	26.3%
18	Le Havre	4.8%	-7.1%	-54.0%	Hamburg	12.0%	1.9%	-2.0%
19	Los Angeles	13.6%	-21.4%	-74.0%	Bandar Abbas	46.4%	-1.2%	-48.0%
20	Busan	-33.8%	-25.0%	-75.3%	Busan	16.1%	24.0%	97.0%
21	Yokohama	16.7%	-18.1%	-83.3%	Jebel Ali	-5.3%	15.1%	90.5%
22	Bremerhaven	7.7%	-3.3%	-17.4%	Brisbane	12.8%	-6.7%	25.1%
23	New York & New Jersey	14.6%	-24.3%	-68.5%	Ulsan	23.6%	11.1%	25.0%
24	Tianjin	-2.9%	2.2%	-17.3%	Lianyungang	-13.1%	-3.4%	18.4%
25	Westport (Malaysia)	92.2%	-2.7%	-19.4%	Cape Town	22.5%	15.2%	29.7%

Total ports average growth rate	72.3%	13.6%	153.5%	1.1%	50.3%	10.3%
Std. Deviation	1.880	0.669	7.988	5.423	1.524	63.765
Gini	0.851	0.863	0.327	0.906	0.933	0.965

Source: Own elaboration

Table 6. Top 27 ranking of emerging containership ports.

Position*	Name	Country	Throughput: Position in TEUs throughput ranking	Throughput: Total (x1000)	Throughput: Variation rate	Degree: Total	Degree: Variation rate	Betweenness centrality: Total	Betweenness centrality: Variation rate
4	Dar es Salaam	Tanzania	203	97	2.4	13	1.6	274.9	78.8
4	Mersin	Turkey	138	401	1.4	31	1.8	454.1	37.0
7	Pointe-Noire	Congo	232	46	1.0	13	1.2	458.1	25.4
9	Ensenada	Mexico	184	143	3.8	9	1.3	5.4	11.9
13	Cochin	India	256	25	1.2	8	1.0	4.4	9.6
13	S. Franco. do Sul	Brazil	163	212	0.1	12	0.7	46.5	20.1
15	Puerto Cortes	Honduras	224	56	1.6	8	1.0	66.8	3.5
17	Ambarli	Turkey	70	1,322	1.2	40	0.7	757.9	8.5
17	Roberts Bank	Canada	52	1,943	0.6	18	0.5	9.8	11.7
18	Mombasa	Kenia	189	125	1.3	11	0.6	214.7	6.5
18	Taichung	Taiwan	219	66	-0.1	10	0.4	39.2	50.5
18	Nagoya	Japan	56	1,784	5.8	19	0.5	62.7	22.9
18	Manila	Philipp	130	429	1.1	24	0.7	78.6	3.3
24	Tanjung Priok	Indonesia	145	341	0.9	18	0.8	58.4	1.6
25	Pyeong Taek	S Korea	179	173	0.3	7	0.4	3.7	11.3
27	Johor	Malaysia	170	203	0.2	19	0.9	77.1	1.2
27	Napier	N.Zeland	166	205	0.0	12	0.5	280.5	1.8
28	Sepetiba	Brazil	91	889	0.0	28	0.4	380.5	3.0
29	Ningbo	China	8	10,277	4.1	69	0.5	2,176.0	2.0
31	Karachi	Pakistan	92	857	3.6	17	0.3	71.5	4.7
31	Dartmouth	Canada	178	175	2.8	9	0.8	2.0	0.6
31	Setubal	Portugal	245	33	1.3	10	0.4	251.3	2.1
33	Venice	Italy	182	148	1.8	9	0.3	97.7	3.9
33	Malaga	Spain	105	628	0.7	23	0.4	444.5	1.5
34	Gdansk	Poland	128	433	3.0	7	0.2	68.7	29.6
36	El Dekheila	Egypt	129	430	0.3	28	0.6	318.9	0.6
36	Cristobal	Panama	75	1,252	0.4	43	0.4	1,372.8	1.1

	Throughput variation rate	Degree variation rate	Betweenness centrality variation rate
Total Average	0.723	0.136	1.535
Std. Deviation	1.880	0.669	7.988
GINI	0.851	0.863	0.327

* Mean of the degree and centrality variation rate ranking position

Source: Own elaboration

Table 7. Top 27 ranking of emerging general cargo ports

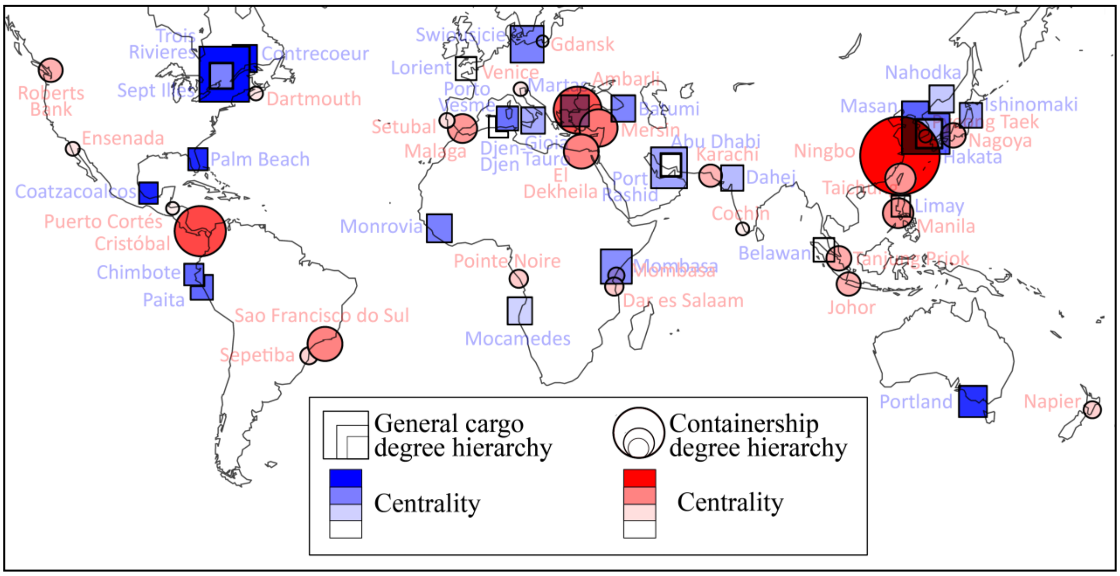
Position*	Name	Country	Throughput: Position in DWTs throughput ranking	Throughput: Total (x1000)	Throughput: Variation rate	Degree: Total	Degree: Variation rate	Betweenness centrality: Total	Betweenness centrality: Variation rate
2	Swinoujscie	Poland	387	406	47.9	28	13.0	306.8	1,183.4
10	Djen-Djen	Algeria	810	82	9.2	14	6.0	42.6	180.6
10	Chimbote	Peru	443	329	36.7	17	7.5	285.1	142.6
12	Ishinomaki	Japan	608	181	7.4	17	3.3	189.0	637.2
13	Batumi	Georgia	535	237	9.2	18	8.0	291.9	52.0
13	Dahej	India	611	177	2.2	17	3.3	108.7	349.2
17	Trois-Rivieres	Canada	263	729	1.6	45	4.0	2,388.5	55.7
18	Sept-Iles	Canada	519	250	3.8	19	3.8	1,007.2	73.4
19	Mocamedes	Angola	473	297	12.8	19	5.3	68.6	47.2
21	Porto Vesme	Italy	798	85	2.4	16	2.2	403.0	165.7
22	Portland	Australia	270	706	5.8	23	1.9	1,084.6	196.8
22	Paita	Peru	624	170	2.7	14	1.8	466.0	371.3
23	Nakhodka	Rusia	579	199	4.3	19	2.2	83.1	155.4
23	Palm Beach	USA	711	122	2.9	14	2.5	1,252.7	49.0
24	Masan	S Korea	124	1,513	111.1	43	20.5	506.3	14.7
26	Martas	Turkey	526	243	5.7	23	2.8	221.7	37.0
26	Lorient	France	733	111	2.6	15	4.0	40.1	24.7
28	Mombasa	Kenia	322	537	2.2	26	2.3	248.5	44.6
29	Limay	Philippines	722	116	3.7	13	2.3	41.1	37.3
29	Belawan	Indonesia	307	577	0.9	15	1.5	40.2	165.4
30	Contrecoeur	Canada	606	181	2.6	17	2.4	307.4	29.6
30	Gioia Tauro	Italy	391	398	0.4	18	1.6	144.5	150.1
31	Monrovia	Liberia	495	272	5.2	20	2.3	318.5	27.3
33	Hakata	Japan	544	229	6.4	20	5.7	139.5	12.1
33	Abu Dhabi	UAE	267	710	3.6	31	5.2	164.9	12.4
36	Port Rashid	UAE	528	241	2.7	14	1.3	41.6	117.4
36	Coatzacoalcos	Mexico	699	129	0.2	13	1.2	1,342.8	162.0

	Throughput: Variation rate	Degree: Variation rate	Betweenness centrality: Variation rate
Total Average	1.050	0.503	10.320
Std. Deviation	5.423	1.524	63.765
GINI	0.906	0.933	0.965

* Mean of the degree and centrality variation rate ranking position

Source: Own elaboration

Figure 9. Emerging ports in 09_11



Source: Own elaboration

This section presents the set of emergent ports, that is, the ports that have best evolved over the period analyzed. One way of approaching this might have been to establish efficiency rankings for the ports by using Data Envelopment Analysis (DEA), and this is undoubtedly an area in which future research will make great strides. However, this study takes an approach which is conceptually much simpler involving the construction of a mean ranking. This allows the analysis to take into account the ports that have exhibited the greatest levels of variation in terms of both degree and centrality. In addition, the ranking also highlights those ports whose growth in centrality has been limited but for whom connectivity has increased, or conversely, those whose centrality has not increased significantly but which have become important regional hubs.

