Efficiency, Costs and Market Power Analysis of the Spanish Port System

Tesis Doctoral

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La importancia de la industria portuaria

La importancia de la industria portuaria se refleja en que la mayoría del comercio internacional se lleva a cabo por el medio marítimo. Durante el 2018, el total de toneladas movidas mediante el transporte marítimo alcanzaron los 11 billones de toneladas con volúmenes que crecieron en ese año a una tasa del 2.7%, por debajo del 4.1% en 2017. El tráfico de mercancías en contenedor aumentó un 4.7% en 2018, un poco menos del 6.4% de incremento del año anterior. En 2018 la UNCTAD preveía un crecimiento económico del 2.6% y una expansión del transporte internacional marítimo con una tasa de crecimiento media del 3.5% en el periodo 2019-2024. Sin embargo, las persistentes tensiones comerciales y la elevada incertidumbre política del 2019 produjeron que las mercancías crecieran un 0.5% en el año 2019. Además, la crisis provocada por la pandemia de la covid-19 ha roto las previsiones de crecimiento de la UNCTAD en

2018 y ahora se prevé que el comercio marítimo caiga un 4.1 % en 2020, aunque espera que se recuperará un 4.1 % en 2021. El número total de buques comerciales con capacidad superior a las 100 toneladas brutas es de 98,140 buques. En 2019, la flota mundial de buques comerciales creció un 4.1 %, lo que representaba la mayor tasa de crecimiento desde 2014. Si nos centramos en el aumento de la capacidad, esta aumentó el 2.6 % en 2019 y, en particular, la de los grandes buques portacontenedores creció un 10.9 %. (UNCTAD, 2017, 2018, 2019, 2020).

De acuerdo con la información proporcionada por la UNCTAD, la globalización, la descentralización de los procesos de producción, la liberalización de la economía y el incremento de las compras on-line son algunos factores que muestran la importancia del comercio internacional. En 2017 el tráfico de contenedores alcanzó los 752 millones de TEU's[1] y en 2018 superó los 793 millones. Las principales rutas del tráfico de contenedores conectan el canal de Panamá (América Central) con Gibraltar (Sur-este Europa) y el Estrecho de Malacca (Sur-oeste Asia) con Bab el Mandab (Sur-este Asia) y el Canal de Suez (Nord-Este África).[2] Además, hay rutas secundarias, de menor distancia y con buques de menor tamaño. Por tanto, se deduce que tener un sistema portuario desarrollado es importante para el desarrollo económico de las regiones.

[1] "Twenty-feet Equivalent Unit", TEU es una medida que homogeneiza los dos principales tamaños de contenedores: 20 y 40 pies.

[2] https://porteconomicsmanagement.org/wp-content/uploads/Map_Main-Maritime-Routes.pdf

El crecimiento del transporte marítimo también se produjo para el sistema portuario español, en el que las toneladas totales aumentaron un 3.4 % respecto al año 2017. Según sus componentes, el crecimiento de la mercancía general transportada en contenedor fue del 5.3 %, el incremento de la mercancía general no transportada en contenedor fue del 7.6 % y los graneles líquidos crecieron un 1.4 %.[3]

La importancia del sistema portuario español se muestra en los siguientes datos estadísticos: acapara el 60 % de las exportaciones y el 85 % de las importaciones; transporta el 53 % del comercio internacional español con la Unión Europea y el 96 % con terceros países.[4] Además, el sistema portuario español contribuye al 20 % del PIB en el sector del transporte, que a su vez supone el 1.1 % del PIB español. Por otro lado, el sistema portuario español genera 35,000 puestos de trabajo directos y 110,000 puestos de trabajo indirectos. La *Table 1.1* muestra la evolución del modo de transporte que toman las mercancías exportadas e importadas.

Table 1.1 Evolución del modo de transporte internacional de mercancías en España

Modo en %	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
Road	21.75	21.09	19.68	18.06	19.26	19.02	19.13	19.73	19.14	19.39
Railway	0.67	0.64	0.72	0.60	0.72	0.71	0.75	0.68	0.83	0.72
Air	0.10	0.12	0.12	0.11	0.11	0.11	0.12	0.13	0.14	0.15
Maritime	77.49	78.15	79.49	81.23	79.91	80.16	80.01	79.46	79.89	79.74

Fuente: Observatorio de Transporte y Logística en España. Anuario 2018.

[3]Monthly statistics of December, 2018 from Puertos del Estado
[4]http://www.puertos.es/es-es/nosotrospuertos/Paginas/Nosotros.aspx

El sistema portuario es el enlace más importante para la cadena de transporte internacional, por esta razón, muchos países los han utilizado para estimular la economía y es un sector estratégico para el gobierno. Además, el sistema portuario es el único enlace entre las regiones continentales y las islas, por tanto, el sistema portuario es importante para promover la cohesión económica entre las diferentes regiones. Esta es la razón por la que la Unión Europea promueve las inversiones en infraestructura portuaria. El sistema portuario tiene la función principal de transportar bienes del modo de transporte marítimo al modo de transporte terrestre (carretera, ferrocarril). De tal modo, tener un buen acceso a los puertos es necesario para asegurar un transporte intermodal eficiente.

La eficiencia de los puertos afecta a la competitividad de los países. Tener un sistema portuario eficiente es importante para reducir los costes de exportación y aumentar la competitividad de los productos nacionales en el mundo. Por otro lado, los precios de los productos importados podrían ser menores, mejorando así el bienestar de los consumidores de la nación. Esta es la principal razón de la intervención del gobierno en el sistema portuario, por tanto, conocer los factores que afectan a la eficiencia portuaria y comparar la eficiencia entre los diferentes puertos es una información muy relevante.

Los niveles de eficiencia dependen directamente de las cantidades de producción y de los factores utilizados. La producción llevada a cabo en el sistema portuario consiste en la manipulación de la mercancía, el facilitar el viaje de pasajeros, proporcionar servicios a los buques y la construcción y mantenimiento de las infraestructuras y superestructuras. Los inputs del sistema portuario pueden clasificarse en infraestructuras, superestructuras y trabajadores.

La demanda de los servicios portuarios responde a la actividad económica de una región. El crecimiento económico, el desarrollo de la producción industrial y la apertura de la economía generan una mayor demanda de servicios portuarios. Por otra parte, el sistema portuario realiza servicios independientemente de la situación económica de la región. La situación geográfica del sistema portuario español, situado al sur-oeste de Europa, lo convierte en una de las puertas de entrada a Europa de grandes buques desde el océano Atlántico. Por tanto, una parte de la demanda de servicios corresponde a la mercancía en tránsito, donde los grandes buques descargan la mercancía en el sistema portuario español para que sea cargada por buques más pequeños y transportada a otros destinos.

Descripción del sistema portuario español

El sistema portuario de titularidad estatal está compuesto por 46 puertos de interés general, gestionado por 28 Autoridades Portuarias bajo el control del Ministerio de Fomento mediante el ente público "Puertos del Estado". La *Table* A.1 en el Appendix A muestra la lista de las Autoridades Portuarias y los correspondientes puertos de interés general gestionados por cada una de ellas.

Las principales funciones de *Puertos del Estado* están basadas en la ejecución de la política portuaria del gobierno y en coordinar y controlar la eficiencia del sistema portuario de titularidad estatal. Por otra parte, este ente público define los objetivos de cada autoridad portuaria, así como su cumplimiento, el control financiero de las autoridades portuarias y sus gastos en inversiones. El transporte marítimo es uno de los eslabones más importantes en la cadena de transporte intermodal, por tanto, *Puertos del Estado* tiene que coordinarse con el resto de entidades dedicadas al transporte y la logística.

Las autoridades portuarias son entidades públicas que tienen su propia personalidad jurídica y patrimonio independiente del estado español. Sus funciones están basadas en garantizar la provisión de servicios en las instalaciones portuarias, como son la gestión y el control de los servicios portuarios. Además, las autoridades portuarias proponen, proyectan, construyen, conservan y operan los trabajos necesarios para las infraestructuras portuarias y las señales marítimas.

Hay diferentes modelos de administración y gestión portuaria que son clasificados en función del peso relativo del sector público y la iniciativa privada en la gestión de la actividad portuaria. El primero es el de los puertos de servicios públicos, en los que la autoridad portuaria es la propietaria de las infraestructuras, superestructuras y se encarga de la provisión de servicios. El segundo modelo se denomina "Tool Ports", en el que la autoridad portuaria mantiene la propiedad de las infraestructuras y las superestructuras, aunque la provisión de servicios es llevada a cabo por la iniciativa privada. El tercer modelo de gestión portuaria se conoce como "Landlord Ports". La autoridad portuaria es la reguladora y la propietaria de las infraestructuras y las empresas privadas se encargan de la superestructura y la provisión de servicios mediante concesiones administrativas concedidas por la autoridad portuaria. Por último, tenemos los puertos de servicios privados, en que la construcción de infraestructuras, superestructuras y la provisión de servicios corresponde a la iniciativa privada.[5]

1.1.2 Reformas legislativas

La evolución del modelo portuario español en las últimas décadas es consistente con la tendencia que observamos en muchos países de nuestro entorno hacia una menor intervención del Estado en la operación de los puertos, dejando al sector público como proveedor de infraestructuras básicas y agente regulador. Un objetivo fundamental de este proceso de creciente privatización ha sido el de aumentar la eficiencia del sector portuario para contribuir a mejorar la competitividad de la economía y para liberar a los presupuestos públicos de los gastos derivados de nuevas inversiones en la infraestructura y superestructura portuarias y en su mantenimiento. Los cambios necesarios en la normativa española se han realizado a través de la *Ley Orgánica 27/1992 de Puertos del Estado* y sus sucesivas modificaciones, incluyendo la *Ley*

[5]La superestructuras son un tipo de infraestructuras que incluyen bodegas de carga para diferentes mercancías, tanques de almacenamiento para graneles líquidos, almacenes en general, talleres y otros tipos de instalaciones administrativas en general.

Orgánica 48/2003, de 26 de noviembre, de régimen económico y de prestación de servicios de los puertos de interés general, que han sido recogidas de forma sistemática en el *Real Decreto Legislativo 2/2011, de 5 de septiembre*, por el que se aprueba el texto refundido de la *Ley de Puertos del Estado y de la Marina Mercante*

La primera ley portuaria se encuentra en la constitución española del 1978, en el artículo 149.1.20ª que atribuye la competencia de los puertos de interés general al estado, dejando que el resto de puertos sean regulados por las Comunidades Autónomas. Antes de la ley orgánica 27/1992, coexistían dos modelos de gestión portuaria en el sistema portuario español: los puertos autónomos y las Juntas de Puertos. El primer grupo era gestionado mediante los correspondientes estatutos de autonomía y el segundo grupo era gestionado de forma centralizada. La ley orgánica 27/1992 adaptó los puertos a un mayor ambiente competitivo. Esta reforma agrupó todos los puertos de interés general en sus correspondientes autoridades portuarias, las cuales dejaron de prestar servicios directamente a favor de un modelo de gestión portuaria Landlord. El sector público era el propietario de la infraestructura, pero la provisión de servicios la proporcionaba la iniciativa privada. Las autoridades portuarias se establecieron legalmente como personalidades jurídicas, con su propio patrimonio, bajo la supervisión de la entidad pública recientemente creada "*Ente Público Puertos del Estado*"(EPPE). Además, la ley orgánica 27/1992 creó el fondo de compensación interportuario para financiar las nuevas inversiones, este sistema sería supervisado por EPPE y totalmente financiado por las aportaciones de las autoridades portuarias.

La ley orgánica 27/1992 estuvo en vigor durante 5 años y fue rectificada por la *Ley Orgánica 62/1997* con el objetivo de aumentar la autonomía de las autoridades portuarias respecto de Puertos del Estado, implicando a las regiones autonómicas y las autoridades locales en la gestión portuaria. Por otro lado, esta reforma introdujo una limitada liberalización de las tarifas portuarias y aumentó la participación del sector privado en la provisión de servicios portuarios. Las autoridades portuarias estaban obligadas a garantizar la provisión de ciertos servicios, que podían ser proporcionados directamente o indirectamente mediante concesiones y contratos. Mediante esta reforma legislativa se aumentó el grado de liberalización de las autoridades portuarias , sin embargo, en el año 2003 se aprobó la ley orgánica 48/2003 como una continuación de la anterior reforma legislativa. Esta nueva reforma legislativa aportó un nuevo rol a las autoridades portuarias que se convertirían en entidades reguladoras, proveedoras de las infraestructuras y oferentes secundarios de la prosivisión de servicios. Las autoridades portuarias podían proporcionar el servicio si no existía iniciativa privada para ello. El objetivo declarado de esta reforma legislativa fue promover la participación del sector privado en la financiación, explotación de las instalaciones portuarias y en la provisión de los servicios. Respecto a la liberalización de las tarifas portuarias, esta ley supuso un progreso, porqué se fijaron unas tarifas uniformes para todo el sector portuario español, de modo que la competencia interportuaria era muy limitada (Castillo-Manzano et al. (2008)). Por último, la entidad pública "Sociedad Estatal de Estiba y Desestiba"fue convertida en .Agrupaciones Portuarias de Interés Económicoz la participación pública sufrió un intento fallido de privatización.

Las reformas de los años 1992, 1997 y 2003 introdujeron un proceso de descentralización con una mayor autonomía para las Autoridades Portuarias. Sin embargo, la *Ley Orgánica 33/2010* modificó la reforma legislativa anterior con el propósito de introducir el modelo de gestión portuaria Landlord avanzado, en que las autoridades portuarias no podían llevar a cabo ningún tipo de servicio. Además, esta reforma legislativa tenía el objetivo de que el sistema portuario fuera autosuficiente económicamente con una rentabilidad sobre los activos no corrientes. Por otro lado, esta ley aumentó la liberalización de las tarifas portuarias, ya que cada autoridad portuaria podía elegir las tarifas para cada mercancía en un rango establecido por *Puertos del Estado* y permitía que los puertos se especializarán en ciertos servicios o mercancías. El sector privado se involucró en el desarrollo de las infraestructuras portuarias a través del mecanismo de arrendamientos y concesiones. Por último, esta reforma propició la fundación del "*Observatorio Permanente del Mercado de los Servicios Portuarios*".

La actual legislación portuaria está regulada por el *RDL 2/2011*, que ha derogado todas las reformas portuarias mencionadas anteriormente. Las autoridades portuarias gestionan los puertos que están bajo su competencia y *Puertos del Estado* coordina y controla la eficiencia del sistema portuario español. El sector privado no está únicamente envuelto en la provisión de servicios, también financia y construye las infraestructuras portuarias. Las autoridades portuarias gestionan la provisión de las infraestructuras con el objetivo de promover la participación privada. Las autoridades portuarias tienen que financiar sus costes corrientes, sus costes financieros y sus activos no corrientes con los ingresos de las tasas y tarifas portuarias. Por otro lado, esta reforma afecta a la competencia intraportuaria, el número de concesiones al mismo operador en la autoridad portuaria está limitado y se impide que el mismo operador pueda proveer más del 50 % de los servicios portuarios en una misma autoridad portuaria.

1.1.3 Descripción cuantitativa

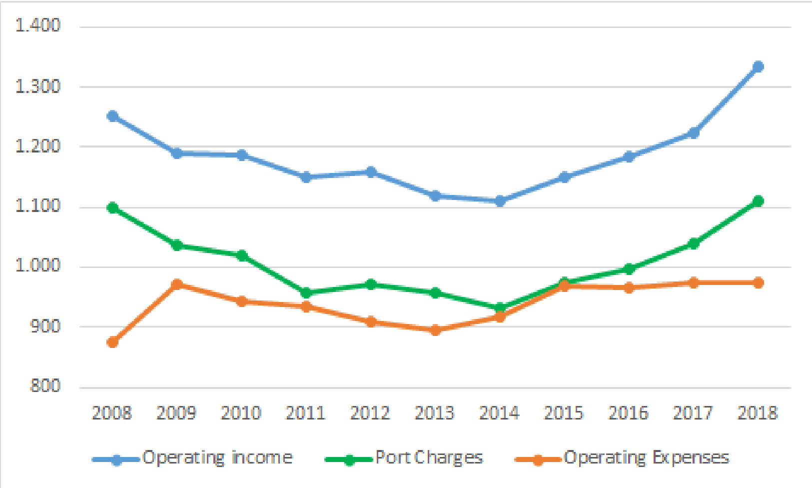
Resultados económicos

En esta subsección se analizan los resultados económicos, los niveles de inversión y la distribución del tráfico para cada puerto. La actual legislación portuaria (RDL 2/2011) establece dos principios de naturaleza económica. El primer principio es el criterio de autosuficiencia económica, por el que los ingresos ordinarios deben financiar sus actividades así como la inversión en instalaciones necesarias, sin necesidad, de recurrir de forma sistemática a aportaciones públicas.[6] El segundo principio establece una equivalencia de los ingresos generados mediante las tasas portuarias y los costes de explotación.[7] Sin embargo, el sistema portuario español no únicamente ha financiado sus gastos de explotación, sino que también ha sido capaz de generar beneficios, véase *Figure* 1.1. El resultado de explotación de todo el sistema portuario español alcanzó los 289 millones de euros en 2018, de los cuales el 48 % corresponde a cuatro autoridades portuarias: Barcelona (17.8 %), Valencia (12.6 %), Las Palmas (11.6 %) y Bahía de Algeciras (6.6 %). En los siguientes apartados se mostrará que se trata de las cuatro autoridades portuarias con mayor tráfico de mercancía transportada en

[6] Art.156 del RDL 2/2011
[7] Art. 163 del RDL 2/2011

contenedor. Por otro lado, hay dos autoridades portuarias que han registrado resultados negativos en sus beneficios de explotación: Ceuta (-0.7 millones de euros) y Melilla (-0.8) millones de euros.

Figure 1.1 Evolución de los resultados de explotación del sistema portuario español, 2008-2018. Euros constantes de 2018



Fuente: Elaboración propia a partir del capitulo 1 de las memorias anuales de las autoridades portuarias de 2008 a 2018

La principal fuente de ingresos de las autoridades portuarias españolas son las tasas que cobran a sus concesionarios y usuarios por la utilización del dominio público portuario o por la prestación de servicios. Las tasas portuarias representan el 85 % de los ingresos totales del sistema portuario español. Las tasas portuarias son cobradas fundamentalmente a tres tipos de agentes: operadores titulares concesiones portuarias, buques y compañías consignatarias.

La *tasa de ocupación* grava la ocupación del dominio público portuario en proporción a los metros lineales de muelle y los metros cuadrados de superficie ocupados por una concesión. La *tasa de actividad* se paga por el volumen de mercancía o los pasajeros embarcados y desembarcados. La *tasa de la mercancía* se paga en función de las toneladas.[8] La *tasa del buque* grava el uso que hacen los buques de las aguas de la zona de servicio y de las obras e instalaciones portuarias fijas que permiten el acceso marítimo al puesto de atraque o de fondeo que les haya sido asignado, y la estancia en los mismos. La tasa del uso especial de la zona de tránsito grava la utilización de las zonas de tránsito, especialmente habilitadas como tales por las autoridades portuarias, y excepcionalmente las zonas de maniobra, por las mercancías y elementos de transporte. La *tasa de ayuda a la navegación* grava la utilización del servicio de señalización marítima. La *tasa del pasaje* grava al número de pasajeros embarcados y desembarcados y la *tasa de la pesca fresca* se paga por el uso de las instalaciones portuarias específicas para la pesca. Se ha prescindido de la tasa de embarcaciones deportivas y de recreo ya que no tienen incidencia sobre la actividad portuaria de mercancías y pasajeros. La *Table* 1.2 muestra la recaudación de las principales tasas portuarias en 2018 en el conjunto del sistema portuario estatal y el peso de cada una sobre el total.

[8] Se excluyen las toneladas de la pesca fresca que tiene su propia tasa.

Table 1.2 Recaudación de las tasas portuarias del sector portuario español en millones de euros de 2018

Tasa Portuaria	Millones de euros	% del total
Tasa de ocupación	277	26.9%
Tasa de actividad	130	12.6%
Tasa de mercancía	280	27.1%
Tasa del buque	247	23.9%
Tasa del uso especial de la zona de tránsito	3	0.3%
Tasa de ayuda de la navegación	12	1.2%
Tasa del pasaje	77	7.5%
Tasa de la pesca fresca	6	0.6%
Total	1,032	100%

Fuente: Informe de gestión del sistema portuario de titularidad estatal 2018, tablas 4.1.1, 4.1.2 y sección 3.1

Los gastos de explotación del sistema portuario español se descomponen en los costes fijos y los que dependen de la actividad portuaria. Los costes fijos vienen determinados por la depreciación de los activos fijos, que dependen del stock de capital y del nivel de inversión de los años previos. Los costes variables dependen del personal contratado, de los gastos para llevar a cabo la provisión de los servicios, impuestos y la contribución a Puertos del Estado.[9]

El artículo 159 del RDL 2/2011 regula el fondo de compensación interportuario. Este fondo constituye un instrumento para la redistri-

[9] Art. 19.1.b) del RDL 2/2011

bución de los recursos del sistema portuario español y es gestionado por Puertos del Estado. El objetivo del fondo es financiar inversiones en infraestructuras portuarias y señalización marítima, así como sus gastos de reparación y mantenimiento, los gastos asociados a la implantación de planes de saneamiento, el desarrollo de programas de investigación, desarrollo e innovación de interés portuario y los daños físicos o situaciones económicas excepcionales.

Table 1.3 Cuenta de pérdidas y ganancias del sector portuario español en millones de euros de 2018

Operación	**Millones de euros**	**% sobre los ingresos de explotación**
1. Ingresos de explotación	1,290	100.0%
a. Tasas portuarias	1,032	80.0%
b. Subvenciones	86	6.6%
c. Otros ingresos	172	13.3%
2. Gastos de explotación	993	77.0%
a. Gastos de personal	255	19.8%
b. Amortización	437	33.9%
c. Otros gastos	300	23.3%
3. Rdo. de explotación (1-2)	297	23.0%
4. Resultados financieros	-17	-1.3%
5. Impuestos sobre beneficios	0.4	0.0%
6. Resultado del ejercicio	280	21.7%

Fuente: Informe de gestión del sistema portuario de titularidad estatal 2018, tablas 4.1.1 y 4.1.2. Las tasas de embarcaciones deportivas y de recreo han sido excluidas.

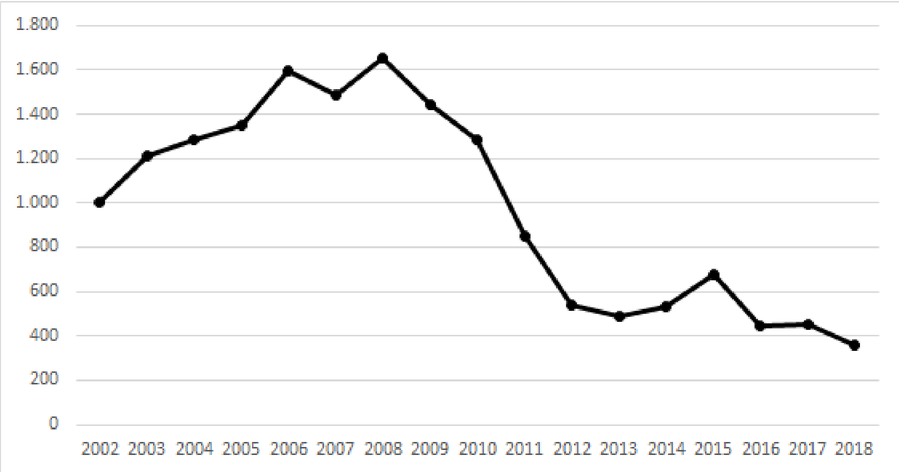
Inversiones

La inversión supone una expansión y modernización de las infraestructuras existentes con la finalidad de adaptarlas a las nuevas necesidades de la demanda de los servicios portuarios. La financiación de las inversiones se realiza mediante los resultados positivos de los ejercicios anteriores, a pesar que se pueden emplear otros recursos como la deuda a largo plazo, el fondo de compensación y los subsidios estatales y europeos.