The analysis looks first at container shipping. Of the ten ports that have grown most in terms of both in degree and centrality, three are in Africa, three in Central America and two in Turkey. This data, which looks at the principal emergent regions, reveals that the developing countries with relatively high rates of GDP are those whose market positions are improving in consonance with their dynamic economic status.

Of the emergent ports, the most important is Dar Es Salaam in Tanzania. During the 10_11 period this port registered a score of 13 for degree and 274.9 for centrality, values which diverge significantly from the overall average values for the sample (16 and 318.9, respectively). Second in the ranking came the Turkish port of Mersin which obtained an above-average score for both degree (31) and centrality (545.1). The importance in the score obtained for centrality reflects the prominent position of the port with respect to transit operations related to the congested entrance to the Suez Canal. The third port on the list is Pointe-Noire, which is located in the Gulf of Guinea, and is reinforcing an advantageous position with respect to the traffic catchment area made up of the East Asia-Europe lines that go round the Cape of Good Hope.

The ranking reveals that there are some Central American ports which have grown significantly. The port that really stands out in this area is Ensenada in Mexico, for which both degree and centrality are low, but which registered a substantial operational throughput of 184,000 TEUs for the period analyzed. This data reflects the existence of a recently built terminal that has successfully become operational[8]. Another port operating in this area and located in the Caribbean is the Puerto Cortes terminal, in Honduras. The most important port within the region, however, is Cristobal, located on the Caribbean gateway to the Panama Canal, a port which has very high indicators for both degree (43) and for centrality (1,372). This terminal achieved a throughput of 1,372,000 TEUs for the time period considered, which is well over the mean throughput of 1,180,000 TEUs. Given this somewhat exceptional scenario, it is hardly surprising that the Panama Port Authority is trying to prevent other Caribbean ports (Kingston, Altamira, Caucedo, Miami or Freeport) from absorbing the containerized traffic using the Canal, by stimulating the growth in the demand within its hinterland and by establishing new hub&spoke activities through the reinforcement of their main container ports.

Brazil also has a special presence in the over-populated area of Santos-Rio de Janeiro, represented on the list emergent ports and their terminals located at Sao Francisco do Sul and Sepetiba.

Developed countries are present in many of the general cargo transport network's main positions, but emergent economies are well-represented in the general ranking of ports whose growth is ascendant. First and foremost the Polish port of Swinousjcie should be highlighted, a port with no significant variation in degree (13) but a significant variation in centrality (1,183.4). This, combined with a discreet level of dwt throughput, i.e. below average, reflects successful policies for the capture of traffic, probably awaiting the acquisition of additional, profitable regular services. This contrasts sharply with the Algerian port of Djen-Djen, which has very low scores for both degree and centrality, but a high volume of throughput, which is probably because it has managed to establish a regular geographically stable supply line. The Peruvian ports of Chimbote and Paita, with above-average throughput, but lower values of centrality and degree, are very important ports on the Pacific Ocean and have strong recently-established supply lines. The largest area of development is located in one of the most important industrial areas in the world, the Great Lakes-San Lorenzo River line, the competitor ports for these important flows of goods and raw materials being Canadian. Here the ports that stand out are, Trois Rivieres, which has a very high score for both degree (45) and centrality (2,388), Sept Illes with a degree of 19 and centrality of 1,007.2, and at a certain distance Contrecoeur. These levels of centrality are typical of continental waters for which the geographical diversification and rerouting of traffic is evidently impossible.

9. Conclusions

The first conclusion of this research is that the general cargo network is relatively strong when compared to the global containerized transport system. This is confirmed by the main indicators since the graph density is low, as are the coefficients for clusterization and the “scale free” power laws whose exponential is also low. The values for these variables reveal that there is a slight hub-dependency, which means that there fewer subsidiary relations between ports and, as a result, better market opportunities.

The second conclusion to be gleaned from the separation graphs is that goods shipped in general cargo vessels are much more likely to be transported to a given destination using a variety of different routes, which has a bonus effect in the cost of maritime transport.

Thirdly, the containership market remains almost entirely focused on servicing

East Asia-Europe and East Asia-West Coast US routes; hence it becomes still difficult for ports that distance themselves from these lines to obtain economies of scale. Nevertheless, on looking at the gravitational models, the TEU volume transported clearly reveals incipient clusterization processes in the containership routes, particularly those for the Caribbean Sea, the West Coast of South America, and for the Middle East hubs.

Finally, it is worthwhile drawing a conclusion with respect to a hypothesized polarization that suggests that the developed economies are positive related to higher levels of containerized traffic, and developing economies with higher levels of general cargo transport. The former have been more greatly affected by the economic crisis, which has led the containership transport industry into a difficult period of alliances, closures and commercial reorientation. Currently, there seem to be some signs of recovery with slight improvements in market quota for container shipping. General cargo transport remains a highly important logistical alternative however; demand is stable and there is worldwide distribution, not only for low cost goods, but also for sophisticated machinery and manufacturing and industrial products which require high levels of care and efficiency when it comes to loading and unloading.

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Footnotes

(1) Automatic Information System (AIS): Traceability system that automatically reports call and departure data to the port authorities. Almost all modern vessels have this security device

(2) ‘The comeback kings’, *Containerisation International,* March 2011

(3) ‘An expanding brief’, *Containerisation International*, July 2010

(4) ‘Too close for comfort’, *Containerisation International*, June 2010

(5) ‘LA terminals add night gates’, *Containerisation international,* October 2010

(6) ‘On the way up’, *Containerisation international*, May 2010

(7) ‘Pushing the boundaries’, *Containerisation international*, February 2009

(8) ‘A long-overdue lift’, *Containerisation international*, November 2010

Capítulo 4. Foreland determination for containership and general cargo ports in Europe (2007-2011)

Figura 3. Primera página de la publicación "General cargo and containership emergent routes: A complex networks description"

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Foreland determination for containership and general cargo ports in Europe (2007–2011)

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ABSTRACT

Monitoring maritime cargo worldwide transport routes is currently a strategic aspect of any port authority activity. These types of vessels carry by-products from the transformation of raw materials, which used to be transported by the world fleet of bulk carriers. These cargoes are handled in different ways when loaded/unloaded, depending on the logistic modes: containerised or uncontainerised.

Regardless of the advantages and drawbacks inherent to both choices, it can be deduced that the signing of a charter party depends largely on the value of the cargo being shipped. It can thus be observed that there is a correlation between the transport flow dynamics and the type of cargo being shifted.

This article analyses the maritime cargo routes that affect the European Continent port system. The aim of this research is to describe how connectivity evolved between the difficult period from March 2007 to March 2011. Information of relevance to the way in which the world maritime traffic of uncontainerised (general cargo hereinafter) and containerised cargo evolved will be shown for that period.

It was decided to use Graph Theory techniques additionally with statistical techniques, so it would be possible to describe the relative importance of each port in the world transport context.

1. Introduction

Changes in maritime trade network structures have led to a strong and direct integration in the supply chain of ports that in many cases are very far away from the production or consumption centres. Therefore, the benefits and economic influence of containership or general cargo terminals outweigh jurisdictional disadvantages, defining a new type of geographical entity called foreland.

The first mention of this term used specifically in connection with maritime literature, comes with the works of Weigend (1956, 1958) and later in Bird (1963, 1971). The latter of these, mentions the "confusing variety of meanings" with regard to this concept of transport geography. This paper takes the definition included in Rodrigue (2010) as its starting point which describes a foreland as "the ocean-ward mirror of hinterland, referring to the ports and overseas markets linked by shipping services from the port".

Modern complex networks (non-random networks according Boccaletti et al., 2006) tools facilitate, not only accurate estimations on the global and local importance of a given node, both in terms of centrality and connectivity (Gonzalez et al., 2008), but they also provide a clear and precise visual representation of the resulting economic relations (Ducruet and Zaidi, 2012), including foreland analysis as it will be shown in this article. They are good complements to conventional statistical analysis and provide information about the port (node) being analysed and the relations (edges) with the other nodes within the network.

The analysis of vessel geographical positions creates huge data bases. This is because there are many call or anchorage positions and also due to the fact that the informational relationships that exist among the nodes are highly complex. This makes it difficult to determine or represent relations between ports accurately. In recent years however, techniques derived from Graph Theory have given rise to fructiferous approaches, including those of Fremont (2007), Ducruet and Notteboom (2010) and Kaluza and Kölzsch (2010).

The goal of this paper is to use modern complex network methodologies to analyse the principal emergent European containership and general cargo ports for the period 2007–2011. The process of containerization for the transport of goods has been increasing at the expense of general cargo activity right from the time when containerships first appeared in 1965. However, there has been no real decline in general cargo transport since then, as there is still a wide variety of goods that do not lend themselves to containerization (Cudahy, 2006). This paper attempts to analyse the dynamic that exists between these two complementary logistical processes. In so doing it is hoped to address such questions

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Fuente: Elaboración propia

Foreland determination for containership and general cargo ports in Europe (2007-2011)

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2. Background

Quantitative analysis of vessel movements either on a global scale or focused on a specific geographical location is a relatively recent development. This is mainly because vector calculation algorithms need to be used, and these were, until recently, reserved to the exclusive domain of major computing infrastructures. However, technological breakthroughs have enabled researchers to process large databases, thereby making it possible to rapidly carry out operations involving the calculation of major matrices and arbitrary depth search algorithms.

Basic data and procedures that concern the structure and economic consequences of global transport networks are contained in a series of manuals that provide not only theoretical data but also time series variables that are often difficult to obtain without having to pay for them. This information includes: charter and freight indexes, market sales, supply and demand for the different vessel types and fleet productivity. The contributions made by Goss (1977), Stopford (1997), Branch (1998), McConville (1999) and Freire and Gonzalez (2009) are good examples of compilations that cover the broad scope of the economics of maritime transport and all of its variants and the multidisciplinary fields which come under this broad umbrella. Where specific logistical questions are concerned, the work of Rodrigue (2010) must be highlighted, because it is a vast yet exhaustive approach to the dynamics of transporting consumer goods and the problems currently faced by the different agents involved.

The problem of the design of maritime networks and optimum hub location are dealt with rigorously using integer programming methods in Gelareh and Pisinger (2011) and Gelareh and Nickel (2011).

With respect to the literature that specifically analyses maritime cargo transport using methodologies based on Graph Theory, the works of Ducruet (2008) and Ducruet *et al.* (2010a, 2010b and 2010c) on containerised traffic are essential reading. In addition, the work carried out by Kaluza and Kölzsch (2010) is highly relevant because it contains an analysis of complex networks of container ships and other vessel types.

3. Sample composition

This research was carried out using a set of Automatic Information System (AIS) positions. The implementation of this new tracer technology in the ship's bridge begins with the IMO A.917(22) 2001 resolution (Harati-Mokhtari et al., 2007), and it is currently compulsory for all vessels over 300GTs, which report call, departure and vessel data to the port authorities by mean of this devices.

A sample of ship paths was built with the following criteria: a) not to consider containerships with less than 1,000TEUs or general cargo vessels with less than 6,000DWT to eliminate short range navigation activity noise; b) consider vessels built before 2007, in order to obtain an equilibrated amount of AIS positions stored per ship; c) eliminate anchorage, strait or canal positions; and d) prioritize for the final sample vessels that perform inter-continental activity. This selection procedure guarantees, as a corollary, that at least the most important ports (AIS call –berthing- positions) will be taken into account.

Regarding the AIS new tracer technology, it must be said that it is currently compulsory for all vessels over 300GT's (IMO, 2000), which report call, departure and vessel data to the port authorities by mean of this devices.

The analysis was conducted by splitting the sample into two periods, the first of which covers the period between March 2007 and March 2008 (Sample 07_08) and between March 2010 and March 2011 (Sample 10_11). This timeframe facilitates conclusions as to the impact of the financial crisis on the configuration of the network and helps to answer whether patterns of containerized and general cargo transport have evolved differently in European Ports.

There were a considerable number of vessels, nodes and edges used in the analysis and the proportion of the total fleet used with respect to both modes of transport was also sizeable, which means that the statistical significance of the results was high. Further, it should be stated that, underlying this type of AIS analysis, there is an optimum fit between the parameters estimated for each port and the real performance declared by Port Authorities, as was shown in Gonzalez et al. (2012).

This information was used in conjunction with a postgreSQL database server to construct a network of the set of ports in the whole of the system analysed, and all the edges that connect every pair of ports to each other. This type of database framework allows arrays tasks, programming languages functionalities and has a strong Geographic Information Systems support (Berkus, 2007). The resulting composition of the sample can be seen in Table 1.

Table 1. Sample composition and network topology

		General cargo		Container ships	
Period analysed		March 2007 March 2008	March 2010 March 2011	March 2007 March 2008	March 2010 March 2011
Name of the sample		07_08	10_11	07_08	10_11
Number of vessels analysed		1,515	1,654	1,164	1,342
Number of calls		44,581	64,281	67,017	89,417
Total number of edges		8,857	14,181	2,511	3,057
Number of different call positions (nodes)		938	1,302	330	390
Average calls per year		29	38	57	66
Degree	**Average**	Tangier (18)	Bristol (21)	Boston (15)	Halifax (15)
	Maximum	Rotterdam (302)	Singapore (416)	Singapore (128)	Singapore (152)
Centrality	**Average**	Algeciras (828)	Wilhelms -haven (1153)	Port Wentworth (272)	El Dekheila (318)
	Maximum	Singapore (83,780)	Singapore (181,898)	Singapore (9,557)	Singapore (13,725)
Network diameter		7	6	6	6
Graph density		0.02	0.017	0.046	0.04
Average path length		2.769	2.777	2.657	2.64
Average Clustering Coefficient		0.425	0.418	0.581	0.593
Maximum capacity recorded		49,370 dwt	51,624 dwt	15,550 TEU	15,550 TEU
Minimum capacity recorded		6,179 dwt	6,179 dwt	1,104 TEU	1,104 TEU
Total fleet used in the sample		24,315,576 dwt	27,470,830 dwt	8,307,558 TEU	10,361,509 TEU
Estimated total world fleet*		108,881,000 dwt	106,385,000 dwt	10,760,173 TEU	15,406,610 TEU
Percentage of fleet analysed out of the total fleet		22.33%	n/d	68.41%	n/d

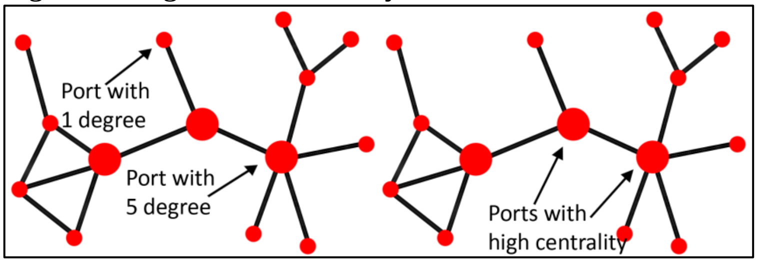
* Review of Maritime Transport 2009 and 2012

Source: Own elaboration

The data clearly shows that the number of call positions, the vessels that became part of the sample, the number of different calls and the average number of calls per year have all increased considerably over the period analysed. Further, there are some important differences with respect to the evolution in the network topology of containership and general cargo types that should be explained.

The analysis rests upon a more precise definition of degree and how this determines connectivity. Ducruet (2008) and Ducruet *et al.* (2010a, 2010b and 2010c) define degree as the number of direct connections affecting a given port (Figure 1). In the sample analysed, this parameter reaches a maximum value in the case of the containership sample for period 10_11 and the port of Singapore, which received vessels coming from 152 different positions. The average degree indicates that the level of connectivity has remained stable at 15 across the two time periods considered.

Figure 1. Degree and centrality



Source: Own elaboration

In the case of general cargo ports, the average degree for both 07_08 (18) and 10_11 (21) is greater than that for containerships. This is because general cargo services tend to be point to point (often between a single seller and a customer) while container shipping networks are organized as pendulum routes with the insertion of transhipment hubs. Moreover, when looking at the increase in port degree over the period 2007-2011 it should be remembered that this increase does not necessarily imply an equivalent improvement for each port in terms of throughput (as will be shown later), but rather the success of policies and strategies that aim to capture new or emerging areas of demand.

Other important point estimation for networks is the concept of centrality (Rodrigue, 2010). The basic mathematical definition states that centrality is the number of times a node crosses an arbitrary route on the network. It is generally a good way of measuring the regional importance of a port, given that the greater a port's centrality the greater the number of routes of which it forms a part (Figure 1). An increase of a port's centrality along different periods of time could confirm, as well, if this node is playing an important role in supply chain integration processes associated with hubs located far away, situation that some authors denominate as "port regionalization" (Notteboom and Rodrigue, 2005).

The mean centrality increased for both types of port activity, but there was a substantial difference in terms of the amounts for each cargo type. In general cargo terminals the numbers increased from 828 to 1,153, a variation of 39.25%, while in containership ports the numbers grew from 272 to 443 a variation of 14.44%. This would seem to suggest that, in terms of the general cargo port hierarchies, the structure is much more sparse (there are more ports acting as hubs) and, in contrast, the structure of the primary and subsidiary ports is rather more concentrated when it comes to containerships, a feature of this kind of traffic which is well documented. The different rates of variation seem to indicate that the general cargo network has evolved towards a greater increase in trade relations than the container network.

The network diameter (Rodrigue et al., 2010) measures the length of the shortest path between the most separate of the nodes, and thus indicates how well-connected the network is. In this study the diameter is constant for the global containership network. In contrast, the general cargo network loses 1 unit of diameter indicating a tendency for the structure to become more highly linked, which might suggest the growing strength of general cargo transport.

The Graph density indicator (Schaeffer, 2007) shows how close the network being analysed is to a totally connected graph (graph density=1). In our samples, the density of the containership network (0.046 in 07_08 and 0.04 in 10_11) is more than double that for the general cargo network (0.02 in 07_08 and 0.017 in 10_11), so the density of linkages between ports is much greater. This, together with the fact that there are fewer ports of call being considered for each of the two modes of transport, reveals the typical structure of a few highly connected containership terminals, in contrast to the sparser network of general cargo ports. The downward trend with respect to this parameter for both modes of transport means that there is a significant loss of connectivity for certain nodes.

The average path length measures “the average number of links that form the shortest path between any two nodes in the network” (Smith, 2008). Therefore, the shorter the length of the path, the more efficient the flow of traffic within the network. In this case this parameter do not varies so much in both vessel classes, and it could be only worth of mention the fact that in containerships is decreasing while in general cargo has grown, which could suggest un-efficiency factors affecting general cargo calls.

Lastly, the average clustering coefficient (Watts and Strogatz, 1998) is computed. Roughly speaking, the lower the estimator, the closer the system is to a small-world network (a structure with a few highly connected ports (hubs) and many which are poorly connected (subsidiary ports). With respect to general cargo vessels this coefficient decreases by 1.64% from 07_08 (0.425) to 10_11 (0.418) which means that some ports that become relevant as global hubs. The positive rate of variation in containerized traffic of 0.86% (from 0.581 in 07_08 to 0.593 in 10_11) reflects a slight decrease of the importance in the global relevance of some big hubs.

4. Methodology

The theoretical framework for this research is based on two techniques and attempts to improve upon the limited number of models that exist which provide a diagrammatic representation of maritime networks and focus upon one specific port. The analysis does this by proposing a way of calculating the foreland which is both clearly defined and invariant.