Para el año 2018, la inversión total efectuada del sistema portuario español fue de 358 millones de euros, de los cuales el 51 % se concentra en cinco autoridades portuarias: Barcelona (13.8 %), Bilbao (13.7 %), Huelva (11 %), Santa Cruz de Tenerife (6.9 %) y Cartagena (6.5 %). La Figure 1.2 muestra la evolución de la inversión total del sistema portuario español, donde se observan las siguientes tendencias: i) una fase creciente entre el 2002 y 2008 con una tasa de crecimiento media del 9.1 %, ii) una fase decreciente del 2009 y 2013 con una tasa de crecimiento media del -15.3 % y, por último, iii) una fase más estable con una tasa de crecimiento media del -3.6 %.

El gasto en inversión no solo ha cambiado únicamente en su cuantía total, también ha cambiado el peso de cada partida respecto del gasto total. La *Figure* 1.3 muestra como la inversión en infraestructura portuaria ha pasado de representar el 60 % del gasto total en inversión

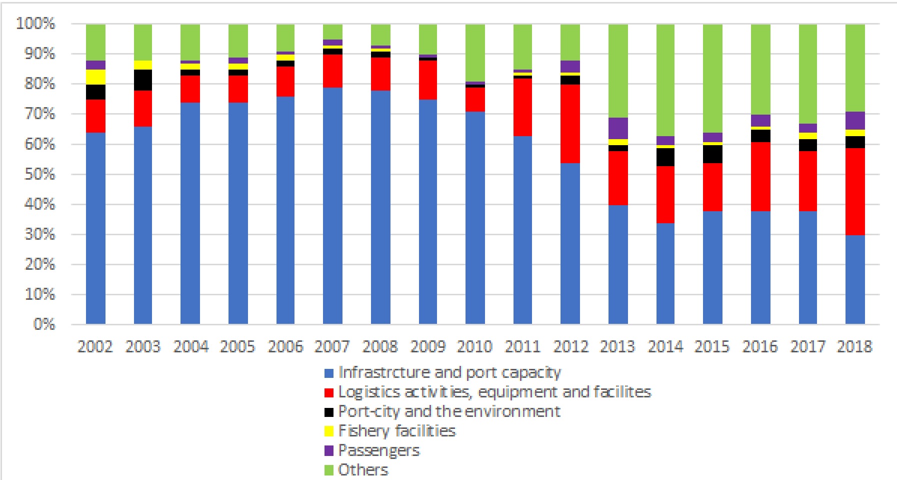
Figure 1.2 Evolución del gasto total en inversión del sistema portuario español, 2002-2018. Millones de euros constantes de 2018



Fuente: Elaboración propia a partir del capítulo 5 de los anuarios estadísticos de EPPE 2002-2018

en 2002 a representar el 30 % del gasto total en 2018, en términos de euros constantes, se ha pasado de 601 a 107 millones de euros.

Figure 1.3 Evolución porcentual de las partidas del gasto en inversión en el sistema portuario español, 2000-2018



Fuente: Elaboración propia a partir del capítulo 5 de los anuarios estadísticos de EPPE 2002-2018

De acuerdo con Cerban y Ortí, (2015, p. 5), "en España se han realizado inversiones en infraestructuras portuarias que no se justificaban de acuerdo con predicciones razonables de demanda, dando lugar a una sobrecapacidad portuaria y a los costes adicionales que ese problema conlleva." Coincidiendo en lo esencial con esta apreciación, el entonces Presidente de Puertos del Estado, José Llorca Ortega, afirmaba en 2013 (CG, 2013, p. 5) que "las inversiones portuarias del lado mar están en nuestros puertos prácticamente realizadas para los próximos veinticinco, treinta años. Existe en estos momentos un alto nivel de sobrecapacidad infraestructural instalada en el sistema portuario español." En la misma línea apunta el informe del Tribunal de Cuentas Europeo (2016) sobre inversiones portuarias cofinanciadas con fondos europeos entre 2000 y 2013, donde se analizan 42 proyectos de los cuales 16 corresponden a puertos españoles. El informe concluye que un tercio del gasto analizado en nuestro país correspondió a proyectos innecesarios, que duplicaban instalaciones ya existentes en puertos cercanos no saturados, y que la mitad de estas infraestructuras seguían en desuso o con un grado muy bajo de utilización tres años después de su puesta en funcionamiento. El Capítulo 5 de esta tesis calcula la capacidad óptima del sistema portuario español y analiza la posibilidad de la existencia de un exceso de capacidad.

Tráfico portuario

El tráfico portuario ha aumentado durante el periodo estudiado, de los 366 millones de toneladas en 2002 a los más de 563 millones de toneladas en 2018 (Véase la *Table* 1.4). Esta cifra representa un incremento del 3.3 % respecto el año anterior y un crecimiento porcentual medio del periodo 2002-2018 del 2.9 %.

Table 1.4 Resumen de la actividad portuaria

	2002	**2006**	**2010**	**2014**	**2018**
Tráfico total (millones de Tm)	366,461	462,164	432,550	482,084	563,557
Pasajeros (miles)	19,219	24,501	26,385	29,331	36,101
Buques (nº)	113,824	119,819	113,717	138,705	167,119
Arqueo (millones de GT)	1,159	1,444	1,877	1,935	2,303

Fuente: Anuarios estadísticos de Puertos del Estado, años 2002, 2006, 2010, 2014 y 2018

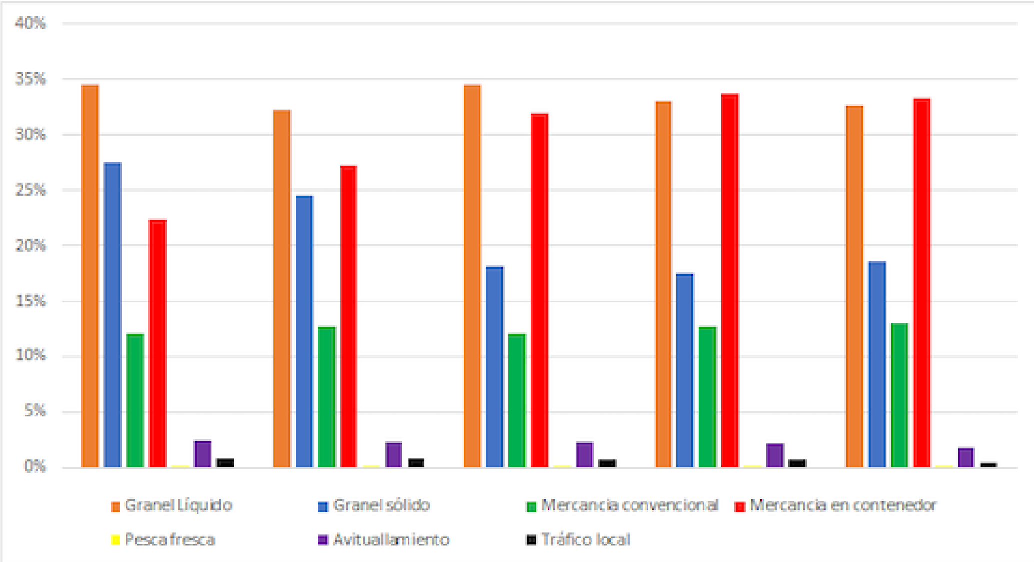
Las autoridades portuarias con mayor volumen de tráfico representan el 68.5 % del tráfico total, son Bahía de Algeciras (19.1 %), Valencia (13.6 %), Barcelona (12 %), Bilbao (6.3 %), Cartagena (6 %), Huelva (5.8 %) y Tarragona (5.7 %).

El tráfico de buques ha evolucionado al mismo ritmo que el tráfico total de toneladas. Ha crecido a una tasa de variación media del 2.6 % en el periodo comprendido entre el 2002 y 2018 y un 7.3 % respecto del año anterior. El análisis del tráfico de buques requiere tener en cuenta los avances tecnológicos de la navegación, que se traduce en buques con una mayor capacidad de carga, por tanto, no únicamente han llegado más buques al sistema portuario español, los que han llegado presentaban una mayor capacidad. De acuerdo con la Table 1.4, se observa que el arqueo ha aumentado un 19 % del 2014 al 2018. El arqueo de los buques, medido en toneladas brutas, mide la capacidad de carga que puede transportar un buque.

El tráfico total se mide en toneladas y está formado por diferentes tipos de mercancía: granel líquido, granel sólido, mercancía convencional, mercancía transportada en contenedor, pesca fresca, avituallamiento y tráfico local. La *Figure* 1.4 representa la evolución de cada tipo de mercancía durante el periodo estudiado.

Del tráfico portuario total, un tercio corresponde al granel líquido, aunque su participación respecto el tráfico total se ha mantenido constante, el nivel ha crecido de los 126 millones de toneladas en 2002 a los 178 millones de toneladas en 2018. El 85 % del granel líquido son productos petrolíferos, por ello, los puertos que disponen de una refinería petrolífera instalada en las cercanías del puerto ocupan las primeras posiciones en el transporte de granel líquido. Bahía de Algeciras es la autoridad portuaria con mayor relevancia en el total de graneles líquidos petrolíferos (20.3 %), seguida de Cartagena (15.9 %), Tarragona

Figure 1.4 Evolución de los diferentes tipos de mercancía respecto el tráfico total en el sistema portuario español para los años: 2002, 2006, 2010, 2014 y 2018



Fuente: Elaboración propia a partir del capitulo 3 de los anuarios estadisticos de EPPE para los años 2002, 2006, 2010, 2014 y 2018.

(12.2 %), Huelva (11 %) y Bilbao (10.9 %).

El 15 % restante los graneles líquidos lo componen productos químicos, aceites, ácidos y gas. Huelva, con todo el tráfico de su puerto interior dedicado a los fósforos, abonos y sosa caustica representa el 27.6 % de todo el tráfico de granel líquido no petrolífero en 2018 y Barcelona, que concentra todo el tráfico de líquidos químicos en el Muelle 32, es la segunda autoridad portuaria con mayor número de toneladas de líquidos no petrolíferos y representa el 22.2 % del total para el mismo año.

El granel sólido supone un 18 % de las toneladas totales para el año 2018 y su participación se ha reducido durante el periodo analizado, ya que en 2002 representaba un cuarto de las toneladas totales. La reducción de la actividad minera de los últimos años es el motivo de esta caída. Durante todo el periodo estudiado, Gijón, con una participación del 16.8 % del tráfico total para el año 2018, es la autoridad portuaria con mayor tráfico de graneles sólidos, debido a la tradición de la actividad minera de la región. Ferrol-San Cibrao (10.5 %) con el transporte de carbón de la planta de Endesa Generación SA y Tarragona (9.8 %) con el transporte de carbón y cereales de los muelles Catalunya y Aragón ocupan la segunda y tercera posición respectivamente del ranking en el año 2018. Por último, Almería (6.2 %) es la cuarta autoridad portuaria con más tráfico de graneles sólidos, concentra todo este tráfico en el puerto de Carboneras con los operadores Holcim SA y Endesa Generación.

La modalidad de tráfico más representativa del sector portuario español es la mercancía general, que considera el transporte de todas las mercancías no consideradas como graneles, ni pesca fresca ni el tráfico interior entre puertos. La mercancía general representa casi la mitad de las toneladas transportadas por el sistema portuario y puede descomponerse en mercancía general contenerizada y mercancía general no contenerizada. La participación de la mercancía general no contenerizada se ha mantenido constante durante el periodo estudiado, representa el 13 % del tráfico total. En cambio, la de la mercancía general contenerizada ha aumentado, ha pasado de los 82 millones de toneladas en

2002 (un cuarto de las toneladas totales) a los más de 181 millones de toneladas en 2018 (un tercio de las toneladas totales). El aumento del tráfico de contenedores es una consecuencia del aumento de los avances tecnológicos de la industria portuaria y la mecanización de la carga.

Para el año 2018, la autoridad portuaria de Valencia concentra 18,5 % del tráfico de la mercancía general no transportada en contenedor y es la autoridad portuaria con más terminales dedicadas a este tráfico (Los puertos de Gandía y Sagunto se dedican al tráfico de mercancía general, madera y automóviles). En segunda posición, la autoridad portuaria de Baleares representa el 16.3 % del tráfico total, aunque viene derivado de la tara del equipamiento Ro-Ro de los casi 9 millones de pasajeros que han embarcado o desembarcado en el año 2018. La autoridad portuaria de Barcelona (15.1 %) es la tercera, justificado por el tráfico de automóviles, multipropósito y polivalente de los muelles 29, 30 y 01. Por último, en el ranking siguen las autoridades portuarias de Las Palmas (5.9 %) y Santa Cruz de Tenerife (5 %), por el suministro de bienes a las islas Canarias.

Respecto a la mercancía transportada en contenedor, el 90.2 % de las toneladas totales en 2018 han pasado por las siguientes autoridades portuarias: Bahía de Algeciras (31.7 %), Valencia (30.3 %), Barcelona (18.2 %), Las Palmas (6.4 %) y Bilbao (3.6 %). La mercancía transportada en contenedor no responde únicamente a la demanda de los servicios portuarios para la exportación e importación de productos, el 60.7 % se considera mercancía en tránsito. La mercancía en tránsito es toda aquella carga que es descargada en las instalaciones portuarias, para ser posteriormente cargada por otro buque, sin que las mercancías entren en territorio nacional. Se considera que son las mercancías por las que el sistema portuario español compite con el resto de países. Por ejemplo, el 91.2 % de las toneladas totales de la mercancía en contenedor de Bahía de Algeciras se considera mercancía en tránsito, aprovecha su ventaja competitiva a nivel europeo al ser la autoridad portuaria que sirve como puerta de entrada al mar Mediterráneo para las rutas atlánticas.

Durante el año 2018, más de 36 millones de pasajeros han pasado por el sistema portuario español, esta cifra incluye los pasajeros que han embarcado o desembarcado, los pasajeros en régimen de crucero y los transportados entre puertos como tráfico local. Desde el año 2002, el tráfico de pasajeros ha crecido con una tasa de variación media del 4.1 % y para el año 2018 ha crecido un 6 % respecto el año anterior. El uso de la vía marítima es poco frecuente para los pasajeros que prefieren la vía aérea para los movimientos interinsulares y el transporte terrestre para los movimientos dentro de la península. Sin embargo, el tráfico de pasajeros en las autoridades portuarias insulares y del norte de África es muy común, concentra el 49.5 % de los pasajeros totales. Las Autoridades Portuarias con más tráfico de pasajeros dentro de la península son Bahía de Algeciras (16.5 %), por su conexión con los puertos del norte de África y Barcelona (12.4 %) por su conexión con la autoridad portuaria de Baleares.

1.2 Objetivos y metodología de la Tesis

El presente trabajo tiene diferentes objetivos. El primero es calcular la eficiencia técnica de las autoridades portuarias en la prestación de servicios sobre tráfico de mercancías y pasajeros en el periodo 2002-2018. Para llevar a cabo este objetivo, se utiliza una función distancia orientada al output y se estima la eficiencia técnica a partir de una función frontera del tipo estocástico (SFA). Del mismo modo, se emplea la metodología no paramétrica (DEA) bajo dos supuestos alternativos, o bien bajo rendimientos constantes a escala (modelo de Charnes, Cooper y Rhodes, 1978), o bien bajo rendimientos variables a escala (modelo de Banker, Charnes y Cooper, 1984). Este análisis nos permite obtener tres indicadores de eficiencia técnica por puerto y año.

A continuación, se realiza un análisis para identificar los principales determinantes que explican los tres indicadores de eficiencia anteriormente obtenidos. Entre los potenciales determinantes se incluyen las terminales portuarias clasificadas en función del tipo tráfico al que están destinadas y tipo de gestión. Además, se incluyen variables relacionadas con la localización geográfica de los puertos, el acceso a infraestructuras complementarias, el tamaño de los puertos y variables para analizar el impacto de las reformas legislativas que afectan al sector portuario durante el períao de análisis. La metodología econométrica empleada es una regresión Tobit para el indicador de eficiencia que se obtiene de la aproximación paramétrica y el estimador desarrollado por Simar y Wilson (2007) para el análisis de los indicadores de eficiencia obtenidos con la aproximación no paramétrica.

El segundo objetivo es estimar la eficiencia económica del sistema portuario español para el mismo periodo. Se incluyen todas las autoridades portuarias excepto Marín y Ría de Pontevedra, Melilla, Pasaia y Vilagarcía de Aurosa. Adicionalmente, se calcula el exceso de capacidad del sistema portuario español. La metodología empleada es la estimación de una función de costes de corto plazo orientada al input empleando una función frontera de tipo estocástico que nos permite obtener los distintos niveles de eficiencia económica por puerto y año. A continuación se realiza un análisis para identificar, al igual que en el objetivo anterior, los principales determinantes de la eficiencia económica.

El tercer objetivo consiste en medir el poder de mercado de los puertos españoles mencionados anteriormente. El método aplicado es el indicador de Boone (Boone, 2008) que requiere información de los costes marginales y las cuotas de mercado. Se regresan las cuotas de mercado por cada tipo de output con respecto a los costes marginales correspondientes. El coeficiente estimado, en valor absoluto, mide el poder de mercado de modo que un mayor valor indica un menor poder de mercado.

Esta tesis consta de siete capítulos que se estructuran de la siguiente forma. El capítulo 1 presenta una descripción del sistema portuario español, detalla los objetivos y metodología de esta tesis junto a las principales conclusiones. El capítulo 2 incluye una revisión detallada de los principales artículos que estudian la eficiencia de distintos sistemas portuarios. En el capítulo 3 se describen los datos que se van a emplear durante el trabajo. El capítulo 4 calcula la eficiencia técnica del sistema portuario español utilizando las metodologías paramétrica y no paramétrica, además de identificar sus principales determinantes. El capítulo 5 mide la eficiencia económica de los puertos españoles a partir de la estimación de una función de costes de corto plazo y, al igual que en el capítulo 4, se identifican sus principales determinantes. Además, se obtiene una medida de los niveles de sobrecapitalización. El capítulo 6 presenta los resultados del índice de Boone que refleja el poder de mercado para cada uno de los outputs analizados. El capítulo 7 recoje las principales conclusiones.

A continuación, presentamos las principales conclusiones de los capítulos 4, 5 y 6.

Conclusiones del capítulo 4

Los indicadores de eficiencia obtenidos a partir de los tres métodos SFA, DEA-CRS y DEA-VRS presentan rankings de eficiencia técnica muy similares como lo demuestran los coeficientes de correlación de orden de rango de Spearman superiores a 0,71. Por lo tanto, se concluye que los rankings obtenidos son robustos a la metodología utilizada. Los puertos más eficientes técnicamente son Bahía de Algeciras, Gijón, Valencia y Ferrol SC. Mientras que los puertos técnicamente menos eficientes son Vilagarcía de Aurosa, Marín y Ría de Pontevedra, Vigo, Málaga y Melilla.

En cuanto a los niveles medios de eficiencia técnica, los obtenidos con el enfoque paramétrico son especialmente bajos, pasando de 0,4067 en el año 2002 a 0,3541 en 2018. Esto implica una reducción media anual de la eficiencia técnica del 0,86 %. Sin embargo, los niveles medios de eficiencia técnica de los métodos no paramétricos tienen un crecimiento medio anual del 0,61 % para el DEA-CRS y del 0,79 % para el DEA-VRS. Además, es interesante observar que los puertos presentan rendimientos decrecientes a escala desde 2010 y, por tanto, se mantiene la tendencia obtenida en González & Trujillo (2008). Por último, se ha producido progreso técnico en el periodo analizado, con un crecimiento medio anual del 1,77 %. Los resultados sobre los determinantes de la eficiencia técnica fueron los siguientes. Los puertos con terminales de contenedores gestionados por empresas privadas son más eficientes con un nivel de significatividad del 1 % para cualquier método utilizado. Mientras que las gestionadas directamente por los puertos no tienen ningún efecto. Se encuentran efectos similares para las terminales de mercancías de carge no contenedorizada, con la diferencia de que cuando la terminal es gestionada directamente por los puertos el efecto es negativo y significativo. Los puertos con terminales de pasajeros son siempre menos eficientes independientemente del método utilizado, aunque los puertos que tienen terminales de gestión privada tienen un mayor impacto negativo. Por último, los puertos que manipulan líquidos tienen un efecto positivo y significativo en la eficiencia portuaria, pero sólo cuando se usan métodos no paramétricos.

En cuanto a la ubicación de los puertos, los puertos en las islas son más eficientes sólo en el caso de que se utilice un DEA-VRS. Con respecto al litoral los puertos de la costa cantábrica son más eficientes que los de la costa mediterránea, mientras que los puertos de la costa atlántica son menos eficientes que los de la costa mediterránea en el caso de utilizar un DEA con rendimientos variables a escala. Una refinería de petróleo cerca de un puerto aumenta la eficiencia técnica, mientras que el uso de acceso ferroviario la reduce, y estos resultados son robustos al enfoque utilizado. Las reformas legislativas aplicadas en los años 2003, 2010 y 2011 no suelen tener un efecto significativo sobre la eficiencia técnica, reforzando así la conclusión de González & Trujillo (2008) y Díaz-Hernández et al. (2008). La ley 33/2010 tiene un efecto negativo a un nivel de significatividad del 10 % y sólo para los métodos no paramétricos. El RD 2/2011 tiene un efecto negativo al nivel de significatividad del 5 % cuando se considera el enfoque paramétrico. Por último, el tamaño del puerto no afecta a la eficiencia técnica independientemente del método utilizado. Esta última conclusión contrasta con Martínez-Burdía (1996) y Bonilla et al. (2002) que mostraron que los puertos más grandes tenían niveles de eficiencia más bajos. También con Martínez-Burdía et al. (1999) y Coto-Millan et al. (2000) que concluyeron que los puertos más grandes eran los más eficientes.

Conclusiones del capítulo 5

La eficiencia económica media obtenida durante el periodo analizado es de 0,8251. Ésta varió de un 0,8457, al principio de la muestra, hasta 0,7961 en 2018, lo cual supone una reducción media anual de la eficiencia económica del 0,38 %. Los puertos más eficientes económicamente son Motril, Avilés, Almería, Sevilla Ferrol y Ceuta; mientras que Valencia, Barcelona, Bahía de Algeciras, Vigo, Tarragona y Las Palmas son los menos eficientes. Los costes totales disminuyen con el tiempo, por lo que se alcanza cierto progreso técnico coincidiendo con el resultado de Álvarez & Tovar (2012). Otra conclusión es la existencia de sobrecapitalización en el sistema portuario español, que posiblemente explique la reducción de inversiones portuarias observadas en los últimos años reforzando las conclusiones obtenidas por Álvarez & Tovar (2012). Los resultados de la segunda etapa muestran que el tipo de gestión importa para las terminales de contenedores y de pasajeros. Las terminales de contenedores gestionadas por la autoridad portuaria tienen un efecto positivo en la eficiencia económica, mientras que cuando son gestionadas por una empresa privada su efecto es negativo pero no significativo. Para el caso de las terminales de pasajeros, el efecto es inverso, las terminales de gestión privada tienen un efecto positivo, mientras que las gestionadas directamente por las autoridades portuarias tienen un efecto negativo. Por último, en el caso de las terminales que manipulan líquidos y mercancías no contenerizadas, el efecto sobre la eficiencia portuaria es negativo independientemente del tipo de gestión. El uso de la conexión ferroviaria y la existencia de una refinería de petróleo cerca del puerto también reducen la eficiencia económica. Los puertos situados en islas son más eficientes y los situados en el litoral cantábrico son más eficientes que los puertos de la costa mediterránea. En cuanto al efecto de las reformas legislativas en el periodo, tanto la del año 2003 como la de 2010 no han afectado significativamente a la eficiencia económica, mientras que la de 2011 tuvo un efecto negativo. Por último, los puertos más sobrecapitalizados y con mayor nivel de índice de mecanización son menos eficientes.