The first of these techniques defines the "proximal foreland" as the set of nodes located at a maximum distance of three edges from the port being analysed. This indicator measures the connectivity of a given port P, by looking at the ports that are associated with it, either through a direct connection or through a prior cargo transfer procedure.

The choice of three edges to define this entity is closely related to the idea of "minimum degree of separation" within a network. The idea has been synthesised and assimilated into everyday conversation in the conjecture that everyone in the world is approximately six or fewer steps away, a very basic simplification of "Average Path Length" measured over a random network (Watts and Strogatz, 1998). Given that the set of AIS maritime transport positions is not random but a small-world type, the Average Path Length must be lower than six (in this case it has an integer part of 3 for both general cargo and containership networks), and this is precisely the parameter we've chosen to carry out the proximal foreland calculus. It is a number that is high enough to ensure that important links will be considered and low enough to avoid spurious links.

The second technique involves evaluating the weight (in units of capacity) of the link between a given port and those that are most closely associated with it. This is made feasible because one knows the previous and subsequent call positions of the vessels that arrive at the port at a given time, and the maximum load capacity for each vessel.

First, the proximal foreland is calculated as follows:

Given vessel B_i and the period of time T, let $R_i^T = (p_{i1}^T, ..., p_{ik_1^i}^T, ..., p_{ik_{n(i)}^i}^T, ...) \in \Re^{m(i)}$ be the route, where: m(i) is the total number of ports of call on the route in the period T; n(i) the total number of berthing ports P on the route i; and $(k_1^i, ...k_{n(i)}^i) \in \Re^{n(i)}$ the profile vector that contains the positions that P occupies along the route taken by the vessel.

Using a programming language that enables the user to calculate vectors on databases (PostgreSQL), an heuristic search is designed within each route in order to obtain a new set S comprising $\sum_{i=1}^{c^T} n(i)$ sub-routes whose length is 7 (nodes at a maximum distance of 3 from the analyzed central port) and whose central port is precisely P, where c^T is the number of "container ships" or "general cargo vessels" included in the sample in the time period T.

Secondly, the nodes with the closest commercial links with a given port P will be represented. The diagram takes into account the maximum load capacity these nodes had during the period analysed and for each of the sub-routes obtained. A fortiori, the difference in the maximum total load for the first and last time period analysed, will also indicate whether the trade flows or carrier strategies of the ports involved in the analysis have expanded or contracted.

Limão and Venables (2007) and Martinez-Zarzoso and Wilmsmeier (2008) have shown how flexible the variables concerning port infrastructures prove to be in different models aimed at establishing the cost of transport. These analyses also highlight the positive relationship that exists between a reduction in the freight price and the size of infrastructures. This relationship is taken into account in the analysis by using the technique introduced by Ducruet *et al.* (2010a, 2010b, 2010c) in their influential, recent series of articles on complex networks of containerised cargo transport. This procedure is adopted in this article for the calculation of maximum port throughput. Besides the wide usage of this estimation in the maritime networks papers published until now, it must be said that the maximum of a random variable can be considered as a good point estimation due to its statistical characteristics of consistency and maximum likelihood (Pachenko, 2006).

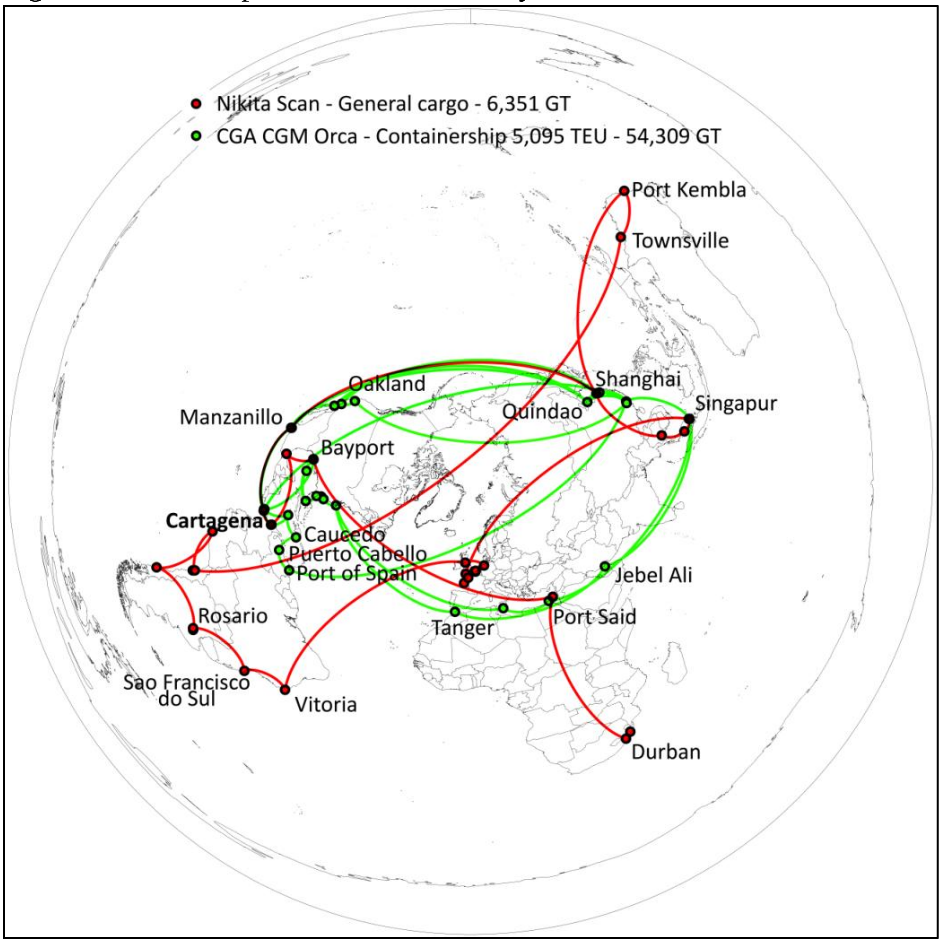
The magnitude of the port dimensions is thus directly and positively related to the maximum annual capacity that that port can handle, and may be simply defined as the maximum capacity of all the vessels that call in the time period analysed (also used in Gonzalez *et al*., 2012). Put simply, there is a need to accurately use the evidence available to express that the greater the capacity arriving at a port, the better the infrastructures must be, which will in turn create higher expectations in terms of the benefits obtained and the charter implemented.

Therefore, every port $p^{T}_{ik^{i}_{j}} \in S$ is characterised not only by two geographical coordinates, but also by a natural number expressed in the commonly used units of cargo capacity for vessels i: DWT in the case of general cargo vessels and TEU in the case of container ships (Rodrigue, 2010). This indicator, known as "Maximum Throughput" (hereinafter MT), indicates the sum of the capacities of all the vessel calling at this port, with the restriction that all of the sub-routes contained in S are performed. By this representation it will be possible to find ports located at significant geographical distance, but with a strong and stable trade relation established, represented in this case by the nodes with higher MT, which constitutes another good evidence of a port regionalization process going on.

For any given port, there is a final meaningful indicator which is "proximal foreland capacity", also measured in TEUs/DWTs, and that corresponds to the total sum of the maximum throughput of each port belonging to S (the proximal foreland being considered). This will indicate the intensity in TEUs/DWTs of the commercial activity within the zone of influence of said port.

Figure 2 shows the trajectory, over the 10_11 period, of the general cargo vessel *Nikita Scan*, which reached Cartagena de Indias after a 23-day voyage from Shanghai and whose first port of call was Manzanillo (Pacific Coast of Mexico) followed by Colon (Panama). After completing its activity at the Cartagena Container Terminal, the ship headed for Veracruz and then went to Houston (both in the Gulf of Mexico), before embarking on a direct 26-day voyage to Ashod (Israel). Therefore, there is a sub-route Shanghai-Manzanillo-Colón-Cartagena-Veracruz-Houston-Ashod with a length of 7, which defines an area of commercial proximity for the central port, in this case, Cartagena de Indias. In light of the fact that this vessel has 6,351 GT, we can obtain a maximum capacity for this sub-route by multiplying 6 by 6,351=39,186 GT, which indicates the maximum intensity of that subset of edges for that particular vessel.

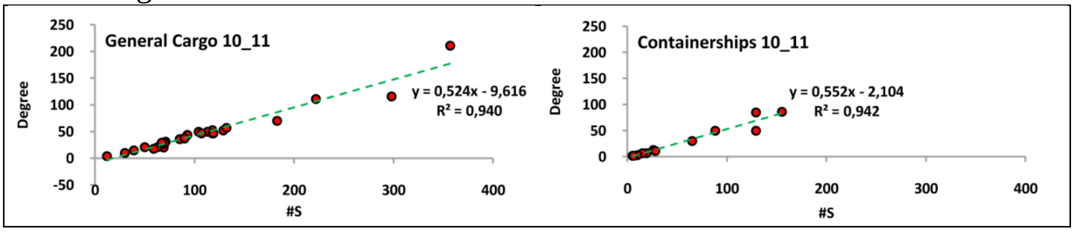
Figure 2. An example of two routes analysed



Source: Own elaboration

A final observation with respect to the accuracy of the calculus involved can be gleaned from Figure 3. The diagram shows the closeness of the fit between the degree of P and the number of ports associated with P using the sub-route calculation procedure (#S) linked to the calculus for the proximal foreland. The high correlation between the two measurements indicates that processing the network nodes, in terms of the extraction of the set of length 7 sub-routes centred on P, in no way distorts the information about connectivity contained in the degree of P. Furthermore, it is clear that the results obtained when calculating the proximal foreland around P, are closely linked to the connectivity of P in terms of degree.

Figure 3. Adjustment between the number of ports belonging to the proximal foreland and the degree



Source: Own elaboration

5. European containerized traffic ports

5.1. Main and emergent containerized traffic ports

Table 2 contains a list of the 10 main and 10 emergent European containership ports. The analysis may be applicable for any world subset of ports, but in this case current situation regarding the restructuration of Far East-European Northern Range pendulum routes due to the demand crisis, puts a special focus of interest in the European ports in order to clarify if the most powerful hubs follow growth trends, or if there are another secondary ports, placed maybe in economically damaged countries, that are starting to become important actors in the imminent new regionalization scenarios.

For the initial world network the parameters analyzed are: MT or the Maximum Throughput for each port (the sum of the TEU capacity of each vessel arriving to the given port), the Degree and Centrality, normalized with respect to the maximum value in the period being considered (i.e. Singapore normalized centrality=1). For the proximal foreland being computed the parameters given are: the number of ports with this type of commercial relation (#S) and the sum of the maximum throughput for each of these ports (capacity). Further, A ranking showing the total Maximum Throughput for the main ports and a world ranking with respect to growing ports in terms of emergent nodes have also been included. The TDC growth rate is the average rate of variation in the MT, and the parameters of Degree and Centrality, and is the indicator that has been used to define and rank the emergent ports from smaller to larger.

Table 2. European containership ports: main and emergent

10 main European containership ports

	07_08					10_11					Position in world 10_11 ranking****	TDC growth rate (%)
	World network			Proximal foreland		World network			Proximal foreland			
	MT **	Degree	Centrality*	#S	capacity**	MT **	Degree	Centrality*	#S	capacity**		
Rotterdam	21.963	85	0.406	173	1,201.855	25.037	109	0.493	186	1,395.595	3	21.22
Hamburg	9.641	51	0.087	100	577.885	11.107	51	0.105	123	693.030	7	11.97
Antwerp	6.713	72	0.206	131	411.999	8.473	73	0.153	150	530.082	13	0.62
Valencia	4.767	77	0.245	126	291.818	7.384	71	0.173	123	455.711	14	5.91
Felixstowe	5.573	46	0.095	93	346.668	7.035	42	0.078	97	442.190	17	-0.12
Le Havre	6.222	63	0.168	113	376.703	6.835	65	0.159	119	432.671	19	2.56
Bremerhaven	5.265	57	0.202	100	332.215	5.905	59	0.162	110	374.490	22	-1.38
Barcelona	3.817	51	0.099	106	240.865	3.992	40	0.031	97	261.662	36	-28.55
Zeebrugge	3.634	37	0.024	60	228.173	3.806	31	0.009	58	235.046	39	-24.66
Southampton	3.791	37	0.020	70	225.909	3.572	21	0.002	39	224.451	41	-46.34
10 most emergent European containership ports												
Ambarli	0.067	9	0.001	19	3.938	1.464	40	0.055	62	92.924	2	2,614.41
Gioia Tauro	0.026	5	0.001	10	1.561	0.915	34	0.014	67	54.013	4	1,775.80
Taranto	0.319	14	0.005	27	20.558	0.987	21	0.025	31	67.126	40	219.69
La Spezia	0.522	22	0.021	60	32.952	2.220	42	0.049	91	144.620	43	183.16
Piraeus	0.359	28	0.080	61	20.749	1.859	38	0.038	66	116.257	50	133.88
Malaga	0.515	21	0.007	43	33.687	0.636	23	0.032	44	38.089	52	130.05
Sines	0.623	18	0.004	42	37.248	1.345	26	0.012	49	83.211	58	120.09
Tarragona	0.106	8	0.001	20	5.626	0.479	6	0.001	9	31.369	69	75.19
Naples	0.519	21	0.013	49	32.326	1.335	22	0.006	66	88.310	87	36.09
Trieste	0.176	21	0.013	38	11.060	0.514	12	0.004	24	33.047	95	26.87
World average***	1.105	15	0.029			1.297	15	0.036				156.45
European average***	1.205	17	0.035	72	221.690	1.420	14	0.038	81	289.695		145.83

* Betweenness Centrality normalized according to max value, ** in millions of TEUs, *** For the world network, computed for all calls available, **** in case of 10 main emergent ports, ranking of risers. Source: Own elaboration

The final two rows of the table contain the average parameters for the World and European ports. It can be seen that the increase in MT for both Europe and the World is similar. Mean connectivity (degree) on the other hand is somewhat different; for the European ports this indicator fell from 17 to 14, while for world ports it remained stable at around 15. This is a clear indicator of the magnitude of the crisis in demand for the European Ports, a problem which is closely related to issues of oversupply in the pendulum routes springing up around the East Asian hubs.

However, the mean number of ports in Europe belonging to the proximal foreland of a given harbour has increased from 72 to 81. This would seem to imply that the loss of trade flows, clearly indicated by the fall in degree, has been offset by commercial expansion into some new areas. The impact of the crisis on European containership ports is also detectable through the slightly smaller average TDC growth rate for European nodes (145.83%) compared to world data (156.45%).

In the list of the main 10 European ports, ranked according to MT for 10_11, many ports appear with low rates of TDC growth and, for the following ports, growth is negative; Felixstowe (-0.12%), Bremerhaven (-1.38%), Barcelona (-28.55%), Zeebrugge (-24.66%) and Southampton (-64.34%). Thus when searching the emergent ports, it appears that they will be located not in the main ports, but in positions in which throughput falls within the highest MT quartiles, and where, therefore, there are fewer problems of congestion or for planning improvements in infrastructure.

The port of Hamburg has failed to grow in terms of degree but has significantly improved in terms of the range of its proximal foreland from 100 ports in 07_08 to 123 in 10_11, a good sign of recovery with regard to the widening scope of its commercial relations. Similarly, Felixstowe’s degree contracted from 46 in 07_08 to 42 in 10_11, but the scope of the proximal foreland evolved from 93 to 97 ports, a positive sign of the growth of the terminal.

The 10 most strongly emergent European containership ports, according to the TDC growth rate, are all located in the Mediterranean Sea, with the exception of Sines which is in the Atlantic Arc region. This would seem to indicate that, despite the critical situation of the macroeconomic framework of these countries, port activity remains an active mechanism for generating trade and profit. At the top of the ranking, Ambarli serves the rapidly growing metropolitan area of Istanbul and the present status of the port reflects the healthy growth rate of the Turkish economy. The port comes second in terms of emergent “world” ports. The next three ports are Italian: Gioia Tauro, Taranto and La Spezia, and come immediately before the Greek port of Piraeus.

The performance of Tarragona, which has a recently-built containership terminal belonging to “Dubai Ports”, seems to be paradoxical: its degree score falls from 8 to 6, and the #S indicator from 20 to 9, yet its position in the ranking is high. The reason for this probably lies in the stability of its centrality and the highly positive evolution of Maximum Throughput that rises from 0.106 million TEUs in 07_08 to 0.479 in 10_11.

5.2. Proximal foreland structure for Rotterdam and Ambarli containerized traffic

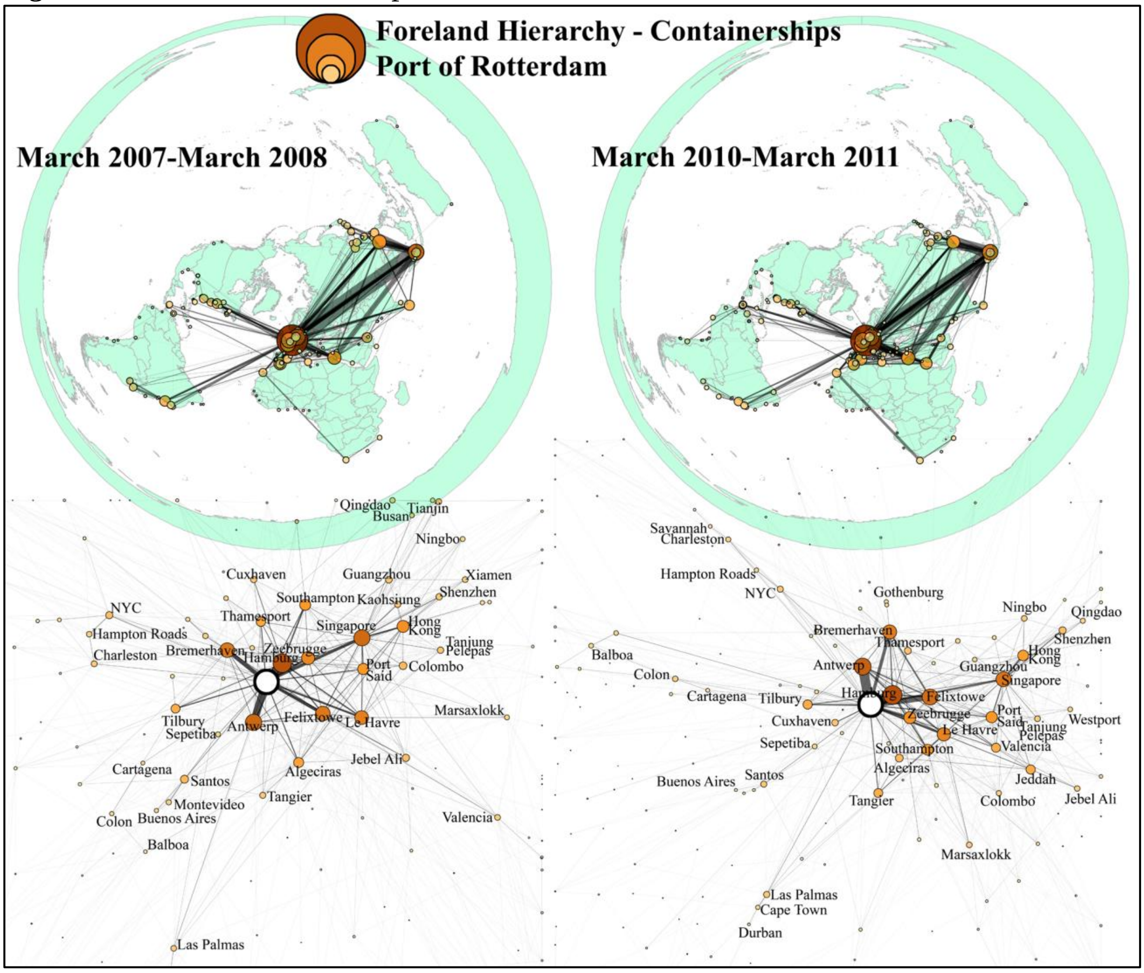
The remaining sub-section provides a representation of the structure of the proximal foreland for some of the most important worldwide hubs and an explanation of some of the specific dynamics reflected in the diagrams. As mentioned in the introduction, there are already some very interesting and inspiring attempts to reveal these structures, but more in-depth computational work is still required to achieve optimal results in terms of accuracy and coherence.