Conclusiones del capítulo 6

Se presentan en este capítulo estimaciones del poder de mercado para diferentes mercados que corresponden a los cuatro productos definidos en los capítulos anteriores más otro submercado definido por el tráfico de contenedores en tránsito. Los resultados muestran que el mercado más competitivo, es decir el que tiene el mayor índice de Boone en términos absolutos, es el submercado de contenedores en tránsito, el mercado de carga en contenedores ocupa el segundo lugar, seguido por el mercado de pasajeros, a continuación el de transporte de líquidos y finalmente el que corresponde al tráfico de carga no contenerizada. En cuanto a la estimación de los índices de Boone por litoral, se observa que el litoral sur y este es más competitivo que el litoral norte, excepto para el mercado de tráfico de carga no contenerizada. La razón principal es que algunos de los puertos de la costa norte tienen como tráfico principal la mercancía general no contenerizada y, sin embargo, la mayoría de los puertos de la costa sur y este tienen como principal el tráfico de contenedores o el de productos petrolíferos.

Chapter 2

Literature review

2.1 Introduction

The purpose of this chapter is to describe and classify the articles that have studied port efficiency. They are classified according to the following criteria. The first criterion is the port system analyzed, then in the first Section the articles that have measured the efficiency of the Spanish port sector are reviewed, while in Section 2 those that have measured other country or region ports efficiency are considered. Regarding the second criterion, within each group a distinction is made between articles that have used a parametric method (distance functions) and those using a non-parametric one, mainly Data Envelopment Analysis (DEA). Finally, Tables B.1 and B.2 in the Appendix B contain summarized information on the sample, objectives, methodology used, the inputs and outputs and results per article reviewed.

2.2 Efficiency analysis of the Spanish port system

In this Section we present fifteen works that study Spanish ports efficiency in the last twenty five years. There is a majority of studies that follow a parametric approach, twelve, while only three consider a non-parametric one.

2.2.1 Parametric methods

The first paper that considers the parametric method, a cost-oriented Cobb-Douglas function, for the efficiency analysis of the Spanish port system is Martínez-Budría (1996). It estimates a cost function for the entire Spanish port system that includes 135 observations of 27 ports for the period 1985-1989, in a second stage analysis the author identifies the determinants of economic efficiency. The only output used is the number of tons of all goods moved by the port authority. The number of passengers is converted into tons by multiplying by a factor of 0.1. The prices of the labor, intermediate consumption and capital inputs are obtained as follows. The price of labor is obtained by dividing the total personnel costs by the total number of workers, the price of intermediate costs is obtained by dividing the cost of consumption, work and external supplies by the total tons, and finally, the price of capital is obtained as the quotient between the depreciation for the period and the number of linear meters of docks with depth greater than four meters. In addition, the author defines three variables: one to indicate whether a port is autonomous, a second variable as an indicator of port concentration and the last one representing gross profits. The study concludes that ports belonging to *Juntas de Puertos* and those of larger size were less efficient.

Baños-Pino et al. (1999) introduce two important novelties with respect to Martínez-Budría (1996). The study estimates a trans-logarithmic cost function, in addition to an input-oriented distance production function and obtains the level of over-capitalization of the quasi-fixed input in the Spanish port system. The database covers the entire Spanish port system and extends the Martínez-Budría (1996) database for the period 1985-1997. The measure of output used is composed by the total tons moved by the port authority and the income obtained from the leasing of port facilities measured in millions of pesetas. The inputs considered in the distance function are the number of workers, the total expenditure on consumption and on supplies except labor and depreciation, and the total capital expenditure approximated as a percentage of net assets. The prices used in the cost function are the price of labor and the price of intermediate consumption obtained in the same way as in Martínez-Budría (1996); and the price of capital which has been approximated as the investment made in one period with respect to the investment made in the previous period. Finally, the quasi-fixed input considered is the linear meters of dock with depth greater than four meters. They conclude that both methods (cost and distance functions) identify over-capitalization of the quasi-fixed input, although the magnitude is smaller in the distance function approach.

In Coto-Millán et al. (2000) the focus is also on the port costs, although the main novelty respect the previous authors is that they use a stochastic frontier cost function. Besides, in a second stage analysis the determinants of economic efficiency are identified. The database incorporates the entire Spanish port system for the period 1985-1989. The structure of outputs-inputs is the same as that used in Martínez-Budría (1996). Their results agree with Martínez-Budría (1996) in that smaller ports and ports managed in a centralized way are the most efficient.

Jara-Díaz et al. (2005), in contrast to previous authors, stopped considering the entire Spanish port system and they consider an estimation of a trans-logarithmic cost model for monthly data from three port terminals located in the Las Palmas port. They used data for the periods 1992-1997 for terminal 1, 1991-1999 for terminal 2 and 1992-1998 for terminal 3. The outputs considered are tons of containerized general cargo, tons of non-containerized general cargo and tons of Ro-Ro cargo. For the inputs and their prices the authors distinguish between total port staff and non-port staff expenditure as a proxy for labor, square meters of surface area as the quasi-fixed input and the sum of depreciation for the period plus the return on working capital is considered the cost of capital. The price of labor is obtained by dividing the personnel expense by the number of workers, the price of capital is obtained as the ratio between the accounting depreciation of all tangible net assets and the active capital of the period (net fixed assets under exploitation); and, finally, the price of electricity is used as a proxy for the price of intermediate consumption. They conclude that containerized cargo has the lowest marginal costs and all terminals have increasing returns to scale.

González & Trujillo (2008) are the first authors to use an output-oriented distance function to calculate the technical efficiency of the Spanish port system. It is also the first paper that uses a parametric methodology to analyze the effect of legislative reforms on technical efficiency. Data are from the nine port authorities with the largest containerized cargo for the period 1990-2002. Tons of containerized general cargo, tons of liquid bulk, number of passengers and the sum of tons of non-containerized general cargo, solid bulk, fresh fish, provisioning, and local traffic are the four outputs considered. The inputs used for the estimation are the linear meters of dock with a deeper than four meters, the square meters of port area and the number of workers. In addition, the authors define two binary variables to control for the location of a port on an island and for the existence of oil refineries close to a given port. They conclude that the legislative reforms did not affect technical efficiency, although technical progress increased during the period analyzed.

There are two studies that use the same database and the output and inputs definitions as in Jara-Díaz et al. (2005): Rodríguez-Álvarez et al. (2011) and Tovar & Wall (2012). The former studies how uncertainty in port demand affects total costs. The authors consider an auto-regressive demand function to calculate demand variability and introduce this expression in a short-run cost function. They conclude that uncertainty in demand has a significant effect on costs and that not considering demand variability leads to an underestimation of terminal efficiency. Tovar & Wall (2012) estimates a demand forecast function and two cost functions, one with uncertainty and one without uncertainty in port demand. They show that the presence of uncertainty in port demand affects the choice of inputs and costs. Specifically, uncertainty in port demand increases the use of land and non-port workers who are hired ex-ante. In addition, with port uncertainty, the presence of economies of scale and scope is greater.

Rodríguez-Álvarez & Tovar (2012) is the first article to analyze the effects of regulatory reforms on economic efficiency and also to analyze the reform of the year 2003 on port efficiency. In addition, it also calculates the over-capitalization rates of the quasi-fixed input for ports in the Spanish port system. Finally, the authors estimate a short-run total cost function for the period 1993-2007. Four outputs are used in the study: tons of solid bulk, tons of liquid bulk, tons of general cargo and the number of passengers. The depreciation during the period approximates the total cost of capital, labor is measured by number of workers, and current expenses and external supplies are identified as the total cost of intermediate consumption. The quasi-fixed input is defined as the square meters of the surface area. Besides, the price of labor is obtained by dividing the total personnel expenditure by the number of workers, the price of intermediate consumption is obtained by dividing the total cost of intermediate consumption by the square meters of surface area and the price of capital is obtained by dividing the total cost of capital by the square meters of surface area. In addition, Rodríguez-Álvarez & Tovar (2012) defines the same binary variables as in González & Trujillo (2008) and a new variable to describe the proportion of containerized cargo with respect to total tons for each port. The authors conclude that for the period of study there was over-capitalization in the quasi-fixed input and technical progress in the Spanish port system. With respect to legislative changes, they find the legislative reforms of 1992 and 1997 had positive effects on economic efficiency, while the 2003 reform had the opposite effect on efficiency levels.

The study of Coto-Millán et al. (2015) analyzes the effects of port regulation and pays particular attention to the effects of competition and of the crisis on technical efficiency. The main novelty with respect to González & Trujillo (2008) and Rodríguez-Álvarez and Tovar (2012) is that data are for the period 2002-2011 and from operating companies located in ports that performed different services. In particular, shipping companies, stevedores, and companies offering logistics, towage, mooring, and ship repair and maintenance services. A stochastic frontier method assuming a Cobb-Douglas functional form is used. They conclude that the reform of year 2003 increased technical efficiency, thus contradicting Rodriguez-Alvarez & Tovar (2012) conclusion.

Tovar & Wall (2015) continued along the line of their 2012's work on the over-investment in inputs, and analyze production technology and technical efficiency to answer the following question. Can a port authority increase freight traffic while reducing the use of inputs? They consider a distance function of a quadratic form following Färe et al. (2005) and Serra et al. (2011). The database includes 400 observations for the period 1993-2012 from all Spanish port authorities with the exception of A Coruña, Avilés, Ferrol-San Cibrao, Huelva, Pasaia and Vilagarcía de Aurosa. The five outputs considered are the number of tons of solid bulk, of tons of liquid bulk, of tons of containerized general cargo, of tons of non-containerized general cargo and the number of passengers. In addition, two quasi-fixed inputs are included: port buildings and infrastructures and surface area in square meters. Variable inputs include the number of workers and intermediate consumption expenditure. The answer to the posed question was positive, they showed that a representative port could increase container traffic and reduce the use of variable inputs by 6.4 percent, keeping the quasi-fixed input constant. The corresponding increases for bulk solids and non-containerized cargo were 4.1 percent and 6.1 percent, respectively.

Coto-Millán et al. (2016) analyzes the impact of public regulation including the effect of the 2010 legislative reform on port efficiency over almost three decades. They extend Tovar & Wall (2015) by widening the database to include the entire Spanish port system except Sevilla for the period 1986-2012 and it was the first article to analyze the effects. An input-oriented distance function is estimated. The outputs used are the same as those in Tovar & Wall (2015). With respect to inputs, capital is approximated as the net assets, labor is defined as the number of workers and intermediate consumption is considered the external supplies and other current cost apart from labor and capital costs. Two control variables are defined to control for the openness of the economy (obtained as the percentage of the monetary volume of foreign trade with respect to GDP) and trade intensity (obtained as the percentage of the monetary volume of domestic trade with respect to GDP). The authors show that there were increasing returns to scale in the period and that the reforms of 1997 and 2003 had positive and significant effects on technical efficiency.

The recent paper Pérez et al. (2020) is the first article to analyze the impact of port specialization on technical efficiency using stevedores to measure the labor input. Moreover, as previously done in Martínez-Budría (1996), Coto-Millán et al. (2000) and Bonilla et al. (2002), the study analyzes the impact of port size on technical efficiency. The database includes the entire Spanish port system for the period 2001-2011, and like Gonzalez & Trujillo (2008) an output-oriented distance function is estimated. Bulk cargo, which includes tons of solids bulk and liquids bulks; and general commodity, which includes containerized cargo, conventional non-containerized cargo, and fresh fish are two outputs considered. Regarding the inputs, the number of stevedores measures the labor factor, while port infrastructure is approximated by the linear meters of dock deeper than four meters and by an indicator that includes the number of cranes and the average capacity of each one of them. The dummy variables previously used in González & Trujillo (2008) and Rodríguez-Álvarez & Tovar (2012) are also considered together with a dummy variable capturing the province in which the port is located. The paper finds that ports specializing in containerized cargo, general cargo and liquid bulk show the highest levels of technical efficiency. In addition, that medium and large ports are the most efficient.

2.2.2 Non-parametric methods

The first article that analyzed port efficiency in the Spanish port system using a DEA approach is Martínez-Budría et al. (1999). In particular, two input-oriented DEA are used. First, a DEA that assumes varying returns to scale (denoted BCC-DEA after Banker et al. 1984) and also a DEA that assumes the same type of returns (denoted additive model DEA after Charnes et al. 1985) but distances to the frontier use a rectangular metric instead of a radial one used in BCC models. The database includes information from all ports in the Spanish port system for the period 1993-1997. Ports are classified into three groups according to their complexity, that is according to a combination of port size and cargo composition. The considered outputs coincide with those in Baños-Pino et al. (1999). Personnel costs, depreciation of fixed assets and total intermediate consumption costs are the inputs. The study concludes that ports of higher complexity have higher levels of efficiency, ports of medium complexity maintain an increase efficiency, while ports of lower complexity suffered a reduction in relative efficiency.

Later, Bonilla et al. (2002) also apply a non-parametric approach to study efficiency with the main novelty of eliminating the ports that the authors considered as influencers (Algeciras, Almería-Motril and Ferrol). Therefore, only information about 23 ports for the period 1995-1998 is used in the paper. Two alternative input-oriented DEA models were computed, a BCC-DEA and a DEA with constant returns to scale (denoted CCR-DEA after Charnes et al. 1978). Total number of cargo tons is the measure for output used while available equipment is that for input. The authors conclude that no significant differences between the two methods used (either with varying or with constant returns to scale) were found. They also found that ports like Barcelona, Bilbao, or Balearic Islands were included in a second highest efficiency group, showing that small ports may have high efficiency levels. Therefore, their results are in disagreement with Martínez-Budría et al. (1999) conclusion that larger ports have higher efficiency levels.

Finally, Diaz-Hernandez et al. (2008) is the first article that uses non-parametric methods to evaluate changes in efficiency and productivity after the period of introduction of new technologies related to container traffic and legislative reforms. An input-oriented BCC-DEA is computed for the first stage and in the second stage of the analysis a Malmquist index is obtained by decomposing total factor productivity into variations in technical efficiency and technological change. The data used correspond to most of ports in the Spanish port system except Avilés, some Balearic ports, Barcelona, Ceuta, Ferrol-San Cibrao, Gijón, Huelva, Pasaia and Vilagarcía de Aurosa for the period 1994-1998. There outputs are considered tons of containerized cargo, tons of non-containerized cargo and tons of solid bulk. Working hours and crane hours are the inputs. The paper finds that the 1998 efficiency was 1.2% lower than the 1994 efficiency, with the largest drop occurring in the last years of the sample. Additionally, technical change is found to be the main factor enabling productivity growth. Finally, ports with the highest rates of technical change are those with the highest number of tons of cargo, especially those with container terminals and with a significant presence of privately owned cranes.

2.3 Efficiency analysis of other port systems

In this Section we present the analysis provided by twenty papers that analyze ports all around the world. Several studies are focused on particular countries or regions while other include samples of ports located in different regions. Most of them use a parametric approach (eleven) while the rest (nine) a non-parametric one.

2.3.1 Parametric methods

Chang (1978) is considered the first article to analyze port efficiency. Its main objective was to present a different approach than that used previously in economic theory, to determine whether the port of Mobile (Alabama, USA) needed an expansion of its facilities. The database includes 20 observations for the period 1953-1973. The author consider a Cobb-Douglas production function with only one output, annual gross income. Regarding inputs, the average monthly number of workers and the value of net assets were used. In the second stage, the author incorporates two binary variables: one which has a value of one when the port is being used to its maximum capacity and another which has a value of one when the port is used at a moderate capacity. The second stage analysis identified factors that influenced total tons by using OLS estimations. The conclusion is that the port of Mobile had to extend its facilities.

Liu (1995), eighteen years later, is the first article to analyze the British port system and the first article to analyze the effects of privatization on port efficiency. Using a database of 224 observations consisted of 28 UK ports for the period 1983-1990, it estimates a stochastic production frontier assuming a trans-logarithmic functional form. The output used was the same as that used by Chang (1978). To measure labor differs from Chang (1978) and uses total personnel expenditure, also to measure capital net asset value is considered but only including fixed asset. In addition, Liu (1995) defined a binary variable to determine the size of the ports, included the capital-labor ratio, introduced a variable to determine whether the port was located in the south or east of the country and finally, a dummy to distinguish between private and public ports. Liu (1995) concluded that large ports with a high capital-labor ratio intensity had a positive and limited impact on port efficiency, but no evidence was found that port privatization was a pattern of efficiency gains.

Nottemboom et al. (2000) was the first article that analyzed port efficiency of different countries using a parametric method. Specifically, it collected data from the 36 largest European container terminals for 1994. The methodology used was a Bayesian stochastic frontier with the Cobb-Douglas functional form. The only output considered was tons of containerized cargo. Regarding inputs, linear meters of quay, hectares of port area and gantry cranes were the three inputs considered. Nottemboom et al. (2000) showed that terminals located in northern Europe were more efficient. Also that either large terminals or small ones but located in large or hub ports were more efficient. Finally, as in Liu (1995), no relationship was found between the type of ownership and the level of efficiency.

Following the path of Nottemboom et al. (2000), Cullinane et al. (2002) presented a study very similar applied to the Asian port sector. The main objective was to relate administrative and ownership structures to port efficiency. The authors estimated stochastic production frontier assuming a Cobb-Douglas functional form for a sample of 15 Asian container ports in the period 1989-1998. The output was container cargo in TEUs. The inputs were linear meters of dock, hectares of port area and, in contrast to Nottemboom et al. (2000), the number of pieces of equipment used in cargo handling. Their results showed that the size of the port terminal was correlated with its efficiency and in contrast to Liu (1995) and Nottemboom et al. (2000), the authors found evidence that those terminals that have been transformed from public to private ownership have improved their efficiency levels.

Estache et al. (2002) is the first article to analyze the reforms carried out in Mexico in the 1990s. These reforms were aimed at restructuring, privatization, liberalization, and competition. The authors estimate a stochastic production frontier function considering two different functional forms: Cobb-Douglas and trans-logarithmic. The analysis uses a panel data with 44 observations from eleven Mexican ports for the period 1996-1999. The output measure used is the tons of cargo handled by the port. Labor is defined as the number of workers and capital as the port surface area in square meters. Estache et al. (2002) showed that the reforms carried out can generate short-term improvements in the performance of port activities. Also that port efficiency gains are important in case the regulator is instructed in passing on the benefits of port reform to users.

Next, Cullinane & Song (2003) replicates the study in Estache et al. (2002) to the Korean port system. The main objective of the article was to evaluate the Korean port liberalization policy and give recommendations on future port policies. Cullinane & Song (2003) uses financial data from the annual accounts of five container port terminals for different years. The methodology applied is a stochastic frontier with the Cobb-Douglas functional form. Output was approximated as turnover excluding property sales. Labor was approximated as non-port personnel expenditure on the one hand and port personnel expenditure on the other hand. Quasi-fixed capital was defined as the net value of fixed assets, equipment, buildings and land; while variable capital as the net value of mobile equipment, including container cranes, yard tractors and forklifts. Cullinane & Song (2003) shows that productive efficiency improved following the implementation of privatization and deregulation policies within the Korean sector. Then, the authors' findings, support the idea that policies promoting competition among port terminals lead to an increase of Korean port sector competitiveness.

The only study in this review that estimates a cost function is Barros (2005) that analyzes the extent of technological change and technical cost efficiency in Portuguese seaports. A stochastic cost frontier is estimated using data from eleven Portuguese ports for the period 1990-2000. Two outputs are considered: total tons of cargo and number of vessels. The price of labor is approximated by personnel expenses divided by the number of workers, and the price of capital is measured as the ratio of profits to the net value of buildings. The main conclusion of the article was that the management of the Portuguese port system was failing to improve the efficiency of the seaports and that there were structural limitations explaining the lower performing of seaports. Because of their small size, seaports analyzed cannot benefit from the same potential for cargo handling as the larger ports. The second conclusion was that most of the seaports analyzed are inefficient, therefore, adjustments were necessary to get closer to the efficient frontier.

Tongzon & Heng (2005) is another study that analyzes the relationship between port ownership and efficiency and also tests whether port privatization is a necessary strategy for ports to gain a competitive advantage. The main novelty is that the study uses worldwide data, not focusing on a specific country or region like previous authors, although it is true that 21 of the 25 terminals used were located in Asia. The methodology used is a stochastic production frontier based on the

Battese & Coelli (1995) model to determine the relationship between technical efficiency, ownership structure and port size. The output and inputs used coincide those in Nottemboom et al. (2000). In addition, the authors use a binary dummy variable to determine port size and for the ownership structure they follow the matrix proposed by Baird (1995, 1997). The matrix has value zero if the port is completely public, value one third if the regulation and ownership is public but the port is privately operated, value two thirds if the ownership and operators are private and there is public regulation, and value one if the port was completely private. The authors find that the participation of the private sector in the port industry is a determining factor in improving port efficiency. The participation of private over public initiative that achieved the highest efficiency index was 0.67. Therefore, complete privatization of port activity was recommended while keeping public regulation.

Chang & Tovar (2014), like some previous authors, analyze policy reforms implemented in a given region. They evaluated and analyzed efficiency and performance of container terminals in Chilean and Peruvian ports. Data were collected from seven Chilean and seven Peruvian ports in the period 2004-2010. Chang & Tovar (2014) estimate an output-oriented distance function and used the distribution of Battese & Coelli (1992) for the calculation of technical efficiency. This study considers three outputs, containerized cargo (measured in TEU's units and tons), tons of Ro-Ro cargo, and tons of bulk cargo. For inputs, the number of workers, the number of docks and the stock of net fixed assets measured in US dollars are considered. In addition, a binary variable identifies the country where a given terminal is located. The authors conclude that the reforms were better in Chile than in Peru, since they allowed for better infrastructure and machinery to the terminals due to private initiative. With respect to total factor productivity, they observed that the 2008 financial crisis negatively affected both countries, although with a greater impact on Chilean terminals. Finally, the greater flexibility of the Chilean reforms with respect to the Peruvian ones, allowed a higher performance of the Chilean port terminals. First, technical efficiency is higher in Chilean terminals throughout the period and, secondly, because of the better prospects for productivity growth, given that technological change is capital-biased.

More recently, Serebrisky et al. (2015) analyze the determinants and measures technical efficiency focusing on Latin American and Caribbean seaports (LAC ports). As in Liu (1995), a stochastic translogarithmic production frontier is estimated. Data correspond to 63 ports with container terminals, of which 18 were located in Central America and Mexico, 10 in the Caribbean and 35 in the rest of South America. The only output considered is containerized cargo measured in TEUs. Similar to Nottemboom et al. (2000) the inputs are linear meters of quay, square meters of surface area and the number of gantry cranes with a capacity greater than 14 tons. In a second stage analysis, the authors identify the determinants of technical inefficiency with respect to ports following a landlord model, the country's corruption index and GDP per capita. They conclude that productivity gains come from linear meters of quay and gantry cranes. Finally, the participation of private initiative in the port industry can be related to efficiency gains, although the highest levels are achieved with the landlord model.