In order to represent the structure of the proximal foreland for a given port a methodology consisting of three steps is used. First, the entire sub-set S of nodes is extracted (using the 7-length sub-routes extraction algorithm formerly explained), taking as a starting point the entire world network of nodes and edges related to containership traffic. Each S-node has a geographical position, and the geographical representation of the set of nodes and edges belonging to S constitutes the second step of this visualization process. The final step involves the separation of the geographical network, relevant to the port in question, according to the effects of attraction and repulsion that each of the ports belonging to S exerts in terms of their MT. A system for analysing networks known as Gephi (Bastian *et al.*, 2009) is used to complete this stage of the work. It must be noted that for the specific representation of the foreland network for these big hubs, only the edges belonging to the 65 percentile are represented. This limitation serves to eliminate the smaller commercial relations and to clarify the evolution of the port under consideration.

Figure 4 shows the separation structure computed for Rotterdam which is the biggest European port. The slight growth in #S (from 173 in 07_08 to 186 in 10_11) is reflected in low levels of change in the graph structure. However, there are important trends which seem to be suggested by looking at the behaviour of specific edges:

- The supply line for Singapore and Hong Kong appears to be reinforced by the proximity of Ningbo and Qingdao. The latter port is no longer dependent on Busan and now supplies the Singapore-Hong Kong-Shenzhen route directly.
- A vibrant route of activity has grown up around the Tangier-Algeciras area. The route uses Southampton as an intermediate transhipment port.
- The Ports of Jeddah (Saudi Arabia) and Westport (Malaysia) are important new intermediary located on the pendulum lines.
- The East Coast US ports of Savannah and Charleston have lost relevance with respect to Atlantic containerized traffic. This traffic currently tends to use NYC and Hampton Roads as the main ports of entry.
- The Las Palmas-Cape Town-Durban supply line is closer to Rotterdam, which has meant a slight increase in traffic for the Cape of Good Hope transit alternative.

Figure 4. Proximal foreland separation for Rotterdam containerized traffic



Source: Own elaboration

The 19 (07_08) and the 62 (10_11) ports belonging to Ambarli's proximal foreland, Ambarli being the main emergent European port, can be clearly seen in figure 5. The intensive development of this Turkish hub is of particular interest:

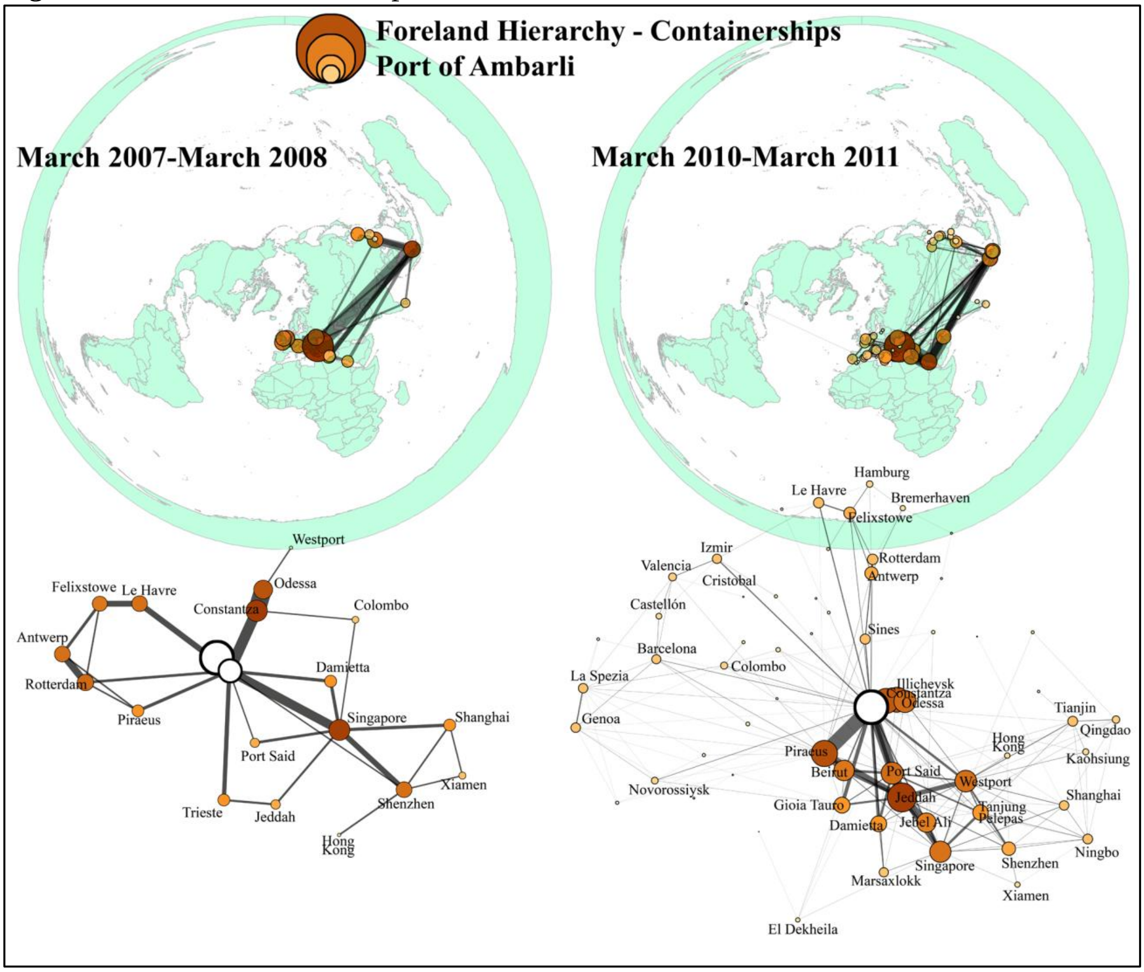
- The countries of the Black Sea have economic growth rates that are closely linked to the presence of their main hubs which act in close conjunction with Ambarli helping the region to act in unison almost as a single meta-hub involving the ports of Illichevsk, Constanza and Odessa in 10_11.

- Singapore is strongly connected in 07_08, via Damietta or Port Said. In 10_11, only Port Said remains as an intermediate hub, and carries out a significant number of supply operations via Jeddah and Jebel Ali. The port of Singapore also used to be the most important port for the Shanghai-Shenzhen line, but currently, these are connected via the Westport and Tanjung Pelepas terminals.

- The question which springs to the fore is whether or not European traffic is becoming less important for the total throughput performance of Ambarli Port. Integration with Northern Range services appears to have been dramatically severed, particularly with respect to the intermediary role of Piraeus and the disappearance of Bremerhaven as a port which is directly connected. The Port of Sines emerges as an important hub within this framework.

- A new cluster seems to be emerging around some Mediterranean Ports, specifically those of Valencia, Castellon, Barcelona, La Spezia and Genoa. With respect to this trend the strength of the link with Gioia Tauro is particularly noteworthy.

Figure 5. Proximal foreland separation for Ambarli containerized traffic



Source: Own elaboration

6. European general cargo traffic ports

6.1. Main and emergent general cargo traffic ports

Table 3 provides a list of the 10 main European general cargo ports according to their Maximum Throughputs in 10_11, and the 10 most strongly emergent European general cargo ports according to TDC growth rate.

Table 3. European general cargo ports: main and emergent

10 main European general cargo ports

	07_08					10_11					Position in world 10_11 ranking****	TDC growth rate (%)
	World network			Proximal foreland		World network			Proximal foreland			
	MT **	Degree	Centrality*	#S	capacity**	MT **	Degree	Centrality*	#S	capacity**		
Rotterdam	29.765	302	0.701	448	1,300.274	31.457	345	0.527	616	1,391.307	5	-1.63
Antwerp	12.847	195	0.228	368	697.629	12.335	219	0.199	462	712.463	8	-1.46
Kiel	6.657	164	0.250	316	344.578	7.284	166	0.165	359	397.853	14	-7.79
Amsterdam	7.500	85	0.054	174	229.869	5.414	115	0.031	241	184.316	24	-11.71
Hamburg	4.235	103	0.060	231	240.704	5.012	108	0.044	271	294.269	26	-1.16
Mariupol	2.436	90	0.065	157	96.868	3.664	127	0.055	228	170.635	35	25.38
Novorossiysk	1.177	56	0.029	93	47.709	3.371	93	0.040	190	142.809	39	96.77
Bremerhaven	2.937	82	0.060	181	167.968	3.299	84	0.020	221	181.212	40	-17.29
Bilbao	3.020	120	0.094	225	162.227	3.250	142	0.076	320	188.338	42	2.26
Ceuta	2.607	182	0.217	291	139.139	3.174	205	0.121	329	178.377	44	-3.27
10 most emergent European general cargo ports												
Leixoes	0.256	17	0.001	33	9.221	1.689	78	0.031	168	106.989	4	1,306.28
Vigo	0.105	7	0.001	19	5.383	1.097	35	0.005	76	61.233	22	448.55
Koper	0.148	14	0.001	35	6.321	0.651	46	0.008	122	37.679	25	423.11
Venice	0.456	39	0.015	74	20.962	2.188	104	0.027	215	124.454	65	208.94
Eregli	0.076	10	0.001	16	3.917	0.402	29	0.001	62	21.954	67	206.26
Augusta	0.109	10	0.001	22	4.680	0.426	41	0.004	91	20.162	71	200.27
Batumi	0.092	4	0.001	13	3.236	0.237	18	0.002	38	11.480	84	169.12
La Spezia	0.100	13	0.001	28	4.773	0.428	22	0.001	59	26.323	101	132.97
Cartagena	0.086	10	0.001	24	4.142	0.288	24	0.001	78	18.998	104	125.39
Vaasa	0.134	7	0.001	12	8.128	0.515	13	0.001	18	32.787	105	123.32
World average***	0.725	18	0.010			0.754	21	0.006				112.25
European average***	0.576	22	0.010	138	174.886	0.575	25	0.007	208	215.182		50.72

* Betweenness Centrality normalized by max value, ** in millions of DWTs, *** For the world network, computed for all calls available, **** in case of 10 main emergent ports, ranking of risers. Source: Own elaboration

It should be noted that despite a worldwide increase in average MT per port (0.725 millions of DWT's in 07_08 and 0.754 in 10_11) the mean values for European ports decrease slightly from 0.576 in the 07_08 sample to 0.575 in 10_11. However, growth, both in average degree and average #S, shows signs of recovery in demand for this type of traffic.

Almost all of the main European general cargo ports have negative TDC growth rates, which range from -1.16 in Hamburg or -1.63 in Rotterdam to values of -11.71 in Amsterdam or -17.29 in Bremerhaven. The maximum TDC growth rate in these main ports is obtained by the Ukrainian port of Novorossiysk, with 96.77%, which is above the average TDC score for European ports (50.72%) but still a long way from the world average (112.25%). These results seem to suggest that the most strongly emergent ports are to be found, not in the list of principal ports, but where levels of throughput performance are not no higher.

We find that the Northwest corner of the Iberian Peninsula has two ports that experience exceptional growth in MT, degree and centrality, the ports of Leixoes and Vigo. Once more, countries whose economies are under pressure show recovering signs in terms of port activity. The Slovenia-Italy area sustains four important general cargo ports whose levels of connectivity have improved substantially: Koper, Venice, Augusta and La Spezia. Again, two of the Turkey-Black Sea ports, Eregli and Batumi, have experienced significant levels of development with respect to their networks.

6.2. Proximal foreland structure for Rotterdam and Leixoes general cargo traffic

Figure 6 provides the separation structure of the proximal foreland computed for Europe's main general cargo port: Rotterdam. The network structure, as mentioned above, is a transport system which is less interconnected than its containership counterpart. The supply lines appear to be radial and there are lower levels of clustering. In the period being analysed, significant trends come to the fore:

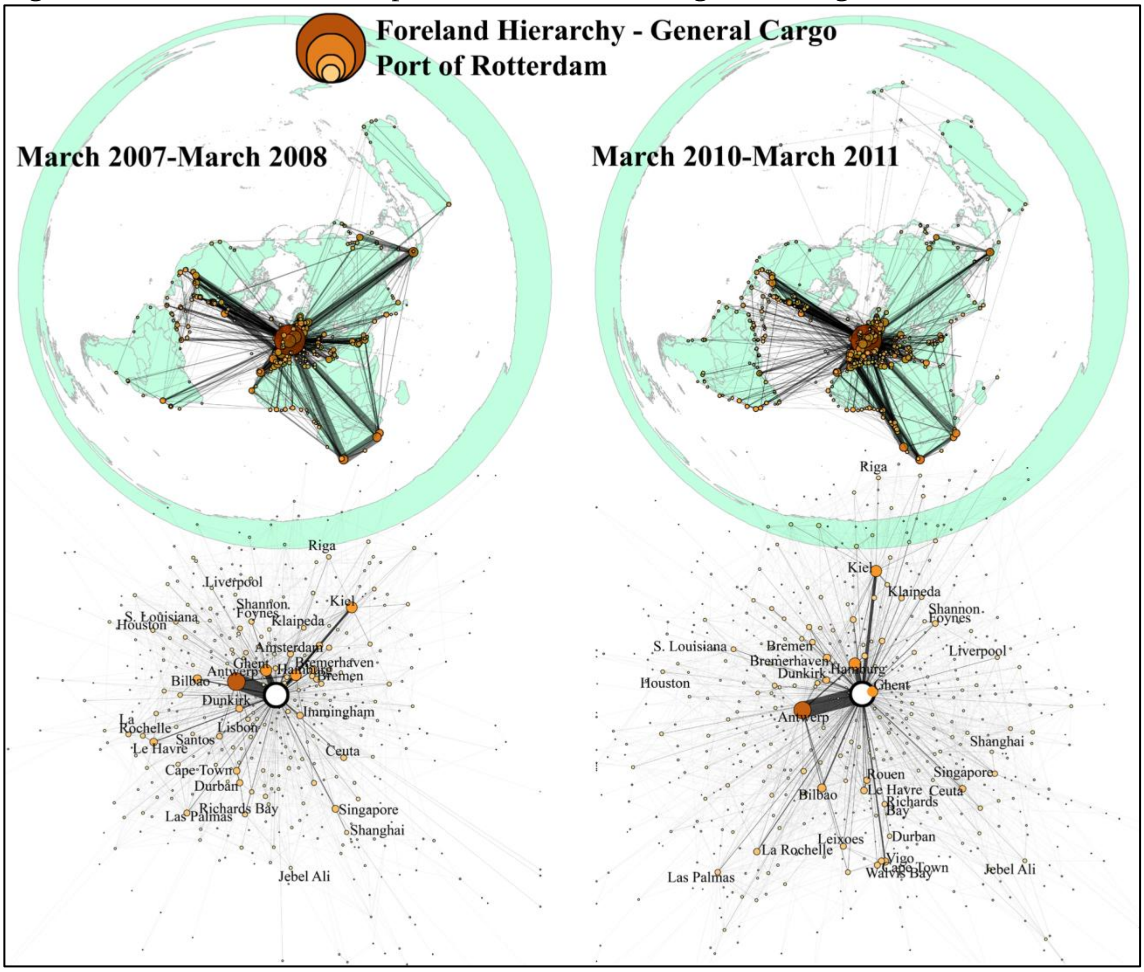
- The constancy of the strength in the link with Antwerp, Hamburg and Ghent.

- A strengthening of the services linking the South African ports of Richards Bay, Durban, Cape Town and Walvis Bay.

- A decline in the influence of Houston (one of the biggest general cargo ports in the world) and Santos.

- The increasing importance of Kiel as the main intermediary port for many calls taking place in the Baltic Sea. The influence of Riga has ceased and has become a subsidiary of Kiel.

Figure 6. Proximal foreland separation for Rotterdam general cargo traffic



Source: Own elaboration

Figure 7 represents the development of the proximal foreland for the most highly emergent European general cargo port of Leixoes in the North of Portugal. There is clear evidence of the growth of an increasingly complex linking structure. The following features stand out:

- A substantial improvement in the Northern Range supply line: the ports of Antwerp, Hamburg, Rotterdam, Bremen and Bilbao combine to form a cluster of intense activity in 10_11.

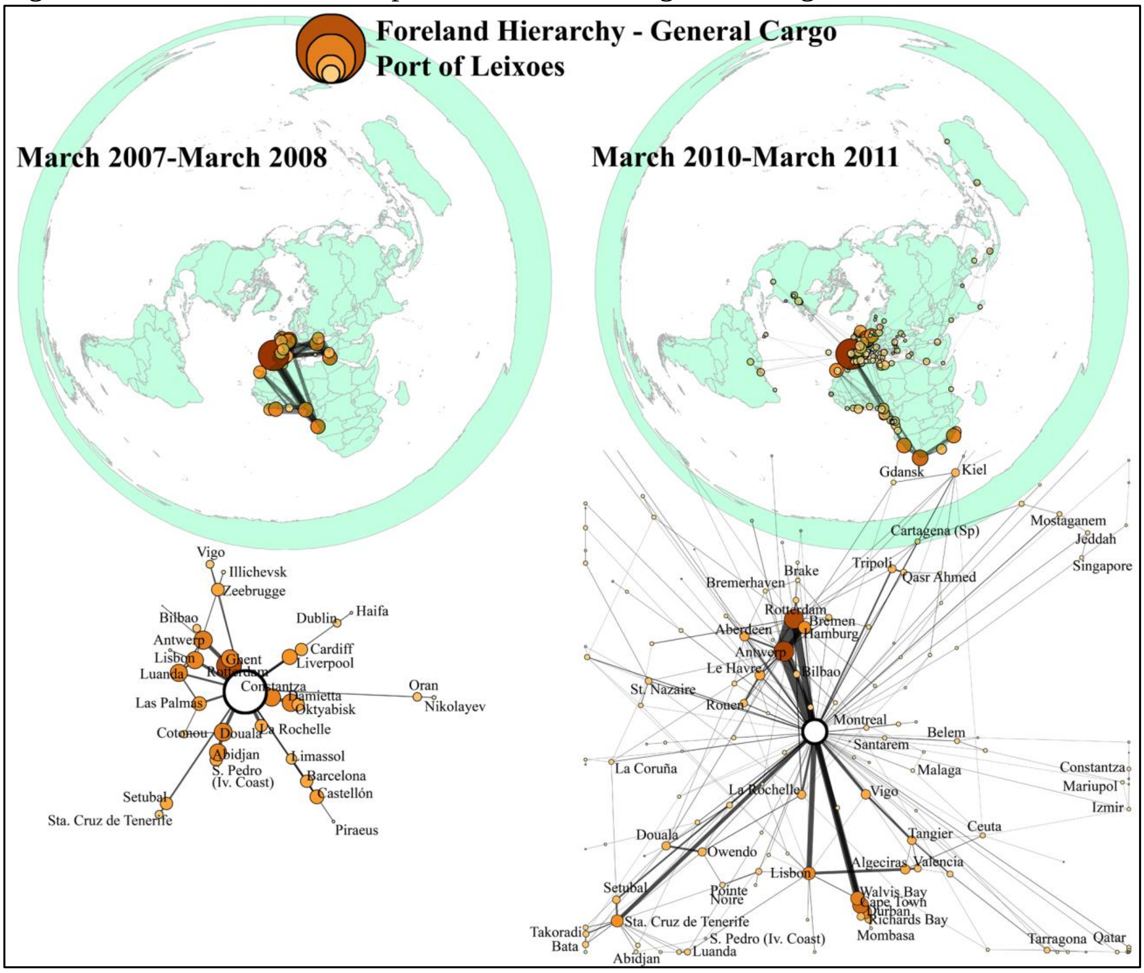
- Connections with many African ports have evolved and grown considerably. In 10_11The Spanish port of Sta. Cruz de Tenerife seems to act as a powerful hub for some of these. In contrast, it was relatively unconnected in 07_08. The South African ports of Walvis Bay, Cape Town, Durban and Richards Bay form a strong conglomerate of commercial activity.