The last paper we review in this sub.section is Perez et al. (2016). This study is like Serebrisky et al. (2015) analyzing whether the efficiency of LAC ports had improved in the last decade and the determinants of inefficiency, including the influence of inter-port and intra-port competition. Data come from the top 40 container terminals in 19 LAC countries for the period 2000-2010. The methodology and output considered are the same as in Serebrisky et al. (2015). The inputs used are linear meters of quay, storage capacity measured in TEU's and total number of cranes. In order to find the determinants of technical efficiency, a binary dummy variable that takes value one when the port has more than three terminals, is used to capture port size. Two more binary dummy variable are also defined to capture Mercosur country membership and to identify terminals that are devoted for transshipment cargo. The conclusions are that terminals located in Mercosur countries were more efficient. Furthermore, container terminals located in large ports, those with more than three container terminals, are more efficient than the rest and container terminals located in ports dedicated to transshipment cargo are less efficient.

2.3.2 Non-parametric methods

Regarding non-parametric methods, we present the following nine works. Roll & Hayuth (1993) is the first paper that applies a new non-parametric method for calculating port efficiency. In particular a CCR-DEA is used to compute the production frontier (Charnes et al. 1978). Data include information of 20 ports, but their identity is not provided. The analysis considers multi-output ports that include: cargo throughput (containerized cargo plus non-containerized general cargo and bulk cargo tons), level of service (defined as the ratio between handling time and total time the vessel is in port), user satisfaction (between 1 and 10 in a satisfaction survey) and the number of vessels. The total number of workers, total investment in capital and the coefficient of variation that measures the concentration of merchandise are the inputs considered. The authors conclude that non-parametric methods are useful to obtain the relative efficiency of ports.

Tongzon (2001) extends the work by Roll & Hayuth (1993) to a different port sample and also to the possibility of variable returns to scale. Data include information from four Australian ports and twelve international ports for the year 1996. Regarding the outputs, Tongzon (2001) also differs from Roll & Hayuth (1993) since it considers three: the number of TEU's of containerized cargo, the number of containers moved per hour and the number of vessels (as an indicator of the speed at which the vessels work). For inputs the study includes the number of berths, the number of cranes, the number of tugboats, the number of stevedores and the delay time (which is the difference between the total time on the berth and the time between the start and end of work on the vessel). The methodology used is an output-oriented DEA in two different approaches, either assuming constant returns to scale, that is, a CCR-DEA (Charnes et al. 1978) or the additive model DEA that assumes variable returns to scale (Charnes et al. 1985). The author finds that the approach used matters. In particular, the Melbourne, Rotterdam, Yokohama and Osaka ports are the most inefficient using both DEA approaches. Three Australian ports, Sydney, Brisbane and Fremantle are efficient under the constant returns to scale but inefficient under the variable returns to scale approaches. Finally, the Hong Kong, Singapore, Hamburg, Keelung, Zeebrugge and Tanjung Priok ports are efficient under both approaches. A general conclusion is that port size is not a determinant of efficiency.

Valentine & Gray (2001) uses the non-parametric methodology to investigate the effects of privatization on port efficiency. It compares efficiency of ports belonging to three different sets: fully private ports, ports that belonged to the public sector and ports that have both public and private characteristics. Data for 31 international ports for 1998 were collected. The results showed that the simple structure (where the involved departments report directly to decision-makers) is more efficient than the organizational structure (there is a long process in decision-making), while the type of ownership does not appear to be significant for port efficiency.

Similarly, Barros (2003) analyzes the technical and allocative efficiency of Portuguese port authorities to check whether state policies have achieved their objective. The database includes information from Portuguese port authorities for the years 1999 and 2000. Barros (2003) compute two input-oriented models, a CCR-DEA (Charnes et al.1978) and a BCC-DEA (Banker et al. 1984) ones. Ten different indicators, vessels, cargo movements, gross tonnage, market share, breakbulk tons, containerized tons, Ro-Ro tons, solid bulk tons, liquid bulk tons and net income are used to measure output. Besides, two indicators, the number of workers and the net asset value as a proxy for capital are used to account for inputs. The conclusion was to propose a policy review to improve port efficiency, since the regulation applied have not achieved its objectives.

Following the same methodology as in Barros (2003), Barros & Athanassiou (2004) searches for those practices that led to an improvement in the performance of the Greek and Portuguese seaports. Information from four Portuguese and two Greek ports for the period 1998-2000 is considered. The inputs are the same as those in Barros (2003), but regarding outputs, the number of vessels, cargo movement, tons of total cargo handled (dry and liquid cargo) and tons of containerized cargo are used. They found that most seaports are efficient with the sole exception of Thessaloniki. Moreover, privatization allowed the ports to improve their productivity, because privatization and competition has been proven to be the best procedure for efficiency improvement as in Jones et al. (1990).

A third paper, Cheon et al. (2010), following the path initiated by Barros (2003) and Barros & Athanassiou (2004), evaluates the influence of port institutional reforms on port efficiency gains attained between year 1991 and 2004. However, the methodology used is different, that is, an output-oriented Malmquist productivity index model. The article uses two different databases, the first including information from 100 international ports for 1991 and the second from 138 international ports for 2004. The only output is containerized cargo measured in TEUs. Linear meters of dock, square meters of surface area and the capacity of the container cranes measured in tons are the three inputs in the study. The authors identify three primary sources of port efficiency gains, that is, improved management and optimization of container terminal operations, adjustment of production scales, and technological progress. As a conclusion, the authors claim that the improvement in total factor productivity of container ports came from reforms in ownership structure and asset management practices.

An interesting paper is that of Bang et al. (2012) that applies the non-parametric method with the objective of measuring the relative efficiency of port operators in terms of operational and financial performance. It further investigates the impact of strategic and operational management on efficiency performance. Two stages of analysis were undertaken, the first one to compute efficiency using an output-oriented DEA approach and the second stage performs a Tobit regression where efficiency is the dependent variable. The database has been formed by combining physical and financial data for a sample of 14 of the 20 largest containerized cargo operators in the world in 2008. Regarding financial data, total assets and capital expenditure in millions of dollars were considered as inputs and operating profit in millions of dollars as output. On the physical data side, the authors considered the number of vessels and capacity measured in TEU's as inputs and containerized cargo measured in TEU's as output. The second stage independent variables used as determinants of port efficiency included among others, total capacity of owned and chartered vessels as a proxy for port size, the ratio of the number of post Panamax container vessels to total container vessels, vessel years, vessel type represented as the ratio of multipurpose vessels to total company vessels. The authors show that the explanatory variables only have effects on financial efficiency. The variable related to port size showed that larger ports achieved better efficiency levels than their competitors. In addition, companies operating large vessels (Post Panamax) achieved higher levels of efficiency. In summary, companies with larger capacity, larger vessels, a higher ratio of chartered vessels and operating in an alliance structure outperformed their competitors.

De Oliveira & Cariou (2015) is the first paper to investigate whether inter-port competition, –captured by the Herfindhal-Hirschman Index of traffic of ports located in the vicinity and the market share of a port – affects port efficiency; and whether this relationship changes when competition is measured at three different levels (local, regional, and global). Moreover, it is the first to use the Simar & Wilson (2007) methodology in a second stage analysis to identify the port efficiency determinants. Information from 200 container ports for the period 2007-2010 is used to undertake the analysis. Like many previous authors, the only output considered was containerized cargo measured in TEUs. Linear meters of dock, the number of gantry and yard cranes, square meters of storage and square meters of port area are the selected inputs. In addition, a binary variable equal to one when the total number of gantry and yard cranes increased from 2007 to 2010 is defined. Results show that inter-port competition impacts port efficiency. With respect to the second objective, a negative impact is observed when competition occurs at the regional level, defined in their study as an area of 400 to 700 km around the given port.

To end this subsection, Schoyen & Odeck (2015) focus their study on the Norwegian port sector to identify the elements that explain the productivity improvement of the six largest Norwegian seaports and to compare Norwegian ports with some Nordic and British seaports. Data include information from six Norwegian ports and fourteen Nordic and UK ports for the period 2009-2014. The only output considered was containerized cargo measured in TEUs. Four inputs, linear meters of quay, square meters of port, number of yard gantry cranes and number of container handling trucks, were defined. They conclude that the average annual productivity growth in the period 2009-2014 was 0.6 percent due to the technological change rather than technical efficiency. For Norwegian ports, five out of the six ports analyzed increased their productivity during the period of analysis. Finally, no statistical evidence of differences in productive performance is found between the Norwegian ports as one group and the Nordic and British ports as another group.

Chapter 3

Data description

3.1 Statistical sources

The statistical information used in this work has been obtained from the following information sources: public statistical yearbooks by Entidad Pública Puertos del Estado (EPPE), the annual reports provided by each port authority and by EPPE, and the annual and audit accounts published in the Boletín Oficial del Estado (BOE). The main problem with empirical studies is the quality of the data used. For this reason, the data have been refined and information cross-checks have been made with different information sources, Eurostat and Observatorio de Transporte y Logística de España (OTLE). In the event of anomalies or discrepancies between the data, the original source of information has been directly consulted and has been required a telephone interview with the person in charge of each matter.

The information related to traffic statistics (tons of merchandise, number of passengers and number of ships) and that on the technical characteristics of the port facilities (linear meters of quay and square meters of surface) has been obtained from the statistical yearbooks and has been contrasted with the second and third chapters of the annual reports, respectively. Finally, the financial information has been obtained from the annual accounts and the audit reports and has been checked with the first chapter of the annual reports. The information related to the number of workers is only available in the annual accounts and the audit reports.

The unit of analysis considered is the port authority (PA).[1] It is the entity in charge of port management and may control more than one port. In general, we gather information for all the port authorities of the Spanish port system. The value of collecting data from all port authorities is that it allows us to capture the effect of the heterogeneity of activities, compare port authorities of different sizes, conditions and with different specialization on traffic. Table A.1 in Appendix A lists the guardianship of the 28 Spanish port authorities on the 46 ports of general interest. Spanish port authorities can be classified in several ways. For instance, there is a group with high international relevance as merchandise distributor centers including Bahía de Algeciras, Barcelona, Las Palmas and Valencia port authorities. There is also a group that include Bilbao, Ferrol-San Cibrao, Marín y Ría de Pontevedra, Sevilla and Vilagarcía de Aurosa which are *ports located in rivers*. Besides, there are *insular port authorities*: Baleares, Las Palmas and Santa Cruz de Tenerife. The rest of port authorities are known

[1]To simplify the presentation we will refer to ports instead of port authorities in the following Chapters of this Dissertation.

as *continental ports*, although some tend to a specific specialization of traffic. For instance, the port of Carboneras included in the Almería port authority is specialized in coal. The ports of Avilés and Vilagarcía de Aurosa are specialized in bulk merchandise. The port of Algeciras is divided into three port areas: the Port of Algeciras, the port facilities in Palmones and the oil facilities in San Roque. The port of the Zona Franca that belongs to the Bahía de Cádiz port authority is specialized in liquid bulk. The Escombreras dock in the Port of Cartagena is specialized in liquid bulk and hydrocarbon traffic. The port of Motril is specialized in solid bulks. Finally, the port of Gandía in the Valencia port authority is specialized in non-containerized general merchandise.[2]

The time period analyzed is between the years 2002 and 2018. Therefore, the sample is made up of an unbalanced panel data of 473 observations: 27 port authorities for the period 2002-2004 and 28 port authorities for the period 2005-2018. The reason is that the port of Motril belonged to the port authority of Almería until 2005, when the port authority of Motril was founded. It is important to underline that the time period considered allows to analyze the effects of three legislative reforms and the economic crisis on the efficiency levels of the Spanish port system.

For the port activity description this research considers four port products or outputs, which are containers, liquid bulk, rest of merchandise and passengers; three productive factors or inputs, that is,

[2] The ports of A Coruña, Ferrol (Ferrol-San Cibrao) and Huelva are divided into two port areas, the inner and the outer.

quay, surface and employees; and financial information variables that includes intermediate consumption, personnel expenses and depreciation of fixed assets. To describe port competitive environment and other important port features, the following variables have been used: the number and type of port terminals, the existence and use of rail access, the coastline, port size, the condition of being an insular port, the existence of oil refineries. To complete the data the three legislative reforms affecting the Spanish port system in the reference period has been included.

3.2 Outputs

Port authorities provide several services including the provision of infrastructures, service to ships, freight handling and logistics, and trip services to passengers. In addition, they also offer services to sports and recreational boats, the collection of garbage from port facilities and the management of the port police, among others.

The nature of port services complicates the measurement of the services provided to ships and the provision of infrastructure. Moreover, as mentioned in the introduction, the main source of income for the Spanish port system corresponds to port charges. Among them, charges related to the tons of freight and the number of passengers represent the 50% of total port charges. For this reason, this research only uses only information referred to freight and passengers to measure port products. Since freight is heterogeneous in the way is transported, three different types will be considered, namely, containers, liquid bulk and other merchandise (othercargo). These three types of freight added to the number passengers are the four port outputs to be used in Chapters 4 and 5 below.

Let me describe briefly those port outputs. Containerized merchandise (*containers*) is showing the greatest growth in recent years respect the rest of freight. For the year 2002 it represented the 22% of total tons in the Spanish port system while the 35% for the year 2018. The received literature has considered different ways to account for containerized merchandise. Total units of containers is used in Tongzon (2001) and Chang & Tovar (2014); while total units of TEUs handled appears in Notteboom et al.(2002), Tongzon (2001), Cullinane et al. (2002), Lin & Lih (2005), Tongzon & Heng (2005), Cullinane et al.(2006), Cheon et al.(2010), Bang et al.(2012), Chang & Tovar (2014), De Oliveira & Cariou (2015), Schoyen & Odeck (2014), Serebrisky et al.(2015) and Pérez et al.(2016). Finally, total tons of containerized merchandise is considered in Roll & Hayuth (1993), Bonilla et al. (2002), Barros & Athanassiou (2004), Barros (2005), Jara-Díaz et al.(2005), González & Trujillo (2008), Díaz-Hernández et al.(2008), Rodríguez-Álvarez et al.(2011), Tovar & Wall (2012), Rodríguez-Álvarez & Tovar (2012), Chang & Tovar (2014), Tovar & Wall (2015) and Coto-Millán et al.(2016). The latter option is chosen in this research. The main reason is that tons is the unit base for freight and the different freights considered are measured in the same way.

Liquid bulk is a type of merchandise that requires specific facilities to be loaded and unloaded by the port authorities. Despite these requirements, it is the fastest merchandise to be handled. It represents one third of the total tons in the Spanish port sector. The 85% of this traffic is composed by petroleum products, therefore, the existence of oil refinery installed near to the port authority attracts a greater quantity of liquid bulk. The 15% of the remaining liquid merchandise includes ammonia, oils, bitumen, chemical products and sulfuric acid. As mentioned above, it is measured in tons as previous authors that considered this input, namely, Bonilla et al.(2002), Barros & Athanassiou (2004), Barros (2005), González & Trujillo (2008), Rodríguez-Álvarez & Tovar (2012), Tovar & Wall (2015) and Coto-Millán et al.(2016).

Othercargo is a broad term that includes solid bulk, non-containerized general merchandise, provisioning (service for the supply of fuel, water and ice to ships), fishing and local traffic (transport carried out inside the port authority). Solid bulk, like the liquids, also requires a specific facilities to be handled by the port authorities. For the year 2002, this item represented the 27% of total tons in the Spanish port sector and for the year 2018, it reached the 19%. The most representative merchandise in solid bulks are cement, cereals, coal, tar and fertilizers. The general non-containerized merchandise content varies across ports and includes paper, wood, vehicles, transport of live animals and food products, among others. In our research, both solid bulk and non-containerized general merchandise are measured in tons like previous authors which considered solid bulk (Roll & Hayuth, 1993, Bonilla et al., 2002, Barros & Athanassiou, 2004, Barros, 2005, González & Trujillo, 2008, Díaz-Hernández et al., 2008, Rodríguez-Álvarez & Tovar, 2012, Chang & Tovar, 2014, Tovar & Wall, 2015 and Coto-Millán et al., 2016.) and those considering non-containerized general merchandise (Roll & Hayuth, 1993, Bonilla et al., 2002, Barros, 2005, Jara-Díaz et al., 2005, González & Trujillo, 2008, Díaz-Hernández et al., 2008, Rodríguez-Alvárez et al., 2011, Tovar & Wall, 2012, Rodríguez-Álvarez and Tovar, 2012, Tovar & Wall, 2015 and Coto-Millán et al., 2016).

The Spanish port system provides services to the maritime transport of *passengers.* Although it is not the most used mode of transport by travelers, there are important routes, for instance, the connection of North Africa with Algeciras and Almería, the connection of the Canary Islands with Huelva and the connection of the Mediterranean ports with the ports of southern Europe. Like González & Trujillo (2008), Rodríguez-Álvarez & Tovar (2012), Tovar & Wall (2015) and Coto-Millán et al. (2016), we use the total number of passengers either on a transport regime or on a cruise regime to measure this port output. Martínez-Burdía et al., (1996) used a different approach converting the number of passengers in tons. They computed 0.1 tons for each passenger, in order to take into account the baggage and vehicles in transit.

To summarize, three types of freight have been identified: tons of *othercargo*, which include general merchandise not containerized, solid bulk, fresh fish, local traffic and provisioning, denoted by y_1; tons of *containerized general merchandise*, denoted by y_2 and, tons of *liquid bulk*, where petroleum products are included, denoted by y_3. Finally, the total number of *passengers*, including both regular shipping line and cruise passengers, is considered as the fourth output and denoted by y_4.

3.3 Inputs

The Spanish port system combines capital and labor for carry out the services explained previously. This research considers the existence of three productive factors (inputs), two of them with quasi-fixed characteristics and the last one which is easy to adjust. This document has not considered another productive factors as cranes, cold stores and pipelines because the lack of reliable data. The productive factors considered are linear meters of quay, square meters of surface and the number of workers.

Quays are necessary for the mooring of ships to perform the task of loading and unloading freight and passengers. This research considers the total linear meters of quay, adding the exploited by the Port Authority and the exploited by private ownership. Only the linear meters of quay beyond four meters of depth were considered, because the rest are destined to the recreative and sports ships. Most authors include this port input with the same definition. In particular, Coto-Millán et al.(2000), Notteboom et al. (2000), Tongzon (2001), Valentine & Grey (2001), Cullinane et al. (2002), Lin & Lih (2005), Tongzon & Hell (2005), Cullinane et al. (2006), González & Trujillo (2008), Cheon et al. (2010), De Oliveira & Cariou (2014), Schoyen & Odeck (2015), Serebrisky et al.

(2015), Coto-Millán et al. (2016) and Pérez et al. (2016).

The *available surface* is important for the storage and logistics tasks and is composed by storage (open, covered and open and closed), roads and the rest (gardens, buildings and port access). This research considers the full surface in square meters, adding the area used by the port authority and the area granted to the private ownership. Square meters is the most common unit of measure used in the literature, see for instance, Tongzon (2001), Estache et al. (2002), Jara-Díaz et al. (2005), González & Serrano (2008), Cheon et al. (2010), Rodríguez-Alvárez et al. (2011), Tovar & Wall (2012), De Oliveira & Cariou (2015), Serebrisky et al. (2015), Tovar & Wall (2015) and Pérez et al. (2016). However, there are authors that use hectares instead as Notteboom et al. (2000), Cullinane et al. (2002), Lin & Lih (2005), Tongzon & Hell (2005), Cullinane et al. (2006) and Schoyen & Odeck (2015).

To measure the *labor* input, we account for the average number of workers. We include all types of workers: administrative, specialized technicians, steveedors, among others. Although labor is the most adjustable productive factor, its downward variations are difficult, since a large part of the workforce are public employees and they have a great negotiation power. The total number of workers is the most used measure of this input in the literature, see for example, Chang (1978), Roll & Hayuth (1993), Tongzon (2001), Baños-Pino et al. (1999), Estache et al. (2002), Barros & Athanassiou (2004), Barros (2005), González & Trujillo (2008), Díaz-Hernández et al. (2008), Rodríguez & Tovar (2012), Chang

& Tovar (2014), Coto-Millán et al. (2015), Tovar & Wall (2015) and Coto-Millán et al. (2016). However, there are other authors which considered labor expenses instead, as Liu (1995), Martínez-Burdía (1996), Martínez-Burdía et al. (1999), Coto-Millán et al. (2000), Cullinane & Song (2003), Barros (2005), Jara-Díaz et al. (2005), Rodríguez-Álvarez et al. (2011) and Tovar & Wall (2012). Finally, the works by Notteboom et al. (2000), Tongzon & Hell (2005), Cullinane et al. (2006), Cheon et al. (2010), De Oliveira & Cariou (2015), Schoyen & Odeck (2015), Serebrisky et al. (2015) and Pérez et al. (2016) consider the number of cranes as an approximation to the number of workers.

To summarize two quasi-fixed inputs, berths and surface, and one variable input, labor, are considered. The *Berths* input, denoted by x_1 and measured in linear meters, includes the linear meters of all private and publicly owned berths deeper than four meters. The *Surface* input, denoted by x_2, is measured in square meters and includes all types of storage, roads and other port facilities, regardless of being of private or public ownership. Finally, the *Labor* input, denoted by x_3, is defined as the total number of workers in each year.

Table 3.1 below shows the output and input averages for each port in the period 2002-2018.

Table 3.1 Input and output averages for each port

Port	**Berths** (meters)	**Surface** (sq meters)	**Labor** (# wrks.)	**Containers** (tons)	**Liquid B.** (tons)	**Othercargo** (tons)	**Passeng.** (# of)
A Coruña	10,612	1,873,486	174	38,875	7,663,430	5,602,045	96,202
Alicante	6,252	1,356,080	127	1,140,059	101,100	1,767,348	283,514
Almería	4,814	799,805	130	33,011	239,549	5,960,653	959,570
Avilés	4,175	489,676	96	32,057	661,772	4,242,837	784
B.Algeciras	18,375	5,368,922	350	44,923,048	23,498,558	12,894,380	5,051,464
B.Cádiz	10,992	4,022,278	189	937,817	202,138	3,412,829	305,664
Baleares	20,381	1,933,828	342	901,929	1,752,229	10,484,109	5,698,464
Barcelona	21,483	9,640,932	546	20,795,941	11,648,858	14,106,934	3,184,095
Bilbao	19,902	3,649,969	286	5,865,409	18,665,998	8,904,048	8,904,048
Cartagena	11,306	2,106,429	169	736,778	20,996,616	5,150,031	94,133
Castellón	7,671	2,128,670	113	1,703,116	8,006,805	4,235,194	403
Ceuta	3,611	797,101	141	83,240	876,282	1,503,030	2,111,089
Ferrol SC	9,519	3,464,051	106	9,309	1,910,281	9,788,110	9,404
Gijón	9,269	3,586,433	168	449,782	1,151,610	17,233,342	22,468
Huelva	8,201	7,185,610	208	93,290	17,651,812	6,643,477	19,595
Las Palmas	19,465	4,384,822	321	11,978,724	5,136,975	6,766,601	1,670,562
Málaga	6,631	1,071,214	174	1,558,761	97,002	1,973,584	679,205
Marín RP	3,721	695,389	77	398,731	59	1,580,302	9
Melilla	2,199	274,646	94	193,856	73,824	638,684	624,138
Motril	2,562	898,084	70	22,638	1,272,161	997,932	192,834
Pasaia	5,404	658,791	137	7,179	36,335	4,159,527	329
SC Tenerife	13,150	2,506,948	230	3,078,595	7,628,858	5,304,095	5,968,931
Santander	7,207	2,631,720	175	33,082	315,210	5,150,696	188,806
Sevilla	5,097	8,091,115	143	998,693	299,989	3,362,561	14,575
Tarragona	15,384	3,650,031	263	1,067,011	19,235,650	11,474,528	12,803
Valencia	21,563	7,029,105	404	41,623,448	3,730,705	12,816,321	607,570

Table 3.1 continued from previous page

Port	**Berths** (meters)	**Surface** (sq meters)	**Labor** (# wrks.)	**Containers** (tons)	**Liquid B,** (tons)	**Othercargo** (tons)	**Passeng.** (# of)
Vigo	11,943	1,127,211	229	2,263,286	72,267	2,136,814	166,935
V. Arousa	2,296	445,141	71	135,390	257,664	680,480	3,703

Source: Own elaboration from Table 3.1.2 of Statistical Yearbooks of EPPE 2002-2018

3.4 Financial data

In Chapter 5, we obtain the economic efficiency indexes of the Spanish port system by means of estimating the cost functions for each port authority, which requires the use of financial data. Data were collected from the different port authorities' Profit and Loss Accounts (PLA) published in the BOE. In a PLA there is information about the port revenue, separating the rates charged to ships, passage, merchandise and concessions. The information on port revenue has not been collected because we cannot distinguish per type of merchandise.

Regarding costs, we distinguish total costs into variable and fixed costs. Variable cost (VC) consist of the sum of personnel cost (item 6 of the PLA), services expenses (item 7A of the PLA) and other current expenses (item 7D of the PLA). Fixed cost (FC) include the depreciation of fixed assets (item 8 of the PLA). In 2008, there was an accounting change that implied, among other things, the information collected was located in different items of the PLA. In particular, from 2002 to 2007 the sum of personnel cost was obtained in item 3, the services expenses in item 6A, other current expenses in item 6C and the depreciation of fixed assets in item 4. Financial data are expressed in constant euros of 2018.

The price of labor, denoted w_l, is obtained dividing the total personnel expenses by the average number of workers in the period. Martínez-Burdía (1996), Baños-Pino et al. (1999), Coto-Millán et al.

(2000) and Rodríguez-Álvarez and Tovar (2012) computed this price dividing the total expenses on staff by the average of workers.

The price of intermediate consumption, w_i, is obtained by dividing the services expenses and other current current expenses by total tons[3]. Other authors use the total expenditure of consumption, external supplies, external jobs and other current expenditures (which is neither exploitation nor personnel expenses) divided by total tons to obtain the price of intermediate consumption, see Martínez-Burdía (1996), Baños-Pino et al. (1999) and Coto-Millán et al.(2000). Rodríguez-Álvarez and Tovar (2012) divide by the total surface area instead by tons to obtain this price. Finally, Jara-Díaz et al. (2005), Rodríguez-Álvarez et al. (2011) and Tovar & Wall (2012) use the price of electricity as a proxy for the price of intermediate consumption.

The price of capital, w_k, is obtained by dividing the depreciation of fixed assets by the total surface area as in Rodríguez-Álvarez & Tovar (2012). Note that Martínez-Burdía (1996) and Coto-Millán et al. (2000) use as a divisor the number of linear meters of the quays deeper more than 4 meters. Alternatively, Baños-Pino et al. (1999) approximate the price of capital by the ratio of total investments in a given year to that of the previous year.

Finally, financial data from the five smallest port authorities in terms of tons handled, Marín y Ría de Pontevendra, Melilla, Pasaia and

[3]We use the definition of total tons in Martínez-Budría (1996), where total tons is the sum of four terms: tons of general containerized merchandise, tons of liquid bulks, tons of othercargo and the number of passengers divided by 10.

Vilagarcía de Aurosa, have been removed to avoid outliers affecting the estimation of cost functions.

Table 3.2 Average expenses, input prices and shares for each port

Port	**TC** (Mill.€)	**FC** (Mill.€)	**VC** (Mill.€)	w_i (€)	w_k (€)	w_l (thous.€)	$Share_i$	$Share_k$.	$Share_l$
A Coruña	23.8	12.6	11.2	0.30	6.77	41.51	0.1805	0.5010	0.3186
Alicante	13.3	4.6	8.7	1.18	3.41	40.90	0.2622	0.3449	0.3929
Almeŕıa	13.8	4.9	8.9	0.55	6.15	42.29	0.2415	0.3564	0.4021
Avilés	12.7	5.4	7.3	0.61	10.92	44.32	0.2378	0.4201	0.3419
B.Algeciras	55.7	22.5	33.2	0.20	4.16	48.16	0.2932	0.3969	0.3099
B.Cádiz	21.3	8.7	12.6	1.09	2.19	41.47	0.2253	0.4066	0.3681
Baleares	44.9	16.2	28.7	1.05	8.34	41.62	0.3132	0.3622	0.3246
Barcelona	113.0	44.8	68.2	0.75	4.58	61.98	0.3000	0.3887	0.3114
Bilbao	59.5	28.0	31.5	0.49	7.71	53.30	0.2745	0.4698	0.2557
Cartagena	21.8	10.5	11.3	0.14	5.02	44.30	0.1717	0.4818	0.3465
Castellón	14.7	6.4	8.3	0.25	3.13	45.55	0.2329	0.4175	0.3496
Ceuta	17.3	3.9	13.4	2.21	4.95	53.08	0.3367	0.2271	0.4362
Ferrol-SCB	13.0	5.9	7.1	0.22	1.67	41.97	0.2066	0.4367	0.3568
Gijón	33.7	18.7	15.0	0.36	5.18	49.38	0.2025	0.5467	0.2508
Huelva	30.8	12.4	18.4	0.37	1.73	44.10	0.2925	0.4062	0.3014
Las Palmas	56.8	25.1	31.7	0.72	6.08	44.74	0.2935	0.4468	0.2597
Málaga	18.7	7.3	11.4	1.33	7.04	40.87	0.2308	0.3888	0.3804
Motril	7.3	2.8	4.5	0.75	3.14	40.34	0.2249	0.3865	0.3887
SC Tenerife	41.1	18.6	22.5	0.79	7.54	42.52	0.3091	0.4527	0.2382
Santander	22.1	8.4	13.6	1.19	3.20	39.85	0.2816	0.3951	0.3233
Sevilla	20.1	8.3	11.8	1.24	1.05	42.55	0.2880	0.3999	0.3121
Tarragona	39.6	17.2	22.4	0.37	4.70	40.15	0.2974	0.4328	0.2697
Valencia	84.4	40.6	43.8	0.43	5.67	48.37	0.2911	0.4711	0.2377
Vigo	27.3	10.5	16.8	1.61	9.41	42.08	0.2631	0.3844	0.3525
Average	33.8	14.4	19.4	0.76	5.17	44.84	0.2607	0.4135	0.3257

Source: Own elaboration with information collected from Profit and Loss Accounts and Audit Reports (2002-2018) published in BOE.

3.5 Environmental and second stage variables

Next Chapters are devoted to identify the determinants of technical and economic efficiency of the Spanish port system. Port activity has many factors, not captured by inputs or outputs, that affect efficiency. This section include several of them denoted as environmental variables and second stage variables. Among these variable we include dummy variables that account for the location of port authorities, access to refineries and rail connection and size. Also dummies that account for the effect of three legislative reforms that affect the Spanish port system. Finally, we are particularly interested in addressing the effect of port terminals on efficiency. We will distinguish terminals by the type of merchandise and by the agent that is in charge of the management.

Regarding geographic location, the variable $C_{Localization}$ is a dummy variable used to distinguish between mainland and island ports. Note that mainland ports merchandises can reach them by road, railway, airport or other port, while for island ports, the possibilities are reduced to airport or other port. Since most merchandise cannot be transported by plane, island ports are the only alternative of entry and exit of commodities from the territory. This variable takes value one for the three island ports, Baleares, Las Palmas and Santa Cruz de Tenerife, and zero for the rest. Note that Sunkeys, (1986), González & Trujillo, (2008) and Rodríguez & Tovar, (2012) also include this feature in their analysis.

A second important geographical feature is the coastline where ports are located. In this way, coastline dummies indicate the sea or ocean at which the port has access. Spain has three different coastlines: the Atlantic ocean, the Cantabric sea and the Mediterranean sea. The distribution of the ports in the Spanish port system in the different coast lines is the following. The $C_{Atlantic}$ dummy takes value one for A Coruña, Bahía de Algeciras, Bahía de Cádiz, Ferrol-San Cibrao, Huelva, Las Palmas, Santa Cruz de Tenerife, Sevilla and Vigo ports.[4] The $C_{Cantabric}$ takes value one for Avilés, Bilbao, Gijón, and

[4] Bahía de Algeciras is located in the borderline between the Atlantic ocean and the Mediterranean see. In fact, it is considered the west gateway of the Mediterranean

Santander, and finally the $C_{Mediterranean}$ dummy is one for Alicante, Almería, Baleares, Barcelona, Cartagena, Castellón, Ceuta, Málaga, Melilla, Motril, Tarragona and Valencia ports.

Port terminals are specialized facilities designed to handle different types of merchandise or to embark passengers and ports are specialized in one or several types of outputs. Given that, we have distinguished port terminals according to the type of traffic and also to the type of management. Therefore, we consider terminals handling containers (denoted by C), those handling liquids and petroleum freight (L) and those handling general non containerized merchandise that includes solid bulks, Ro-Ro and provisioning for the ships (MG). Finally, terminals for general and cruise passengers (P) are also considered. For each type of terminal we distinguish among those privately managed (PR) and those managed directly by the port authority (PB). Therefore, we denote by $TPRC$ the number of containerized terminals in a port which are privately managed; similar notation is applied for all other possible examples. We are very interested in finding the effect of each type of terminal on port efficiency. Table C.1 gives a detailed description about the number of the different terminals and the evolution of that number along the period of study.

The existence of oil refineries located in the vicinity of the port facilities attracts a greater amount of liquid bulk. This type of merchandise is considered the fastest by the ports. The binary variable $C_{Refinery}$ was created and it takes value one for the ports with oil refinery (A Coruña,

attracting abundant transshipment cargo. Despite that it could be included among the Mediterranean ports, we include it among the ports in the Atlantic.

Bahía de Algeciras, Bilbao, Cartagena, Castellón, Huelva, Santa Cruz de Tenerife and Tarragona) and zero for the rest. The following authors considered the existence of oil refineries to analyze the competitive environment in the Spanish port system: González & Trujillo (2008) and Rodríguez & Tovar (2012).

In the same way, having railway connection is an advantage for the port, because the merchandise has different inland alternatives to enter and exit the port (road, rail and pipe) and the probability of congestion is lower. We exclude the alternative of pipe because it is very correlated with ports which have oil refinery. The environmental variable, C_{Train} is set to one when the port has railway access and uses it.

Port size is one of the features that has been considered in the literature to analyse port efficiency, see Liu (1995), Martínez-Burdía (1996), Coto-Millán et al. (2000), Bonilla et al. (2002) and Cullinane et al. (2002). The dummy variable, $C_{Berths15000}$, is defined to account the size of the port. It takes value one in case a port has a total berth size longer than 15,000 meters. The ports that take value one are Baleares, Barcelona, Bilbao, Las Palmas, for the full period of analysis; and Bahía de Algeciras, Santa Cruz de Tenerife, Tarragona and Valencia only from 2008. We also include as control variable the index of mechanization of ports, denoted by MI, that is approximated by the share of total containerized tons over total tons handled by the port.

Finally, many authors have been concerned about the effects of Spanish legislative reforms on technical and economic efficiency with mixed conclusions, see for instance González & Trujillo (2008) and Díaz-Hernández et al. (2008), Rodríguez-Álvarez & Tovar (2012) and Coto-Millán et al. (2016).

In the international context, there are authors that have analyzed the effect port regulation and the privatization process on efficiency. Liu (1995) for the British ports for the period 1983-1990; Cullinane et al. (2002) for major container ports in Asia from 1989 to 1998; Tongzon & Heng (2005) for the case of 25 container terminals ports, Cheon et al. (2010) evaluated how port institutional reforms have influenced for increase efficiency and Serebrisky et al. (2015) for the Latin American and Caribbean ports are examples of contributions analyzing the effect of changes in ownership on efficiency. Estache et al. (2002) and Cullinane & Song (2003) analyze the effect of changes in regulation in Mexico and in Korea, respectively. To account for three Spanish legislative reforms included in the period of analysis, three dummy variables are defined. C_{Law03} stands for the 48/2003 law and takes value one from year 2004 to 2010. C_{Law10} corresponds to the 33/2010 law and takes value one for years 2010 and 2011. Finally, C_{Law11} accounts for the 2/2011 Royal Decree and takes value one for years 2011 to 2018. Table 3.3 gives a brief description of each law.

Table 3.3 Relevant features of the three legislative reforms

Law	Descentralitation	Privatization	Liberalization
Law03	-Increases PA capacity to outsourcing	-Limits PA activities: PA becomes a regulatory body and provider of infrastructure. PA would only provide cargo handling and other subsidiary services if no private firm were available. -First attempt towards privatisation of the state-owned cargo handling firm *Sociedad Estatal de Estiba y Desestiba*.	-Limits the areas of public domain. -Promoted private sector participation in port infrastructure. -Increased inter-port competition, but kept the uniform tariff system.
Law10	-Increased PA financial autonomy (based on the principles of economic self-sufficiency and cost coverage). -Flexible pricing model. Each PA is able to adapt to its economic reality at any moment.	-Advanced landlord model: landlord port authorities that do not carry out any kind of port services.	-Competitive flexible pricing model -Reduced concession contract periods -The *Observatorio Permanente del Mercado de los Servicios Portuarios* is created to promote prize and quality competition.
Law11	-Economic and financial management autonomy is strengthened on the basis of the principles of outsourcing	-Private participation in the construction, financing and exploitation of port facilities is encouraged.	-Inter-port competition and operators access are improved. -The number of concessions to the same operator are limited in each PA, the same operator cannot have more than 50% of services.

Chapter 4

Technical efficiency analysis

4.1 Introduction

As noted in the literature review Chapter, different techniques have been applied to study technical efficiency in port activity. The main objective of Chapter 4 is to compute technical efficiency applying two different methods: a Stochastic Frontier Analysis (SFA) and Data Envelopment Analysis (DEA) in both using an output-oriented approach. Data collected directly from the ports by the author are used to build an unbalanced panel data of 473 observations for the entire Spanish port system for the period 2002-2018. In a second stage analysis, the technical efficiency values previously computed are used to find the determinants of efficiency. Among those determinants we include port terminals according to their specialization and the type of management, the location of ports on islands, the proximity to oil refineries, the use of rail access, sea frontage, legislative reforms in the period and port size.

One of the main novelties of this Chapter is the use of two different techniques for computing technical efficiency and the comparison of the corresponding results. Regarding the technical efficiency determinants, it is, to the best of our knowledge, the first time that information both about port terminals characteristics and the use of rail access to the ports is included among the determinants. With respect to the port reforms previously analyzed, it is important to remark that the work of González & Trujillo (2008) showed that the port reform of 1992 and 1997 did not lead to an improvement in port efficiency. Díaz-Hernández et al. (2008) using DEA techniques confirmed the González and Trujillo (2008) result for the 1997 reform. In contrast, Coto-Millán et al. (2016) found that the 1997 and 2003 reforms improved port technical efficiency. Finally, the relationship between port size and efficiency has also been studied by previous authors, Bonilla et al. (2002) showed that larger ports had lower levels of efficiency. In contrast, Martínez-Burdía et al. (1999) concluded that larger ports were more efficient.

Non-parametric techniques have been already used in the literature. The Martínez-Burdía et al. (1999) work uses a BCC-DEA model and an additive model to calculate the relative efficiency of ports. Bonilla et al. (2002) use DEA to analyze port efficiency. Díaz-Hernández et al. (2008) evaluate the effect on efficiency of the introduction of new technologies and legislative reforms using DEA. Regarding the use of parametric techniques, Gónzalez & Trujillo (2008) use an output-oriented distance function and also include the location of ports on islands and the proximity of ports to oil refineries among the determinants of efficiency.

Coto-Millán et al. (2016) employ an input-oriented distance function to analyze the impact of public regulation on technical efficiency for the period 1986-2012. Finally, Pérez et al. (2020) use an output-oriented distance function to analyze the impact of port specialization and size on technical efficiency.

This Chapter is organized as follows. Section 2 describes the parametric and non-parametric methodology. Section 3 describes the data. Section 4 shows the results of the efficiency indexes obtained from the two alternative methodologies. Additionally, the determinants of the efficiency are explored in a second stage analysis. Finally, Section 5 presents the main conclusions.

4.2 Methodology

4.2.1 Stochastic Frontier Analysis

Ports handle different types of merchandises, containerized or not, and are also providing services for passengers. It is then more appropriate to describe the port production process as a multiple-output technology by the use of the technology set concept, S. This set consists of all input-output vectors (x, y) such that x can produce y, where $x \in R_+^K$ is the input vector and $y \in R_+^M$ is the output vector. Distance functions (introduced by Shephard 1953, 1970) can be used to estimate multiple-output technologies when there is no information on input prices and it is not appropriate to assume optimizing port behavior. The distance function estimation allows us to measure the relative efficiency of ports in relation to the technological frontier. (Coelli et al., 2005).

The distance function can take either an input or an output orientation. An input-oriented distance function is defined as the largest scalar, δ, by which all inputs be proportionally divided and still the same amount of the output be obtained. That is:

$$D_I(x,y) = \max_{\delta} \{\delta : (x/\delta) \in L(y)\}, \tag{4.1}$$

where $L(y)$, the input set, represents the set of all x which can be used to produce y. A value of $D_I(y,x)$ equal to one, i.e. $\delta = 1$, reveals that production is technically efficient or that x belongs to the frontier of $L(y)$, whereas a value of $D_I(x,y)$ greater than one will indicate that x belongs to the interior of $L(y)$ and production in not efficient. Input-oriented distance functions are required to satisfy the following theoretical properties: homogeneous of degree 1 in x, non-increasing and quasi-concave in y and non-decreasing and concave in x.

On the other hand, an output-oriented distance function is defined as the smallest scalar, μ, by which all outputs can be proportionally divided, using the same level of inputs. That is:

$$D_O(x,y) = \min_{\mu} \{\mu : (y/\mu) \in P(x)\}, \tag{4.2}$$

where $P(x)$, the output set, consists of all y that can be obtained using x. A value of $D_O(x,y)$ equal to one, i.e. $\mu = 1$, reveals that production is efficiently carried out, so that y belongs to the frontier of the production possibility set. Whereas a value of $D_O(x,y)$ smaller than one implies that y is in the interior of $P(x)$. The properties required for output-oriented distance functions are: homogeneus of degree 1 in y, non-increasing and quasi-convex in x, non-decreasing and convex in y. Note that, under constant returns to scale, the input distance function is equivalent to the inverse of the output distance function, i.e., $D_O(x,y)\, D_I(x,y) = 1$, (Färe et al., 1994).

Both approaches are used in the literature. Coto-Millán et al. (2016) employ an input-oriented distance function to compute technical efficiency in the Spanish port sector. The justification is that ports have control over inputs but do not have control over outputs, therefore, they consider demand as exogenously given. However, Gonzalez & Trujillo (2008) use an output-oriented distance function because ports have difficulties to adjust the productive factors. Berths and surface are quasi-fixed factors and labor is generally including public sector workers which numbers are difficult to adjust, particularly when the number need to be reduced. From our point of view the reasons to use output-oriented distance function are more persuasive, thus we opt for an output-oriented approach.

It is usual to present distance functions in a compact way as follows

$$D_O(x,y) = f(x,y,\lambda)e^{\varepsilon}, \tag{4.3}$$

where $f(x, y, \lambda)$ is the functional form of the deterministic component of the frontier and λ is a vector including all unknown parameters. The second term corresponds to the error term. Different algebraic forms of f have been considered including the Linear, Cobb-Douglas, Quadratic, Trans-log, Generalized Leontief and CES functional forms among others. In the same manner the precise choice of the structure of the error term allows the authors to opt for a deterministic or stochastic frontier approach.

Regarding the choice of f, it is desirable that the functional form be flexible, easy to calculate and homogeneous of degree one in outputs. The trans-logarithmic form satisfies the above criteria and has been widely adopted in previous studies (e.g. Lovell et al., 1994, Coelli & Perelman, 2000).[1] The translog distance function for port i, for $i = 1, 2, ..., N$ producing M outputs and using K inputs in year t is:

$$\begin{aligned} \ln D_{Oit} = \alpha_0 &+ \sum_{m=1}^{M} \alpha_m \ln y_{mit} + \frac{1}{2} \sum_{m=1}^{M} \sum_{n=1}^{M} \alpha_{mn} \ln y_{mit} \ln y_{nit} \\ &+ \sum_{k=1}^{K} \beta_k \ln x_{kit} + \frac{1}{2} \sum_{k=1}^{K} \sum_{l=1}^{K} \beta_{kl} \ln x_{kit} \ln x_{lit} \\ &+ \sum_{k=1}^{K} \sum_{m=1}^{M} \delta_{km} \ln x_{kit} \ln y_{mit} + \sum_{a=1}^{A} \psi_a C_a + \sum_{s=1}^{S} \omega_s g_s + \varepsilon_{it}, \end{aligned} \quad (4.4)$$

where α_m is the coefficient for the output m and α_{mn} is the coefficient for the second-degree effects of the outputs m and n, for $m, n = 1, ..., M$. Similarly, β_k is the coefficient for input k; β_{kl} is the coefficient for the

[1] The Cobb-Douglas functional form is a usual alternative although it is only first-order flexible and it is a particular case of the translog function. The latter is more flexible since it has enough parameters to provide second-order approximations.

second-degree effects of the inputs k and l, for $k,l = 1,...,K$; and δ_{km} is the coefficient for the interactive term corresponding to input k an output m. Besides, C_a is the environmental variable a, for $a = 1,...,A$, ψ_a is the coefficient of environmental variable C_a, ω_s is the coefficient for the time dummies g_s, for $s = 1,...,S$ and ε_{it} is the composed error term. To ensure homogeneity of degree 1 in outputs, the following restrictions are imposed:

$$\sum_{m=1}^{M} \alpha_m = 1, \sum_{m=1}^{M} \alpha_{mn} = 0, \sum_{k=1}^{K} \delta_{km} = 0. \tag{4.5}$$

Since $\ln D_{Oit}$ is continuously differentiable the parameters α_{mn} and β_{kl} will be symmetric, i.e. $\alpha_{mn} = \alpha_{nm}$, $\beta_{km} = \beta_{mk}$.

Regarding the error term, we opt for the true fixed effects stochastic frontier proposed by Greene (2004). Thus, the error term has the following structure:

$$\varepsilon_{it} = v_{it} + u_{it}, \tag{4.6}$$

where the first component v_{it} is a random variable with zero mean and variance σ_v^2 that is assumed to follow a i.i.d $N(0,\sigma_v^2)$ distribution. It is considered as statistical noise arising from the omission of relevant variables from x and measurement errors related to the functional form chosen. The non-negative component u_{it} is used to measure the technical inefficiency of each port in each time period. Denote $N^+(\mu,\sigma_u^2)$ the truncated-Normal distribution which is assumed with μ mean and variance σ_u^2. Since we are considering the Battese-Coelli (1992) approach to parametrize time effects, the inefficiency term, u_{it}, is modeled as a truncated-normal random variable, u_i defined above multiplied by a specific function of time showing time-varying decay as follows, $u_{it} = exp(-\eta(t - T_i))u_i$, where T_i is the last period, η is the decay parameter. Both u_i and v_{it} are i.i.d and are distributed independently of each other and the covariates in the model. Thus if $u_{it} = 0$, it means that port i is technically efficient, it is operating at the frontier.