- Some important lines with East Asia emerge: Mostaganem-Jeddah-Singapore.

- The influence of the Turkey-Black Sea harbours, which performed strongly in 07_08 decline significantly in 10_11, where Constantza-Mariupol-Izmir line becomes distanced from the centre of the graph.

- Some emergent activity with ports located along the River Amazon has converted Santarem and Belem into significantly related nodes.

Figure 7. Proximal foreland separation for Leixoes general cargo traffic



Source: Own elaboration

Conclusions

A detailed study of maritime cargo transport networks, using modern database technologies, enables one to understand the current reality of the commercial links that ports establish with one other. The aim of the analysis has been to apply a generalisation of the mathematical concept of distance between two nodes, which is to be understood not as a geographical separation, but as the volume of trade flows between each element within the system.

Instruments like "proximal foreland calculus methodology" allow freight forwarders and shipping companies to familiarise themselves with the geographical location of the demand for services, demand which has been characterised by intense volatility during this crisis years. It also allows those involved to distinguish between emergent areas and those areas in decline, and helps them to locate potential areas of business.

The period covered with these set of AIS data available is short (2-3 years), but it covers the main years of the worldwide demand crisis, and it could indicate vector gradients of growth, decay or recovering for both transport modes analyzed. With respect to the main network indicators of centrality and degree, it is possible to extract various conclusions.

The average level of degree (direct connectivity) has decreased in European containership ports, while for the total set of world positions, the indicator points to stagnation. For general cargo ports however, the average level of degree increased for both the European subset and the entire set of global positions. This is an evidence of the different consumption crisis impact in Europe over both different markets: affected, in terms of connectivity, much more to high value-added goods market (usually containerized) than to the general cargo affreightment.

The average normalized centrality increases for containership traffic and decreases for general cargo modes, and in World and European samples. This behaviour suggest a trend to a de-concentration process (port regionalization) affecting box terminals, and consisting in the emergence of secondary ports as new important actors in the global supply chain, probably acting almost as pure transhipment hubs, this may be the case of some terminals placed at Ambarli or Gioia Tauro.

With regard to the analysis of foreland parameters, European containership ports were unable to match general cargo ports in terms of increases in foreland capacity. This constitutes further evidence that general cargo terminals have outperformed their container counterparts capturing foreign trade during the crisis years.

Hence, despite losses in each port's total volume of throughput, attempts to offset the crisis in demand by expanding into new markets have been successful, given that there has been an increase in the average number of ports belonging to the forelands, and that the volume of cargo handled in the terminals linked by this relationship of proximity has increased.

It should also be highlighted that the Mediterranean ports appear to remain, not only influential with respect to containerized logistics, but are successful in creating emergent activity, despite the adverse economic pressures being experienced by their hinterlands. In terms of general cargo, the European South Atlantic Facade (Leixoes-Vigo) appears to be establishing a globally linked port region which is highly connected.

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Conclusiones

Las principales conclusiones que se pueden extraer como colofón de esta tesis son:

PRIMERA: Sobre una base de datos económicos (movimientos de buques de carga) se diseñó formalmente, usando la Teoría de Grafos, una red compleja que permite especificar la influencia y jerarquía portuaria, relaciones que son difíciles de determinar utilizando las herramientas convencionales de análisis estadístico descriptivo o análisis multivariante.

SEGUNDA: Se especificó un método de cálculo del foreland de proximidad (*proximal foreland*) como aportación fundamental de la investigación presentada. De este modo, se mejoraron las incipientes aportaciones que otros autores iniciaron en la década anterior desde dos puntos de vista alternativos:

a) Desde el punto de vista formal, se aportó una definición matemática precisa del foreland, que ha permitido desde su exposición en el tercer artículo publicado, aplicar de forma invariable las numerosas librerías informáticas resultantes a multitud de casos particulares: Autoridad Portuaria de Sines, Puerto de Cartagena de Indias, puertos pertenecientes a la Fachada Atlántica, puertos del Mediterráneo, Puertos de Interés General españoles y puertos del Atlántico Sur (África-Sudamérica).

b) Desde el punto de vista cuantitativo, se introduce el concepto numérico de intensidad y potencia del foreland, altamente correlacionados con el *throughput* real y estimado de mercancías y, por tanto, válidos como estimadores de influencia portuaria. En este sentido también es importante precisar que no sólo se ofrecen potencias e intensidades medidas en unidades de capacidad[19], sino que el método propuesto para el foreland de proximidad también es capaz de ofrecer las rutas reales más transitadas (puertos y trayectorias), así como los países y regiones portuarias con los que se tiene una mayor relación.

[19] TEUs en el caso de portacontenedores y TPMs (DWTs) en el caso de buques de mercancía general

TERCERA: Con respecto a los buques que realizan transporte marítimo, en base a la investigación realizada se puede concluir con rotundidad que:

a) El número de buques portacontenedores en servicio ha aumentado a lo largo del período 2008-2011 (desde 1.164 hasta 1.342, respectivamente) en una proporción mucho mayor que el número de buques de mercancía general en el mismo período (de 1.515 a 1.654).

b) Se percibe también una mejora, en promedio, del número de escalas anuales por buque. En el caso de los buques de mercancía general, en 2008 se calculó un promedio anual de 54 escalas, mientras que en 2011 la media alcanza las 71. Los buques portacontenedores presentan una mayor frecuencia de servicios que los buques de mercancía general, con un promedio de 97 escalas anuales en 2008 y de 112 en 2011.

CUARTA: Respecto a las diferencias estructurales entre las dos modalidades logísticas de transporte de carga general, se puede concluir que la red de mercancía general es mucho más dispersa que la red de mercancía contenerizada, tanto en lo que respecta a la conectividad portuaria, como en la presencia de relaciones de tipo puertos hub-puertos subsidiarios. Asimismo, se puede afirmar que la crisis económica ha provocado un claro fenómeno de repliegue de los flujos de carga contenerizada en cada vez menos puertos, lo que no se ha notado en el caso de la mercancía general convencional.

QUINTA: En términos de geografía económica del transporte marítimo contenerizado, se puede indicar que la principal línea de suministro sigue siendo el servicio Este de Asia-Northern Range Europeo (vía Singapur). En este tipo de trayectos es preciso destacar el protagonismo ascendente de nuevas terminales intermedias de *transhipment* que, aprovechando los problemas de congestión de los grandes hubs, cada vez absorben más tráfico, como es el caso de Westport (Malasia), Jeddah (Arabia Saudi), Ambarli (Turquía) y Sines (Portugal).

SEXTA: En los buques portacontenedores se está produciendo un progresivo desvío de servicios Este de Asia-Northern Range que pasan por el Canal de Suez, hacia rutas que doblan el Cabo de Buena Esperanza (Suráfrica) y realizan nuevas operaciones en los dinámicos y emergentes mercados del Atlántico Sur.

SÉPTIMA: Conviene resaltar las expectativas que la apertura del Canal de Panamá está provocando, en términos de crecimiento del grado y la centralidad, en numerosos hubs adyacentes a las dos costas de Estados Unidos y en el Mar Caribe.

OCTAVA: Se puede afirmar que, al menos en términos de conectividad y a pesar de la adversa situación económica de los países referidos, las terminales diseminadas por el Mar Mediterráneo tienen mejores perspectivas de crecimiento que los tradicionales hubs del Northern Range Europeo.

NOVENA: La geografía económica del transporte marítimo de mercancía general se caracteriza, a diferencia de la carga contenerizada, por poseer forelands radiales, con escasa presencia de relaciones estables de tipo *hub and spoke*, y con parámetros de grado y centralidad crecientes en promedio para todos los puertos. El Golfo de México y el Este de Asia son las áreas con mayor actividad en este tipo de modalidad logística, y existen indicios de que, en estas áreas, las rutas de cabotaje son muy superiores a las grandes líneas regulares de suministro, lo que está relacionado con la extraordinaria incidencia del *tramp shipping* en este tipo de tráficos.

DÉCIMA: Se aportan elementos de análisis suficientes para poder afirmar que, no sólo las terminales de portacontenedores son protagonistas fundamentales de las economías emergentes (Atlántico Sur), sino que también las modalidades de mercancía general siguen siendo buenas opciones para los países ya desarrollados en multitud de casos.

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