The econometric estimation of equation (4.4) by the use of Stochastic Frontier techniques requires some previous manipulation since the dependent variable is unobserved. Firstly and following Lovell et al. (1994), taking advantage of the linear homogeneity in outputs property, the distance function is normalized by arbitrarily choosing one of the outputs, say y_M, that is, $D_O(x, \frac{y}{y_M}) = \frac{D_O(x,y)}{y_M}$. Hence, the normalized output-oriented distance function can be written as:

$$\begin{aligned}\ln\left(\frac{D_O}{y_M}\right)_{it} &= \alpha_0 + \sum_{m=1}^{M-1}\alpha_m \ln y^*_{mit} + \frac{1}{2}\sum_{m=1}^{M-1}\sum_{n=1}^{M-1}\alpha_{mn}\ln y^*_{mit}\ln y^*_{nit} \\ &+ \sum_{k=1}^{K}\beta_k \ln x_{kit} + \frac{1}{2}\sum_{k=1}^{K}\sum_{l=1}^{K}\beta_{kl}\ln x_{kit}\ln x_{lit} \\ &+ \sum_{k=1}^{K}\sum_{m=1}^{M-1}\delta_{km}\ln x_{kit}\ln y^*_{mit} + \sum_{a=1}^{A}\psi_a C_a + \sum_{s=1}^{S}\omega_s g_s + \varepsilon_{it},\end{aligned} \tag{4.7}$$

where $y^*_{mit} = \frac{y_{mit}}{y_{Mit}}$ and only $(M - 1)$ outputs are considered. Secondly, plugging (4.6) in (4.8), the stochastic frontier approach suggested by Aigner et al. (1977) is applied, in which deviations from the frontier are defined in this following equation:

$$-\ln y_{Mit} = TL\left(x_{it}, y^*_{it}, C_{it}, g_{it}\right) + v_{it} + u_{it}, \tag{4.8}$$

where $TL(\cdot)$ denotes the trans-log terms in (4.8) as a function of the vectors corresponding to inputs, normalized outputs and control variables (i.e. C and g) for each port and period. We now can identify u_{it} with $-ln(D_{Oit})$ as the non-negative value associated with technical inefficiency. In fact, technical efficiency is $TE_{it} = \frac{1}{D_{Oit}} = e^{u_{it}}$. The standard estimator of u_{it} is the conditional mean function $E[u_{it}|\varepsilon_{it}]$.

4.2.2 Data Envelopment Analysis (DEA)

DEA, based in the theory of Farrell (1957), is the other of the principal methods to estimate frontiers. The main difference with the SFA is that DEA is a non-parametric method which involves mathematical programming instead of the use of econometric methods. It allows multiple inputs and outputs for the same period. Similarly to the distance functions presented in the previous subsection, DEA models can be either input-oriented, the objective is to minimize the use of inputs to achieve a given output vector; or can be output-oriented, the objective is to maximize the level of the output vector produced with the input vector held constant.

There are two different specifications. On the one hand, efficiency rates are computed when technology is assumed to have constant returns to scale (CRS). This approach was proposed by Charnes, Cooper and Rhodes (1978) and we denoted it as DEA-CRS. On the other hand, Banker, Charnes and Cooper (1984) propose a more general specification by considering a technology that has varying returns to scale

(VRS) when measuring efficiency rates, we denote it as DEA-VRS.[2] The CRS assumption is appropriate when all firms are operating at an optimal scale. However, this is not the usual situation when firms face regulations and imperfect markers. That is why we compute the two different specifications and allow for the final restriction in (4.9) when computing the DEA-VRS.

Similarly to the SFA analysis,[3] there are N ports. Each port, i produces M outputs combining K different inputs, where vector y_i is the port's i output vector, $y_i \in R_+^M$, and x_i is the input vector, $x_i \in R_+^K$. The measurement of the output-oriented TE under either constant or variable returns to scale using DEA is obtained by solving the following mathematical programming problem, presented in its envelopment form. It is solved for each period and each port, i, where ϕ_i is an scalar and λ_i a vector of non-negative constants:

$$
\begin{aligned}
&\max_{\phi_i,\lambda_i} \phi_i \qquad (4.9)\\
&\text{subject to:}\\
&-\phi_i y_{im} + \sum_{j=1}^{N} \lambda_{ij} y_{jm} \geq 0 \ \forall m, \text{ where } m = 1,...,M\\
&x_{ik} - \sum_{j=1}^{N} \lambda_{ij} x_{jk} \geq 0 \ \forall k, \text{ where } k = 1,...,K\\
&\lambda_i \geq 0.\\
&\sum_{j=1}^{N} \lambda_{ij} = 1. \text{For the VRS model.}
\end{aligned}
$$

[2]The DEA literature denotes the approaches proposed by Charnes, Cooper and Rhodes (1978) and Banker, Charnes and Cooper (1984) as CCR and BCC DEAs, respectively.

[3]To make the expressions easier, the sub-index t will be saved in the expressions.

Notice that $1 \leq \phi_i$. Therefore, $\frac{1}{\phi_i}$ defines a TE measure that varies between zero and one, where the ports considered technically efficient are those with $\phi_i = 1$.

Regarding the technical efficiency indexes obtained by DEA, some authors (Simar and Wilson, 2007) have discussed the validity of the DEA efficiency scores in the usual inference that is pursued in most of the two-stage applications, for ignoring that estimated DEA efficiency scores are calculated from a common sample of data. Simar and Wilson (2008) show the risk of relevant serial correlation, because treating the data as independent observations is not appropriate. To avoid this bias, Simar and Wilson (2007) develop a new algorithm, which defines an underlying data generating process that is consistent with a two-stage estimation procedure. This Simar and Wilson approach will be used in the second stage analysis obtained for DEA inefficiency indices.

4.3 Data

In this section we provide a short description of the variables and data employed in the estimation of the SFA and DEA. A wider and more detailed description of all the data used in the thesis is in Chapter 3.

In particular, we build an unbalanced panel data composed of 473 observations from 28 port authorities in the period 2002 to 2018. Similarly to González & Trujillo (2008), four outputs and three inputs are considered. The outputs are the following:

- Othercargo (y_1): measuring the number of tons of general not containerized merchandise, solid bulk, fresh fish, provisioning and local traffic.

- Containers (y_2): measuring the tons of containerized general merchandise.

- Liquid bulk (y_3): measuring the tons of petroleum and liquid products.

- Passengers (y_4): denoting the total number of passengers, including both regular shipping line and cruise passengers.

There are ports in the sample not having activity in some of the outputs. To fix the problem of undefined natural logarithms, zeroes have been substituted by twos. According to Battese (1997, pp 252), this procedure does not affect the estimates of the basic parameters.

Regarding the inputs, two quasi-fixed inputs and one additional input were considered:

- Berths (x_1): denoting the linear meters of all private and publicly owned berths deeper than four meters.[4]

- Surface (x_2): denoting the squared meters of all types of facilities like storage spaces, roads and other spaces of port authorities regardless of being of private or public ownership.

- Labor (x_3): measuring the number of employees in each port.

[4]Less than four deep-water berths are usually employed for water-sports activities and are useless to handle merchandise or passengers.

Additionally, two environmental variables were introduced:

- $C_{Localization}$ is a dummy variable standing for the distinction between mainland and island ports. This variable takes value one for the three island ports, Baleares, Las Palmas and Santa Cruz de Tenerife, and zero for the rest of ports.

- $C_{Refinery}$ is a dummy variable denoting the proximity to an oil refinery. A Coruña, Bahía de Algeciras, Bilbao, Cartagena, Castellón, Huelva, Santa Cruz de Tenerife and Tarragona are the eight ports with this characteristic, taking this dummy variable zero value for the rest of ports take zero value for .

Note that freight loaded or unloaded in mainland ports can be reached by road, railway, airport or other port, while for island ports, the possibilities are reduced to the airport or other port. Since most of merchandise cannot be transported by plane, island ports are the only alternative of entry and exit of commodities from the territory. Also, the proximity to a refinery allows to attract liquid bulk which is easy and quick to handle in this type of installation. Finally, time dummy variables, g_t, are included for t starting in 2003 and ending in 2018, which take value one for the considered year t and zero otherwise. Table 4.1 shows a summary of the descriptive statistics of outputs and inputs.

Table 4.1 Descriptive statistics of inputs and outputs

Variable	Obs.	Mean	Standard dev.	Min	Max
Berths (x_1) [m]	473	10,171	6,514	1,535	28,910
Surface (x_2) [m^2]	473	2,929,735	2,541,250	240,671	11,099,352
Labor (x_3) [$\# of\ workers$]	473	198	111	43	578
Othercargo (y_1) [$Tons$]	473	6,066,606	4,587,620	430,218	20,308,604
Containers (y_2) [$Tons$]	473	5,071,213	11,978,239	0	60,593,409
Liquid Bulk (y_3) [$Tons$]	473	5,498,762	7,649,714	0	31,763,061
Passengers (y_4) [$\# of\ pass.$]	473	973,899	1,703,909	0	8,942,434

Source: Own elaboration.

Data for the second stage analysis

Among the determinants of the TE, we include as relevant variables the different types of terminals used by ports, several environmental variables that include the two used in the previous analysis ($C_{Localization}$ and $C_{Refinery}$) together with others that indicate whether the port uses its railway access, the coast line in which the port is located, several dummies to account for the effect of several legislative reforms, and finally, a variable accounting for port size. All these variables are described in detail in Section 3.5.

Regarding terminals, they are distinguished depending on the type of freight that the terminal manages and whether the terminal is privately or publicly managed. In particular,

- TPRC: number of privately managed container terminals.
- TPBC: number of publicly managed container terminals.
- TPRL: number of privately managed terminals for liquid products.

- TPBL: number of publicly managed terminals for liquid products.
- TPRMG: number of privately managed terminals for general freight.
- TPBMG: number of publicly managed terminals for general freight.
- TPRP: number of privately managed passenger terminals.
- TPBP: number of publicly managed passenger terminals.

Secondly, to complement the $C_{Localization}$ dummy, we introduce a group of dummy variables indicating the coast line or the geographical area where the port is located:

- $C_{Atlantic}$ takes value one for A Coruña, Bahía de Algeciras, Bahía de Cádiz, Ferrol-San Cibrao, Huelva, Las Palmas, Santa Cruz de Tenerife, Sevilla and Vigo.
- $C_{Cantabric}$ takes value one for Avilés, Bilbao, Gijón, and Santander
- $C_{Mediterranean}$ takes value one for Alicante, Almería, Baleares, Barcelona, Cartagena, Castellón, Ceuta, Málaga, Melilla, Motril, Tarragona and Valencia.

Also, a new environmental variable, C_{Train} is defined in order to study whether access to railway connection affects efficiency. Table D.1 in Appendix D lists detailed information of all ports with railway access and the precise years in which each port has used such facility. We are interested in analyzing the potential effect of legislative reforms on port efficiency. Table 3.3 in section 3.5 describes the three significant legal reforms passed in the period of study and the following dummies are defined to capture their effects. C_{Law03} stands for the 48/2003 law and takes value one from year 2004 to 2010 and zero for the rest of years. C_{Law10} corresponds to the 33/2010 law and takes value one for years 2010 and 2011. Finally, C_{Law11} accounts for the 2/2011 RD. [5] Variables $C_{Localization}$ and $C_{Refinery}$ will be also included as potential determinants of port efficiency.

Finally, a dummy variable, $C_{Berths15000}$, is used to account for the size of the ports. It takes value one in case a port has a total berth size longer than 15,000 meters. The ports that take value one are Baleares, Barcelona, Bilbao, Las Palmas, for the full period of analysis; and Bahía de Algeciras, Santa Cruz de Tenerife, Tarragona and Valencia only from 2008. Table 4.2 shows the descriptive statistics of the different types of port terminals and other second stage analysis variables.

[5] It is important to note that the 2/2011 RD includes a derogatory provision by which Laws 27/1992, 62/1997, 48/2003 and 33/2010 are hereby repealed.

Table 4.2 Descriptive statistics for the second stage variables

Variable	**Obs.**	**Mean**	**Standard dev.**	**Min**	**Max**
TPRC	473	0.7928	1.1768	0	6
TPBC	473	0.0211	0.1440	0	1
TPRL	473	1.8055	1.5460	0	7
TPBL	473	0.0930	0.3251	0	2
TPRMG	473	2.3763	1.9803	0	9
TPBMG	473	0.1924	0.6098	0	3
TPRP	473	0.3087	0.6903	0	3
TPBP	473	1.3086	1.6855	0	8
$C_{Localization}$	473	0.1078	0.3105	0	1
$C_{Refinery}$	473	0.2875	0.4531	0	1
C_{Train}	473	0.5793	0.4942	0	1
$C_{Atlantic}$	473	0.3954	0.4894	0	1
$C_{Cantabric}$	473	0.1797	0.3843	0	1
$C_{Mediterranean}$	473	0.4543	0.4985	0	1
$C_{Berths15000}$	473	0.2241	0.4174	0	1

Source: Own Elaboration

4.4 Results

4.4.1 The distance function estimation

Spanish ports are heterogeneous in size, traffic specialization, location and other variables which advise us to use fixed effects estimation techniques to avoid the possibility of biased coefficient estimations and capture non-observable differences in ports.[6] Table 4.3 displays the maximum likelihood estimates of coefficients and standard deviations of all the variables included in the output-oriented distance function. First-order coefficients are significant and show the expected sign.[7] Output variable coefficients are negative which indicates that the distance from the frontier increases when production grows. On the other hand, all the input variable coefficients are positive. Therefore, when the use of inputs increase for a given output level, the distance from the frontier is reduced. These first order coefficients can be interpreted as elasticities evaluated on the data average, since each of the variables has been differentiated by their respective geometric mean. The greatest input elasticity corresponds to labor, reaching 0.689; followed by the quasi-fixed input Berths with a value of 0.263. The quasi-fixed input surface is not considered since it is only significant at 10% level. Our results coincide with those in previous papers, in particular Baños-Pino et al. (1999), González & Trujillo (2008), Nuñez-Sánchez & Coto-Millán (2012) and Coto-Millán et al. (2016); that also obtained that the labor factor has the greatest elasticity, followed by berths and all of them showed increasing returns to scale.

Regarding the environmental variables, both $C_{Localization}$ and $C_{Refinery}$ variables have positive and significant coefficients. Similarly to González

[6]For the estimation of equation (4.4) we have used the command *xtfrontier* for panel data using the time-varying decay model option available in Stata 15 software.

[7]The dependent variable values for the output-oriented distance function has remained positive, according to the Coelli and Perelman (1996) procedure and also used in Chaterine et al. (2000). Hence, the coefficients of the first order coefficients have the opposite sing with respect to González and Trujillo (2008), but the interpretation of these coefficients is the same.

& Trujillo (2008), we find that ports located in islands as well as those with refineries nearby benefit from an outward shift of the frontier as compared to the others. However, we find that the "island effect" is greater than the refinery one, i.e. 6.9 vs. 5.7 which contrast to González & Trujillo (2008) where the refinery effect was stronger, i.e. 4.9 vs. 2.5.

The time dummy coefficients show the effect of the corresponding year in the production frontier that affect all the ports simultaneously. These coefficients are significant from 2004 to 2009 and from 2015 to 2018. They are used to measure the existence of technical change between periods. Technological change (TC) is calculated applying equation (4.10) and results are presented in Table 4.5. Looking at the third column in Table 4.5, we may conclude that ports showed little TC (1.77% average), improvements are not every year and are independent from the legislative regulation.

$$TC_{t+1,t} = \omega_{t+1} - \omega_t \tag{4.10}$$

Finally, Table 4.4 displays the estimated values of the relevant parameters in the error term specification in equation (4.6). Note that a large proportion of the total error variance, i.e. 96%, is related to the component used to measure technical inefficiency, u. Also, parameter η has a negative sign indicating that efficiency has declined in the period as also suggested by the last row of Table D.2 in the Appendix D.

Table 4.3 Estimated output-oriented distance function

Variable	**Coefficient**	**Estimates**	**Std. Error**
$\text{Ln}(y_1)$	α_{y_1}	-0.7680***	0.0184
$\text{Ln}(y_2)$	α_{y_2}	-0.0482***	0.0078
$\text{Ln}(y_4)$	α_{y_4}	-0.0817***	0.0096
$\frac{1}{2}\text{Ln}(y_1)\text{L}(y_1)$	$\alpha_{y_{11}}$	-0.0304***	0.0033
$\frac{1}{2}\text{Ln}(y_2)\text{L}(y_2)$	$\alpha_{y_{22}}$	-0.0072***	0.0014
$\frac{1}{2}\text{Ln}(y_4)\text{L}(y_4)$	$\alpha_{y_{44}}$	-0.0093***	0.0016
$\text{Ln}(y_1)\text{Ln}(y2)$	$\alpha_{y_{12}}$	0.0191***	0.0028
$\text{Ln}(y_1)\text{Ln}(y_4)$	$\alpha_{y_{14}}$	0.0131***	0.0033
$\text{Ln}(y_2)\text{Ln}(y_4)$	$\alpha_{y_{24}}$	-0.0008	0.0016
$\text{Ln}(x_1)$	β_{x_1}	0.2634***	0.0579
$\text{Ln}(x_2)$	β_{x_2}	0.0791*	0.0469
$\text{Ln}(x_3)$	β_{x_3}	0.6894***	0.1003
$\frac{1}{2}\text{Ln}(x_1)\text{Ln}(x_1)$	$\beta_{x_{11}}$	0.1231	0.1904
$\frac{1}{2}\text{Ln}(x_2)\text{Ln}(x_2)$	$\beta_{x_{22}}$	0.1218	0.0774
$\frac{1}{2}\text{Ln}(x_3)\text{Ln}(x_3)$	$\beta_{x_{33}}$	1.0974***	0.2983
$\text{Ln}(x_1)\text{Ln}(x_2)$	$\beta_{x_{12}}$	0.2466	0.1921
$\text{Ln}(x_1)\text{Ln}(x_3)$	$\beta_{x_{13}}$	-0.7052**	0.3458
$\text{Ln}(x_2)\text{Ln}(x_3)$	$\beta_{x_{23}}$	-0.4262***	0.1514
$\text{Ln}(y_1)\text{Ln}(x_1)$	$\delta_{y_1x_1}$	-0.0083	0.0263
$\text{Ln}(y_1)\text{Ln}(x_2)$	$\delta_{y_1x_2}$	0.0027	0.0193
$\text{Ln}(y_1)\text{Ln}(x_3)$	$\delta_{y_1x_3}$	0.0784***	0.0276
$\text{Ln}(y_2)\text{Ln}(x_1)$	$\delta_{y_2x_1}$	-0.0134	0.0094
$\text{Ln}(y_2)\text{Ln}(x_2)$	$\delta_{y_2x_2}$	0.0065	0.0041
$\text{Ln}(y_2)\text{Ln}(x_3)$	$\delta_{y_2x_3}$	0.0114	0.0137
$\text{Ln}(y_4)\text{Ln}(x_1)$	$\delta_{y_4x_1}$	0.0018	0.0137

Table 4.3 continued from previous page

Variable	**Coefficient**	**Estimates**	**Std. Error**
$\text{Ln}(y_4)\text{Ln}(x_2)$	$\delta_{y_4x_2}$	0.0046	0.0067
$\text{Ln}(y_4)\text{Ln}(x_3)$	$\delta_{y_4x_3}$	-0.0397***	0.0127
g_{2003}	ω_{2003}	0.011	0.0308
g_{2004}	ω_{2004}	0.0645**	0.0315
g_{2005}	ω_{2005}	0.1282***	0.0333
g_{2006}	ω_{2006}	0.1534***	0.0355
g_{2007}	ω_{2007}	0.1723***	0.0374
g_{2008}	ω_{2008}	0.0832**	0.0411
g_{2009}	ω_{2009}	-0.1008**	0.0437
g_{2010}	ω_{2010}	-0.0817*	0.0476
g_{2011}	ω_{2011}	-0.0205	0.0512
g_{2012}	ω_{2012}	0.0345	0.0564
g_{2013}	ω_{2013}	0.0025	0.0605
g_{2014}	ω_{2014}	0.0924	0.0645
g_{2015}	ω_{2015}	0.1393**	0.0685
g_{2016}	ω_{2016}	0.1870**	0.0745
g_{2017}	ω_{2017}	0.2645***	0.0792
g_{2018}	ω_{2018}	0.2826***	0.0829
$C_{Localization}$	ϕ_{loc}	0.6970***	0.2489
$C_{Refinery}$	ϕ_{ref}	0.5688***	0.1757
$Constant$	α_0	0.9470***	0.0979

***, ** and * indicate that estimates are significantly different from zero at the 0.01, 0.05 and 0.10 levels, respectively

Table 4.4 Estimates for the distance function error term parameters

Parameters	**Estimates**	**Std. Error**
μ	1.1584***	0.1475
η	-0.0098**	0.0039
σ_u^2	0.2748***	0.1005
σ_v^2	0.0123***	0.0008

***, ** and * indicate that estimates are significantly different from zero at the 0.01, 0.05 and 0.10 levels, respectively

Table 4.5 Technical change for each period

Period	$\omega_{t+1} - \omega_t$	$TC_{t+1,t}$
2002-2003	(0.0110 - 0)	0.0110
2003-2004	(0.0645 - 0.0110)	0.0535
2004-2005	(0.1282 - 0.0645)	0.0637
2005-2006	(0.1534 - 0.1282)	0.0252
2006-2007	(0.1723 - 0.1534)	0.0189
2007-2008	(0.0832 - 0.1723)	-0.0891
2008-2009	(-0.1008 - 0.0832)	-0.1840
2009-2010	(-0.0817 -(-0.1008))	0.0191
2010-2011	(-0.0205 -(-0.0817))	0.0612
2011-2012	(0.0345 - (-0.0205))	0.0550
2012-2013	(0.0025 - 0.0345)	-0.0320
2013-2014	(0.0924 - 0.0025)	0.0899
2014-2015	(0.1393 - 0.0924)	0.0469
2015-2016	(0.1870 - 0.1393)	0.0477
2016-2017	(0.2645 - 0.18705)	0.0775
2017-2018	(0.2826 - 0.2645)	0.0181

Another interesting feature to analyze is whether there are economies of scale. Port i's economies of scale (ES) at period t are defined by $ES_{it} = \sum_{k=1}^{K} \frac{\partial \ln D_0(y_{it}, x_{it})}{\partial \ln x_k}$. Table 4.6 shows the Spanish port average ES for each year. A value of ES greater (lower) than one shows increasing (decreasing) returns to scale. Note that from 2002 to 2009 there are increasing returns to scale and from 2010 to 2018 there are decreasing returns to scale. Considering the full period average, there are decreasing returns to scale. This result contrasts with those found by previous authors. Martínez-Burdía (1996), Coto-Millan et al. (2000), González & Trujillo (2008) and Coto-Millán et al. (2016) found increasing returns to scale. Note that for González & Trujillo (2008) the ES were falling over time.

Table 4.6 Average of economies of scale for each year

Year	**Economies of Scale**	**Std. Err.**
2002	1.0388	0.0745
2003	1.0211	0.0729
2004	1.0184	0.0838
2005	1.0443	0.1010
2006	1.0415	0.9895
2007	1.0260	0.0999
2008	1.0004	0.1035
2009	1.0068	0.1032
2010	0.9833	0.1088
2011	0.9568	0.1098
2012	0.9157	0.1025
2013	0.8899	0.1015
2014	0.8856	0.1044
2015	0.8615	0.1002
2016	0.8436	0.1028
2017	0.8303	0.1003
2018	0.8357	0.1013
Average	*0.9523*	

Table 4.7 shows the average of TE for each port and approach used. Those values are equal or lower than one, because of the output-oriented distance function approach used. The average TE of the Spanish port system is 0.377 for the parametric method and 0.441 and

0.487 for the non-parametric methods. Therefore, a second stage analysis is interesting to find the main determinants of TE. Tables D.2, D.3 and D.4 in Appendix D display the per port and year TE indicators for the SFA, DEA-CRS and DEA-VRS approaches, respectively. One goal of this study is to compare the TE rankings derived by the three different approaches used. Table 4.8 displays the Spearman's rank-order correlation coefficients between the SFA, DEA-CRS and DEA-VRS approaches. We obtain relatively high values for the correlations between the three indices analyzed. In particular, the correlation between the index obtained by SFA and the indices obtained by DEA under CRS and VRS are 0.74 and 0.75 respectively, meanwhile the correlation between the indices obtained by DEA is 0.71. These results indicate that the rankings obtained are robust to the different methodologies, and therefore no significant differences are expected depending on the approach selected.

Table 4.7 TE averages per port using the SFA, DEA-CRS and DEA-VRS approaches

Port	**SFA**	**DEA-CRS**	**DEA-VRS**
A Coruña	0.2858	0.4679	0.4744
Alicante	0.2633	0.1514	0.1514
Almería	0.6773	0.4678	0.5276
Avilés	0.4562	0.3928	0.4313
B. Algeciras	0.7362	0.9223	0.9343
B. Cádiz	0.2624	0.1606	0.1737
Baleares	0.3347	0.3352	0.5636
Barcelona	0.6274	0.4702	0.7948
Bilbao	0.3862	0.5697	0.6421
Cartagena	0.3644	0.8508	0.8542
Castellón	0.3147	0.6394	0.7199
Ceuta	0.3289	0.3653	0.3792
Ferrol S.C.	0.6383	0.7104	0.7845
Gijón	0.9466	0.8330	0.8651
Huelva	0.3160	0.8959	0.9084
Las Palmas	0.2861	0.3159	0.3833
Málaga	0.2538	0.1659	0.1703
M.R. Pontevedra	0.2206	0.1905	0.1905
Melilla	0.1613	0.1885	0.1885
Motril	0.2278	0.2944	0.2945
Pasaia	0.3141	0.2586	0.2603
S.C. Tenerife	0.2226	0.4838	0.4999
Santander	0.4038	0.2555	0.2606
Sevilla	0.2773	0.2673	0.2673
Tarragona	0.3569	0.7240	0.8088
Valencia	0.5810	0.6922	0.8211
Vigo	0.1746	0.1154	0.1183
V. Aurosa	0.1349	0.1398	0.1388
Average	*0.3784*	*0.4411*	*0.4872*

Table 4.8 Spearman's rank-order correlation coefficients between the TE indices using SFA, DEA-CRS and DEA-VRS

Method / Method	SFA	DEA-CRS	DEA-VRS
SFA	1	•	•
DEA-CRS	0.7389	1	•
DEA-VRS	0.7504	0.7131	1

4.4.2 Second stage: The determinants of technical efficiency

Table 4.9 provides the results for the second stage, where the main objective is to identify the key determinants of the TE. In the first column, a Tobit regression[8] is performed regarding the TE of the parametric method. In the second and third columns, the methodology of Simar and Wilson (2007) is followed when considering the TE obtained from the two non-parametric methods.

[8] Tobit regression has been selected instead the OLS regression because the dependent variable is restricted between 0 and 1.

Table 4.9 Results of the second stage

Variable	**Coeff.**	**SFA**	**Std. Err.**	**DEA-CRS**	**Std. Err.**	**DEA-VRS**	**Std. Err.**
Constant	δ_0	0.3017***	0.0272	0.2623***	0.0409	0.2652***	0.0503
TPRC	δ_{tprc}	0.0753***	0.0118	0.0690***	0.0175	0.0856***	0.0207
TPBC	δ_{tpbc}	0.0989*	0.0568	-0.0767	0.0933	-0.0804	0.1179
TPRL	δ_{tprl}	-0.0067	0.0061	0.0285***	0.0093	0.0196*	0.0110
TPBL	δ_{tpbl}	0.0050	0.0261	0.1129**	0.0436	0.1501***	0.0535
TPRMG	δ_{tprmg}	0.0506***	0.0061	0.0493***	0.0089	0.0826***	0.0116
TPBMG	δ_{tpbmg}	-0.0548***	0.0209	-0.0569*	0.0302	-0.1077***	0.0365
TPRP	δ_{tprp}	-0.1223***	0.0171	-0.1184***	0.0265	-0.2136***	0.0330
TPBP	δ_{tprp}	-0.0033	0.0096	-0.0513***	0.0153	-0.0645***	0.0175
$C_{Localization}$	δ_{loc}	-0.0492	0.0624	0.1794*	0.0936	0.3418***	0.1081
$C_{Refinery}$	δ_{ref}	0.0397**	0.0198	0.3978***	0.0313	0.4223***	0.0404
C_{Train}	δ_{tra}	-0.0552***	0.0214	-0.1000***	0.0314	-0.0918**	0.0396
$C_{Cantabric}$	δ_{can}	0.1423***	0.0234	0.0486	0.0346	-0.0246	0.0421
$C_{Atlantic}$	δ_{atl}	-0.0161	0.0213	-0.0603*	0.0314	-0.1155***	0.0377
C_{Law03}	δ_{law03}	-0.0167	0.0217	0.0177	0.0315	0.0128	0.0394
C_{Law10}	δ_{law10}	0.0091	0.0253	-0.0657*	0.0366	-0.0768*	0.0440
C_{Law11}	δ_{law11}	-0.0491**	0.0203	-0.0217	0.0292	-0.0079	0.0373
$C_{Berths15000}$	$\delta_{berths15000}$	-0.0216	0.0277	-0.0547	0.0409	0.0896	0.0514

***, ** and * indicate that estimates are significantly different from zero at the 0.01, 0.05 and 0.10 levels, respectively.

According to the results shown in Table 4.9, we find that the type of management matters and the sign of the effect depends on the type of cargo of the terminal. Ports with container terminals managed by private firms are more efficient at 1% level of significance for any method used. While management directly by port have barely no effect. When general merchandise terminals are considered, a significant and positive effect on port technical efficiency and for all method considered is found in ports having that type of terminals. However, when the terminal is managed directly by ports the effect is negative and significant. For terminals handling liquids and petroleum freight and passengers the type of management does not matter for the sign of the effect. Ports with passenger terminals are always less efficient regardless of the method used, although ports that have privately managed terminals have a larger negative impact. Finally, ports handling liquids have a positive and significant effect on port efficiency but only when a particular method is used.

Regarding port location, ports in islands are found to be more efficient only in case a DEA with variable returns to scale is used. With respect to the coastline, ports in the Cantabric coast are more efficient than those in the Mediterranean coast according to the SFA method, while ports in the Atlantic coast are less efficient as compared with those in the Mediterranean coast in case a DEA with variable returns to scale is used. An oil refinery nearby a port increases technical efficiency, while the use of railway access reduces it, and these results are robust to the approach used. The legislative reforms have typically no effects on technical efficiency. Only the 33/2010 law has a negative effect at 10% level of significance and in case the non-parametric methods are used. The 2/2011 RD has a negative effect at 5% level of significance when the parametric approach is considered. Finally, port size has no effect regardless the method used.

4.5 Conclusions

Spanish ports technical efficiency has been analyzed in this Chapter by applying some alternative techniques, an output-oriented distance function and two different non-parametric options, DEA-CRS and DEA-VRS. The technical efficiency rankings obtained present a relative high relationship as shown by the Spearman's rank-order correlation coefficients above 0. 71. Therefore, we can conclude that our TE ranking is robust to the methodology used. The most technically efficient ports are Bahía de Algeciras, Gijón, Valencia and Ferrol.[9] In contrast, the least technically efficient ports are Vilagarcía de Aurosa, Marín and Ría de Pontevedra, Vigo, Málaga and Melilla. Regarding average technical efficiency levels, those obtained using the SFA approach are particularly low, going from 0.4067 in the year 2002 to 0.3541 in 2018. This implies an annual average reduction of technical efficiency of 0.86%.[10] However, the average levels of technical efficiency of the non-parametric method have an average annual growth of 0.61% for the DEA-CRS and of 0.79% for the DEA-VRS approaches. Additionally,

[9] Note that ports are in different ranking positions depending on the methodology used. To select the above four more efficient, we only consider those ports that appear among the nine more efficient (one third of total number of ports) in the three proposed rankings and choose those with the lowest sum of their positions in the rankings.

[10] Note the restrictions of the Battese & Coelli (1992) in that the direction of change of efficiency is the same for all ports and that the rate of change is the same every year.

it is interesting to note that ports present decreasing returns to scale since 2010 and, therefore, the trend of returns to scale calculated in González & Trujillo (2008) is maintained. Finally, there has been technical progress in the period analyzed, with an average annual growth rate of 1.77%.

In a second stage analysis, multiple determinants of efficiency were analyzed. In particular, the type of port terminals according to the type of cargo and management, several legislative reforms in the period, some environmental variables that include the localization of ports in islands and the proximity of the port to an oil refinery, the use of railway access for incoming and outgoing cargo, port coastline location and port size. The results of this second stage analysis are relatively similar regardless the technique used. The type of management matters and the sign of the effect depends on the type of cargo of the terminal. Ports with container terminals managed by private firms are more efficient at 1% level of significance for any method used. While those directly managed by ports have barely no effect. Similar results are found for general merchandise terminals, with the difference that when the terminal is managed directly by ports the effect is negative and significant. Ports with passenger terminals are always less efficient regardless of the method used, although ports that have privately managed terminals have a larger negative impact. Finally, ports handling liquids have a positive and significant effect on port efficiency but only when a particular method is used.

Regarding port location, ports in islands are found to be more efficient only in case a DEA-VRS is used. With respect to the coastline, ports in the Cantabric coast are more efficient than those in the Mediterranean coast according to the SFA method, while ports in the Atlantic coast are less efficient as compared with those in the Mediterranean coast in case a DEA with variable returns to scale is used. An oil refinery nearby a port increases technical efficiency, while the use of railway access reduces it, and these results are robust to the approach used. The legislative reforms implemented in the years 2003, 2010 and 2011 have typically not significant effect on technical efficiency, therefore reinforcing the conclusion in Gonzalez & Trujillo (2008) and Díaz-Hernandez et al. (2008) works. The 33/2010 law has a negative effect at 10% level of significance and only for the non-parametric methods. The 2/2011 RD has a negative effect at 5% level of significance when the parametric approach is considered. Finally, port size does not affect technical efficiency regardless the method used. This latter conclusion contrasts with Martínez-Burdía (1996) and Bonilla et al. (2002) that showed that largest ports had lower levels of efficiency. Also with Martínez-Burdía et al. (1999) and Coto-Millan et al. (2000) who concluded that the largest ports were the most efficient.

Chapter 5

Economic efficiency analysis

5.1 Introduction

In the previous Chapter, both parametric and non-parametric approaches were used to calculate technical efficiency. The main objective of Chapter 5 is the estimation of a frontier cost function to calculate economic efficiency. In addition, the existence of over-capitalization in the quasi-fixed input of Spanish ports is estimated. The data used are similar to those in Chapter 4, that is, an unbalanced panel data with 405 observations for the period 2002-2018 from all ports in the Spanish port system with the exception of Marin and Ria de Pontevedra, Melilla, Pasaia and Vilagarcía de Aurosa ports. A second stage analysis is undertaken to identify the determinants of economic efficiency. These determinants are the type of port terminals according to their specialization and type of management, the location of ports on islands, the existence of oil refineries, the use of rail access, coasline, the over-capitalization index, the mechanization index, and the port size.

Although there are articles that have calculated the economic efficiency and over-capitalization rates of the Spanish port system, this Chapter contributes by using a more recent database to explain the effects of the fall in port activity during the economic crisis and the fall in port investment in recent years.[1] To the best of our knowledge, this study is the first that includes information on the type of port terminals, rail usage and levels of over-capitalization among the determinants of economic efficiency. Regarding the port reforms considered in this Chapter, the previous work by Rodríguez-Álvarez & Tovar (2012) showed that the 1992 and 1997 reforms improved economic efficiency while the 2003 reform worsened it and ports with higher mechanization index were less efficient (Note that ports with higher mechanization index are those of larger size). Both, Baños-Pino et al. (1999) and Rodríguez-Álvarez & Tovar (2012) found over-capitalization of Spanish ports. Finally, Martínez-Burdía (1996) showed that larger ports were more inefficient, while Coto-Millán et al. (2000) concluded that larger ports offer higher levels of economic efficiency.

Other articles have previously calculated economic efficiency and its determinants. Martínez-Budría (1996) employs for the first time a cost function for the Spanish port system. Coto-Millán et al. (2000) use a stochastic cost function to calculate the economic efficiency of Spanish ports. Rodríguez-Álvarez & Tovar (2012) use a multiproduct

[1] See Table E.2 in Appendix E.

cost frontier function to analyze the effect of the legislative reforms on economic efficiency. Finally, it should be noted that Rodríguez-Álvarez et al. (2012) use the variables of port location on islands, the existence of oil refineries and the mechanization index. This Chapter is organized as follows. Section 2 presents the cost frontier function methodology and the computation of the optimal level of the quasi-fixed input. Section 3 describes the data. Section 4 outlines the functional form followed to estimate the cost frontier function. Section 5 shows the results of the cost frontier function, the levels of the over-capitalization index and economic efficiency, describes the data used in the second stage and analyzes the main determinants of economic efficiency. Section 6 concludes.

5.2 Methodology

5.2.1 The cost frontier function

In this Chapter we are interested in analyzing firm efficiency by using the dual of the production function, the cost function. It is defined as the minimum cost of producing a particular level of output given the prices of a set of inputs and the technology. Formally, $TC(y,w) = \min\{w^T x : g(x) \geq y\}$ for the case of one output, y, and a vector of inputs, x, where $g(x)$ is the production function and w is the vector of exogenously determined input prices. Obviously, when a producer is technically inefficient its production costs must exceed the above defined theoretical minimum. That is the reason why several authors use a frontier cost approach as an alternative to the frontier production function model. Note that when using the cost approach any source of inefficiencies, technical or allocative (the choice of the optimal mix of inputs) appear as higher costs. Both alternatives are obtained and compared in this research.

When firms produce several outputs, the use of cost functions is easier since the concept of production function is substituted by a more general one, the transformation function, $T(y, x) = 0$, where y and x are the output and input vectors as defined in Section 4.2 of Chapter 4. Assuming that production satisfies certain regularity conditions (monotonicity, smoothness and quasi-concavity), the cost frontier function can be represented in the following form:

$$TC(y,w) = TC(y_1,...,y_M;w_1,...,w_K), \tag{5.1}$$

where this function is monotonic in outputs and in each input price and homogeneous of degree one and concave in input prices. In order to measure the economic efficiency, each firm's observed total cost is compared with respect to the minimum cost defined by the cost frontier function. That is,

$$TC_i \geq TC(y_{1i},...,y_{Mi};w_{1i},...,w_{Ki}), \tag{5.2}$$

where TC_i is the observed total cost of firm i and sub-index i added to outputs and input prices indicates the outputs produced and input prices paid by that firm. Note that expression (5.2) can be restated as

$TC_i = TC(y_i; w_i)(1/EE_i)$, where $0 < EE_i \leq 1$ measures (cost) economic efficiency; implying the the firm operates in an efficient way if $EE_i = 1$, while it is inefficient otherwise. As it happens with the distance function analyzed in Chapter 4, the cost frontier function can be calculated following either a deterministic or an stochastic approach. The main difference between them is that the deterministic frontier estimation assumes that deviations between total cost from the cost frontier are explained only by inefficiencies, while the stochastic frontier approach assumes that each firm faces its own cost frontier function; which is randomly located by not only inefficient behavior of the firm but also by several stochastic factors not controlled by the firm. An appropriate and compact specification of a stochastic cost frontier function is:

$$TC_i = TC\left(y_i, w_i\right) exp\left(\varepsilon_i\right), \tag{5.3}$$

where $\varepsilon_i = v_i + u_i$. Note that v_i accounts for the random effects that affect the location of the firm $i's$ stochastic cost frontier, while $u_i \geq 0$ corresponds to the economic inefficiency. That is, EE_i is measured by $1/exp(u_i)$.

5.2.2 Optimal quasi-fixed capital stock

To better understand efficiency, we need to incorporate the fact that firms can be restricted in their input choices. In the long run, firms can select the optimal mix of inputs given input prices and technology. However, in the short run firms have their choice of particular inputs, the quasi-fixed inputs, restricted implying non-optimal use of such inputs (see Caves et al. ,1980, 1981, Friedlaender et al.,1993, Keeler & Formby, 1994, Morrison, 1988, Nemoto et al.,1993, Oum & Waters, 1997, and Rodríguez-Álvarez & Tovar, 2012, among others). It is, therefore, important to measure the difference between the actual use of quasi-fixed inputs and the optimal one to assess whether firms are operating under excess capacity or they are overcapitalized. The optimal quasi-fixed input can be obtained from the short-run total cost function defined as:

$$TC(y,w,K) = VC(y,w,K) + rK. \tag{5.4}$$

where the TC in (5.1) is decomposed into two terms, the variable cost function, VC, and the fixed costs one that is defined as rK; where K is the quasi-fixed input and r its price. The optimal level of quasi-fixed input is the K^* that satisfies the following first order condition:

$$\frac{\partial TC(y,w,K^*)}{\partial K} = \frac{\partial VC(y,w,K^*)}{\partial K} + r = 0. \tag{5.5}$$

Or equivalently,

$$\frac{-\partial VC(y,w,K^*)}{\partial K} = r. \tag{5.6}$$

where the left hand side is the firm's shadow price of the quasi-fixed input $(r^s(K))$. In other words, the effect of the savings in the variable cost function when the restriction under which the firm operates is relaxed (the quasi-fixed input is raised) by an infinitesimal amount. Therefore, K^* is the optimal choice of the quasi-fixed input since for that level of the quasi-fixed input, its price coincides with the firm's shadow price. Note, that when $\frac{\partial TC(y,w,K)}{\partial K} > 0$, that is, when $r^s(K) < r$, the quasi-input K is overused since $\frac{\partial VC(y,w,K^*)}{\partial K}$ is increasing in K.

5.3 Data

As in Chapter 4, now we briefly describe the data used to estimate the cost function. A more detailed description is in Chapter 3. In order to estimate the cost function, we have used a unbalanced panel data of 405 observations. These are less observations than those employed in the distance function estimation. This panel data includes 24 ports with annual observations for the period 2002-2018 but to avoid the presence of outliers, the five smallest and the five five handling less tons are excluded. That is, Marín y Ría de Pontevedra, Melilla, Pasaia and Vilagarcía de Aurosa are not considered in this Chapter. The 24 ports analyzed are different in terms of size, some have freight and passengers traffic, there are ports that do not have passenger traffic and freight traffic can be divided in different types. Besides, some ports are specialized in some type of merchandise.

As dependent variable we consider the total costs (TC), which are the sum of variable and fixed costs. Variable costs are defined as the sum of staff cost, services expenses and other current operating expenses. Fixed costs include the depreciation of fixed costs.[2] The outputs considered in the estimation are the same as in Chapter 4, *Othercargo* (y_1), *Containers* (y_2), *Liquid bulk* (y_3), and *Passengers* (y_4).

[2]Costs and input prices are deflated and expressed in constant euros of 2018.

Regarding input prices (or per unit costs), the prices of labor, intermediate services and capital are defined as follows:

- w_l stands for the price of labor and is obtained as the quotient between the staff expenses and the number of workers.

- w_i denotes the price of intermediate services, which is defined as the quotient between the expenses in operating and other current services and the total tons.

- w_k stands for the capital price and is obtained by dividing the depreciation of fixed assets, approximated by the depreciation costs, by the total surface area measured in square meters.

Finally, we introduce a "quasi-fixed" input (K), defined in Chapter 3 as the squared meters of all types of port facilities like storage spaces, roads and other spaces of port authorities.[3] Also, a trend variable (t) is introduced in the analysis. Table 5.1 shows a summary of the descriptive statistics of all the variables used in the cost function estimation.[4]

[3] K is in fact surface denoted x_2 in Chapter 3. The reason of using K is that this is the usual notation of the quasi-fixed input in the literature.

[4] Table 3.1 in Chapter 3 provides information of the inputs and outputs averages per port.

Table 5.1 Descriptive statistics

Variable	Unit	Description	Mean	Std. dev.	Min	Max
TC	deflated €	Total cost	33,822,837	25,840,223	4,360,772	154,820,963
FC	deflated €	Fixed cost	14,424,338	11,787,373	1,810,581	70,752,183
VC	deflated €	Variable cost	19,398,500	14,723,961	2,550,191	84,064,780
y_1	Tons	Othercargo	6,788,893	4,528,746	628,769	20,308,604
y_2	Tons	Containers	5,891,818	12,762,379	0	60,593,409
y_3	Tons	Liquids	6,406,569	7,903,423	1,502	31,763,061
y_4	# of pass.	Passengers	1,111,050	1,799,742	0	8,942,434
K	m^2	Surface	3,334,586	2,529,016	360,451	11,099,352
w_i	deflated €/Tons	Per unit intermediate consumption cost	0.76	0.57	0.11	3.20
$w_k = r$	deflated €/m^2	Per unit capital cost	5.17	2.65	0.64	13.25
w_l	deflated €/# of wrk.	Per unit labor cost	44,843.42	5,872.44	33,361.18	68,692.0
t	Years	Unit time	9.05	4.89	1	17
$share_i$	no unit	Intermediate consumption share	0.2607	0.0616	0.1099	0.5212
$share_k$	no unit	Capital share	0.4136	0.085	0.2089	0.1785
$share_l$	no unit	Labor share	0.3257	0.0694	0.1785	0.5005

Second stage variables

The variables used in the second stage are those that may affect the position of the corresponding port cost function with respect to the cost frontier and are the same as those used to explain technical efficiency (Table 4.2). Additionally, we include the over-capitalization index (OI), in order to check whether this index affects cost inefficiency. Finally, a control variable MI is introduced[5] as an index of mechanization of ports, that is approximated by the share of total containerized tons over total tons handled by the port. Table 5.2 shows the descriptive statistics of the second stage variables.[6]

[5]Following Rodríguez-Álvarez & Tovar (2012)

[6]Table C.1 in Appendix C provides information about the number of terminals per type and port.

Table 5.2 Descriptive statistics for the second stage variables

Variable	Obs	Mean	Std. dev.	Min	Max
TPRC	405	0.8840	1.2364	0	6
TPBC	405	0.0247	0.1554	0	1
TPRL	405	1.9877	1.5630	0	7
TPBL	405	0.1012	0.3405	0	2
TPRMG	405	2.5284	2.0878	0	10
TPBMG	405	0.1827	0.6342	0	3
TPRP	405	0.3605	0.7335	0	3
TPBP	405	1.4593	1.7608	0	8
$C_{Localization}$	405	0.1259	0.3322	0	1
$C_{Refinery}$	405	0.3358	0.4729	0	1
C_{Train}	405	0.5753	0.4949	0	1
$C_{Atlantic}$	405	0.3778	0.4854	0	1
$C_{Cantabric}$	405	0.1679	0.3742	0	1
$C_{Mediterranean}$	405	0.4543	0.4985	0	1
OI	405	6.1024	3.3194	0.34	18.52
MI	405	0.1978	0.2172	0	0.79
$C_{Berths15000}$	405	0.2617	0.4401	0	1

Source: Own Elaboration

5.4 Econometric specification

To estimate the cost function in equation (5.4), we use a multiproduct translog stochastic frontier. This is a very common option in the received literature that provides more flexibility in the analysis to approximate the unknown cost function. Since the total cost function is required to be homogeneous of degree one in variable input prices, the following restrictions on the translog cost function are imposed,

$\sum_{b=1}^{B}\beta_b = 1$, $\sum_{b=1}^{B}\beta_{bv} = \sum_{v=1}^{V}\beta_{bv} = 0$ and $\sum_{b=1}^{B}\theta_{mb} = 0$ for all m.[7] The expression presented below has been normalized with one of the input prices, to ensure that the function used is linearly homogeneous in input prices. The expression to be estimated reads:

$$\begin{aligned}\ln\left(\frac{TC}{w_B}\right)_{it} = {} & \beta_0 + \sum_{m=1}^{M}\alpha_m \ln(y_m)_{it} + \frac{1}{2}\sum_{m=1}^{M}\sum_{n=1}^{N}\alpha_{mn}\ln(y_m)_{it}\ln(y_n)_{it} \\ & + \sum_{b=1}^{B-1}\beta_b \ln\left(\frac{w_b}{w_B}\right)_{it} + \frac{1}{2}\sum_{b=1}^{B-1}\sum_{v=1}^{V-1}\beta_{bv}\ln\left(\frac{w_b}{w_B}\right)_{it}\ln\left(\frac{w_v}{w_B}\right)_{it} \\ & + \sum_{m=1}^{M}\sum_{b=1}^{B-1}\gamma_{mb}\ln(y_m)_{it}\ln\left(\frac{w_b}{w_B}\right)_{it} + \theta_k \ln K_{it} + \frac{1}{2}\theta_{kk}(\ln K_{it})^2 \\ & + \sum_{m=1}^{M}\theta_{mk}\ln(y_m)_{it}\ln K_{it} + \omega_t t + \frac{1}{2}\omega_{tt}t^2 + \sum_{m=1}^{M}\omega_{mt}t\ln(y_m)_{it} \\ & + \sum_{b=1}^{B-1}\omega_{bt}t\ln\left(\frac{w_b}{w_B}\right)_{it} + \omega_{Kt}t\ln K_{it} + \varepsilon_{it}, \end{aligned} \tag{5.7}$$

where β_0 stands for the constant, $\left(\frac{TC}{w_B}\right)_{it}$ refers to normalized total costs of port i where we have used labor price to do the normalization, $(i = 1,...,24)$ in period t, $(t = 1,...,17)$, while $\left(\frac{w_b}{w_B}\right)_{it}$, for $b \neq B$ refers to relative input prices for port i in period t. Since the function is continuously differentiable, the coefficients capturing second-degree effects from outputs and input prices, α_{mn} and β_{bv} will be symmetric, i.e. $\alpha_{mn} = \alpha_{nm}$, $\beta_{bv} = \beta_{vb}$. The interactive effects between outputs and normalized input prices are captured by the γ_{mb} coefficients. To have an estimation of technical progress the typical terms including a trend, t, and its interactions with output, the quasi-fixed input and the relative input prices captured by the ω coefficients are included.

[7]Similarly, for the cost function to exhibit constant returns to scale, the following restrictions are required: $\sum_{m=1}^{M}\alpha_m = 1$, $\sum_{m=1}^{M}\alpha_{mn} = \sum_{n=1}^{N}\alpha_{mn} = 0$ and $\sum_{m=1}^{M}\theta_{mb} = 0$ for all b.

Also, first and second-degree effects corresponding to the quasi-fixed input together with its interactions with outputs are captured by the θ coefficients. Finally and similarly to Chapter 4, ε_{it} is the error term with the following structure $\varepsilon_{it} = v_{it} + u_{it}$, where the first component v_{it} is a random variable that follows a i.i.d $N(0,\sigma_v^2)$ distribution with zero mean and variance σ_v^2, also known as the idiosyncratic error. Therefore, it is statistical noise that takes into account factors out of control of the firm which may affect total cost including measurement errors related to the functional form chosen. The non-negative component u_{it} is used to measure how far the total cost of the port is operating respect the cost frontier. Denote by $N^+ \left(\mu,\sigma_u^2\right)$ the truncated-Normal distribution, which is iid and truncated at zero with mean μ and variance σ_u^2. Since we are considering the Battese-Coelli (1992) approach to parametrize time effects, the inefficiency term, u_{it}, is modeled as a truncated-normal random variable multiplied by a specific function of time showing time-varying decay as follows, $u_{it} = exp(-\eta(t - T_i))u_i$, where T_i is the last period, η is the decay parameter. Both u_i and v_{it} are i.i.d and are distributed independently of each other and the covariates in the model. Therefore, if $u_{it} = 0$, it means that the port i is operating at optimal level of total cost, while when $u_{it} > 0$, it is operating above the efficient total cost frontier and economic inefficiency can be calculated.

5.5 Results

5.5.1 The cost frontier function estimation

As pointed out in Chapter 4, Spanish ports heterogeneity advise us to use fixed effects estimation techniques to avoid the possibility of biased coefficient estimations and capture non-observable differences in ports.[8] The results of the likelihood estimation of equation (5.7) are presented in Table 5.3. Variables are in logs and have been deviated from their arithmetic mean to deal with the different magnitudes in which they are measured. Besides, since variables are expressed in logs, estimated coefficients are interpreted as elasticities. Table 5.4 displays the estimated parameters in the cost function error term.

[8] As done in Chapter 4, for the stochastic frontier estimation of (5.7) we have used the command *xtfrontier* for panel data using the time-varying decay model option available in Stata 15 software.

Table 5.3 Estimated short run total cost function

Variable	**Coefficient**	**Estimates**	**Std. Error.**
$Ln(y_1)$	α_{y1}	0.1419***	0.0148
$Ln(y_2)$	α_{y2}	0.0201***	0.0026
$Ln(y_3)$	α_{y3}	0.0607***	0.0065
$Ln(y_4)$	α_{y4}	0.0108***	0.0029
$\frac{1}{2}Ln(y_1)Ln(y_1)$	α_{y1y1}	0.1516***	0.0191
$\frac{1}{2}Ln(y_2)Ln(y_2)$	α_{y2y2}	0.0020***	0.0004
$\frac{1}{2}Ln(y_3)Ln(y_3)$	α_{y3y3}	0.0270***	0.0029
$\frac{1}{2}Ln(y_4)Ln(y_4)$	α_{y4y4}	0.0013***	0.0004
$Ln(y_1)Ln(y_2)$	α_{y1y2}	0.0026	0.0038
$Ln(y_1)Ln(y_3)$	α_{y1y3}	0.0455***	0.0118
$Ln(y_1)Ln(y_4)$	α_{y1y4}	0.0056	0.0043
$Ln(y_2)Ln(y_3)$	α_{y2y3}	-0.0016	0.0014
$Ln(y_2)Ln(y_4)$	α_{y2y4}	0.0004	0.0004
$Ln(y_3)Ln(y_4)$	α_{y3y4}	-0.0031	0.0023
$Ln(w_i)$	β_i	0.2388***	0.0098
$Ln(w_k)$	β_k	0.4363***	0.0134
$Ln(w_l)$	β_l	0.3249***	0.0140
$\frac{1}{2}Ln(w_i)Ln(w_i)$	β_{ii}	0.1550***	0.0140
$\frac{1}{2}Ln(w_k)Ln(w_k)$	β_{kk}	0.1283***	0.0323
$\frac{1}{2}Ln(w_l)Ln(w_l)$	β_{ll}	-0.0578	0.0357
$Ln(w_i)Ln(w_k)$	β_{ik}	-0.3412***	0.0343
$Ln(w_i)Ln(w_l)$	β_{il}	0.0311	0.0390
$Ln(w_k)Ln(w_l)$	β_{kl}	0.0845	0.0604

Table 5.3 continued from previous page

Variable	Coefficient	Estimates	Std. Error
$Ln(K)$	θ_K	0.4842***	0.0161
$\frac{1}{2}Ln(K)Ln(K)$	θ_{KK}	0.1434***	0.0354
t	ω_t	-0.0002	0.0017
$\frac{1}{2}t^2$	ω_{tt}	-0.0009***	0.0001
$Ln(y_1)Ln(w_i)$	γ_{y1i}	0.0977***	0.0132
$Ln(y_1)Ln(w_k)$	γ_{y1k}	-0.1795***	0.0227
$Ln(y_1)Ln(w_l)$	γ_{y1l}	0.0818***	0.0220
$Ln(y_2)Ln(w_i)$	γ_{y2i}	0.0007	0.0019
$Ln(y_2)Ln(w_k)$	γ_{y2k}	-0.0034	0.0025
$Ln(y_2)Ln(w_l)$	γ_{y2l}	0.0027	0.0025
$Ln(y_3)Ln(w_i)$	γ_{y3i}	0.0603***	0.0058
$Ln(y_3)Ln(w_k)$	γ_{y3k}	-0.0267***	0.0074
$Ln(y_3)Ln(w_l)$	γ_{y3l}	-0.0336***	0.0081
$Ln(y_4)Ln(w_i)$	γ_{y4i}	0.0002	0.0026
$Ln(y_4)Ln(w_k)$	γ_{y4k}	-0.0071**	0.0029
$Ln(y_4)Ln(w_l)$	γ_{y4l}	0.0068**	0.0028
$Ln(y_1)Ln(K)$	ω_{y1K}	-0.2017***	0.0232
$Ln(y_2)Ln(K)$	ω_{y2K}	-0.0007	0.0025
$Ln(y_3)Ln(K)$	ω_{y3K}	-0.0298***	0.0078
$Ln(y_4)Ln(K)$	ω_{y4K}	-0.0036	0.0029
$Ln(y_1)t$	ω_{y1t}	0.0020*	0.0011
$Ln(y_2)t$	ω_{y2t}	-0.0004**	0.0001
$Ln(y_3)t$	ω_{y3t}	0.0005*	0.0003

Table 5.3 continued from previous page

Variable	Coefficient	Estimates	Std. Error
$Ln(y_4)t$	ω_{y4t}	-0.0000	0.0002
$Ln(w_i)Ln(K)$	ω_{iK}	-0.1624***	0.0196
$Ln(w_k)Ln(K)$	ω_{kK}	0.1360***	0.0312
$Ln(w_l)Ln(K)$	ω_{lK}	0.0263	0.0311
$Ln(w_i)t$	ω_{it}	0.0011	0.0008
$Ln(w_k)t$	ω_{kt}	0.0042***	0.0042
$Ln(w_l)t$	ω_{lt}	-0.0053***	0.0014
$Ln(K)t$	ω_{Kt}	0.0007	0.0015
Constant	β_0	-0.2064***	0.0318

***, ** and * indicate that estimates are significantly different from zero at the 0.01, 0.05 and 0.10 levels, respectively

Table 5.4 Estimates for the cost function error term parameters

Parameters	Estimates	Std. Error
μ	0.1461	0.1481
η	-0.0230**	0.0040
σ_u^2	0.0484	0.0320
σ_v^2	0.0005***	0.0000

***, ** and * indicate that estimates are significantly different from zero at the 0.01, 0.05 and 0.10 levels, respectively

The first order coefficients, both for outputs and input prices, are statistically significant and have the correct sign showing that the estimated cost function is increasing in outputs and input prices. The linear component of the variable trend is not significant but the quadratic one together with some interactive terms with the capital and the labor prices are. Evaluating $\frac{\partial lnTC(y,w,K)}{\partial t}$ at the sample mean we obtain a value of $-0.0009t$, therefore, there is technical progress during the period analysed that increases in t. Regarding input prices, the price of capital, w_k, is the greatest of all, followed by labor price.[9] First order coefficients of the inputs prices capture the optimal share of each component of the variable cost. According to Shephard's Lemma:

$$\frac{\partial \ln TC\,(y,w,K)}{\partial \ln w_j} = \frac{\partial VC\,(y,w,K)}{\partial w_j}\frac{w_j}{VC} = X_j^*\frac{w_j}{VC} = s_j^*(y,w,K), \tag{5.8}$$

where X_j^* and s_j^* denote the conditional factor demand and the optimal share in the total cost of input j, respectively. According to the estimated total cost function, the optimal intermediate consumption and labor shares are $s_i^* = 0.2388$ and $s_l^* = 0.3249$. Comparing these values with the observed average values in Table 5.1, the intermediate consumption input is overused while labor is underused.[10]. Table 5.4 estimates show that the inefficiency term u is responsible for the 99% of the total error variance and since the sign of η is negative but small, economic efficiency is moderately decreasing across the period.

[9]Both Martínez-Burdía (1996), Baños-Pino et al.(1999) and Coto-Millán et al.(2000) found that labor price was the largest input price. Note that labor costs represented a higher proportion of the total cost in the period of those contributions. However, in the period 2002-2018, labor cost share declined from 35% to 26%. See the third column of Table E.1 in Appendix E.

[10]Table E.1 in Appendix E provides the evolution of the of the total cost component shares along in the period.

Equation (5.6) above defines the level capital that minimizes the long run cost. By computing the marginal effect $\frac{\partial TC(y,w,K)}{\partial K}$ evaluated at the sample mean, we obtain a positive number. In particular, $\frac{\partial TC(y,w,K)}{\partial K} = \frac{\partial lnTC(y,w,K)}{\partial lnK}\frac{TC}{K} = 0.4842\frac{3.38E+07}{3334586} = 4.91 > 0$. This implies that ports are not using the optimal level of capital.

Table 5.5 reports information about the average marginal cost of each output, the over-capitalization index (OI) and economic efficiency (EE) for each port considered.[11] The first four columns present the average of marginal cost for each type of traffic and port. These values are obtained by computing for $m = 1,2,3,4$ and $i = 1,...,24$, $MC_{mi} = \frac{\partial lnTC(y,w,K)}{\partial lny_m}|_i\frac{\overline{TC}_i}{\bar{y}_{mi}}$, where $\overline{TC}_i$ and $\bar{y}_{mi}$ are the average total cost and output m level of port i, respectively.[12] Column fifth shows the average of over-capitalization index for each port computed as $OI_i = \frac{\partial lnTC(y,w,K)}{\partial lnK}|_i\frac{\overline{TC}_i}{\bar{K}_i}$, where $\bar{K}_i$ is the average level of capital used by port i. Note that OI greater than zero means over capitalization. Finally, the last column shows the average EE_i in the period for each port i as explained at the end of subsection 5.2.1.[13]

[11]The acronym "n.a." in the first four columns appears when the corresponding port has not enough traffic to obtain the marginal cost.

[12]Note that $\frac{\partial lnTC(y,w,K)}{\partial lny_m}|_i$ includes all the coefficients that are significant and in case a variable is included, it is evaluated at the port i specific sample mean. For instance, $\frac{\partial lnTC(y,w,K)}{\partial lny_1}|_i = \alpha_{y1} + \alpha_{y1y1}\ln\bar{y}_{1i} + \omega_{y1t}t$.

[13]Table E.3 in Appendix E reports the EE index per port any year in the period.

Table 5.5 Average of marginal cost of outputs, over-capitalization index and economic efficiency

Port	MC_{y1}	MC_{y2}	MC_{y3}	MC_{y4}	OI	EE
A Coruña	0.42	n.a.	0.19	2.10	7.36	0.8478
Alicante	0.99	0.23	2.74	0.64	5.57	0.8871
Almería	0.50	n.a.	n.a.	0.16	8.38	0.9445
Avilés	0.77	n.a.	1.13	n.a.	11.43	0.9906
B. Algeciras	0.42	0.03	0.15	0.19	5.23	0.6664
B. Cádiz	0.65	0.46	3.35	1.32	2.81	0.8748
Baleares	0.99	1.37	2.79	0.09	6.93	0.7741
Barcelona	0.83	0.14	0.96	0.63	4.68	0.6220
Bilbao	0.63	0.24	0.31	3.25	7.73	0.7659
Cartagena	0.27	0.67	0.05	4.06	6.69	0.8033
Castellón	0.59	0.27	0.11	n.a.	4.21	0.8838
Ceuta	3.34	3.32	2.43	0.13	8.69	0.9109
Ferrol-SC	0.32	n.a.	0.27	n.a.	1.59	0.9392
Gijón	0.32	2.92	0.58	n.a.	3.95	0.8704
Huelva	0.62	n.a.	0.17	n.a.	2.01	0.7536
Las Palmas	0.50	0.12	0.92	0.46	6.72	0.7187
Motril	1.17	n.a.	0.42	7.90	4.95	0.9911
Málaga	0.71	3.66	3.83	0.27	10.52	0.8179
SC Tenerife	0.80	0.29	0.61	0.10	7.74	0.8496
Santander	0.87	n.a.	4.42	1.64	3.26	0.8556
Sevilla	0.77	0.40	3.79	n.a.	1.21	0.9340
Tarragona	0.59	1.77	0.22	n.a.	4.24	0.7871
Valencia	0.39	0.06	1.00	1.89	6.24	0.6042
Vigo	0.60	0.26	n.a.	1.09	14.47	0.7110
Average	*0.85*	*0.95*	*1.38*	*1.52*	*6.11*	*0.8251*

5.5.2 Second stage: The determinants of economic efficiency

After obtaining the EE index for each port and given the heterogeneity in Spanish ports mentioned above, it is interesting to undertake a second stage analysis to identify the main determinants of economic efficiency.

Results of the second stage

To undertake the second stage analysis we estimate the following expression,

$$\begin{aligned} EE_{it} = & \delta_0 + \delta_{tprc}TPRC_{it} + \delta_{tpbc}TPBC_{it} + \delta_{tprl}TPRL_{it} + \delta_{tpbl}TPBL_{it} \\ & + \delta_{tprmg}TPRMG_{it} + \delta_{tpbmg}TPBMG_{it} + \delta_{tprp}TPRP_{it} + \delta_{tpbp}TPBP_{it} \\ & + \delta_{Loc}C_{Localization} + \delta_{Ref}C_{Refinery} + \delta_{Tra}C_{Train} + \delta_{Atl}C_{Atlantic} \\ & + \delta_{Can}C_{Cantabric} + \delta_{Med}C_{Mediterranean} + \delta_{Law03}C_{Law03} + \delta_{Law10}C_{Law10} \\ & + \delta_{Law11}C_{Law11} + \delta_{oi}OI_{it} + \delta_{ic}IC_{it} + u_{it}, \end{aligned} \tag{5.9}$$

where EE_{it} is the dependent variable, and the explicative variables include the above mentioned environmental variables. Since the independent variable is defined between zero and one, we undertake a Tobit regression where the term u_{it} stands for the error term with zero mean and variance, σ_u^2, being this term identical and independently distributed.

Table 5.6 reports the estimates for equation (5.9) coefficients. From the signs of these coefficients we conclude that the type of management matters for container and passenger terminals. Container terminals managed by the port authority have a positive effect in economic efficiency, while when managed by a private company its effect is negative but not significant. For the case of passenger terminals the effect is reversed, privately managed terminals have a positive effect on efficiency, while those directly managed by port authorities have a negative one. Finally, for those terminals handling non-containerized merchandise and liquids and petroleum freight the effect on port efficiency is negative regardless of the type of management. Regarding the second-stage variables controlling for location, we conclude that ports located in islands are more efficient and the ports located in the Cantabric coastline are more efficient than those in the Mediterranean coast. Besides, ports close to refineries and with access to rail achieve low levels of EE. With respect to the legislative reforms, we find that the former in the time did not affect EE, while the latter, the RD 2/2011, had reduced EE. Lastly, the most overcapitalized ports and those with higher mechanization index achieve worse levels of EE.

Table 5.6 Determinants of the economic efficiency

Variable	**Coefficient**	**Estimates**	**Std. Error**
$Constant$	δ_0	1.0570***	0.0113
$TPRC$	δ_{tprc}	-0.0038	0.0041
$TPBC$	δ_{tpbc}	0.0417**	0.0184
$TPRL$	δ_{tprl}	-0.0126***	0.0021
$TPBL$	δ_{tpbl}	-0.0662***	0.0088
$TPRMG$	δ_{tprmg}	-0.0209***	0.0021
$TPBMG$	δ_{tpbmg}	-0.0175**	0.0073
$TPRP$	δ_{tprp}	0.0355***	0.0060
$TPBP$	δ_{tpbp}	-0.0295***	0.0031
$C_{Localization}$	δ_{loc}	0.1381***	0.0199
$C_{Refinery}$	δ_{ref}	-0.0475***	0.0065
C_{Train}	δ_{tra}	-0.0267***	0.0074
$C_{Cantabric}$	δ_{can}	0.0445***	0.0079
$C_{Atlantic}$	δ_{atl}	-0.0190	0.0075
C_{Law03}	δ_{law03}	0.0065	0.0071
C_{Law10}	δ_{law10}	-0.0032	0.0082
C_{Law11}	δ_{law11}	-0.0191***	0.0066
OI	δ_{oi}	-0.0076***	0.0009
MI	δ_{mi}	-0.1612***	0.0192
$C_{Berths15000}$	$\delta_{berths15000}$	-0.0541***	0.0089

***, ** and * indicate that estimates are significantly different from zero at the 0.01, 0.05 and 0.10 levels, respectively.

5.6 Conclusions

The measurement of economic efficiency of the Spanish ports and the estimation of the optimal level of the quasi-fixed input are the two main objectives of this Chapter. Moreover, in a second stage analysis, the determinants of the economic efficiency will be identified and analyzed. As in Chapter 4, these will be the type of port terminals, the localization of ports in islands, the proximity of the port to an oil refinery, the use of railway access for incoming and outgoing cargo, port coastline location, legislative reforms and port size. However in this Chapter the overcapitalization and the mechanization indices will be included among the possible determinants.

We find that the average economic efficiency during the period analyzed is 0.8251. Although, the economic efficiency for 2002 was 0.8457 and the economic efficiency for 2018 was 0.7961. This means an average annual reduction in economic efficiency of 0.38 %. The most economically efficient ports are Motril, Avilés, Almería, Sevilla, Ferrol SC and Ceuta; while Valencia, Barcelona, Bahía de Algeciras, Vigo, Tarragona, and Las Palmas are the least efficient ones. In addition, total costs are shown to decrease over time, therefore, some technical progress is attained coinciding with the result in Álvarez & Tovar (2012). Another conclusion is the existence of overcapitalization in the Spanish port system, which possibly explains the reduction in port investments observed in recent years reinforcing the conclusions obtained by Álvarez & Tovar (2012).

The results of the second stage show that, the type of management matters for container and passenger terminals. Container terminals managed by the port authority have a positive effect in economic efficiency, while when managed by a private company its effect is negative but not significant. For the case of passenger terminals the effect is reversed, privately managed terminals have a positive effect on efficiency, while those directly managed by port authorities have a negative one. Finally, for those terminals handling non-containerized merchandise and liquids and petroleum freight the effect on port efficiency is negative regardless of the type of management. The use of the railway connection and the existence of the oil refinery close to the port also reduce economic efficiency. Ports located in islands are more efficient and those located in the Cantabric coastline are more efficient than Mediterranean coast ports. Regarding the effect of the legislative reforms in the period, both the reforms of the years 2003 and 2010 have not significantly affected economic efficiency, while that of 2011 had a negative effect. Finally, the most overcapitalized ports and those with greater level of mechanization index are less efficient.

Chapter 6

Market power analysis

6.1 Introduction

Once the technical and economic efficiency levels have been calculated, the objective of Chapter 6 is to measure the market power of Spanish ports. The method applied is the Boone indicator that uses the marginal costs obtained from the estimated short-run cost frontier function in Chapter 5 and market shares. Data are therefore the same used in Chapter 5. The Boone indicator methodology has been applied mainly to banking competition (see Van Leuvensteijn et al., 2011; Shijaku, 2017, and Rapapali & Simbanegavi, 2020; among others). The main novelty of this Chapter is to apply this methodology to the Spanish port sector for the first time. In particular, the Spanish port activity is divided into five markets that correspond to the four outputs used along this dissertation plus the sub-market corresponding to transshipment containerized cargo. Different concentration indices, the concentration index of the five largest ports (C_5) and the Herfindahl-Hirshman Index

(HHI) are first computed to give a glimpse on how market shares are distributed in each market. Next, two different samples for each market are used to give estimations of the Boone indicator. Both a reduced and an extended samples are defined according to the size of the port market shares in a given market. The extended sample includes all ports that have reached at least a 0.1% market share, while the reduced only those reaching at least a 5%. The reason is to avoid distortions introduced by ports with reduced presence in the market. Also and to be more precise in giving market power estimates, ports have been classified according to the sea frontage or coastline they are located: the *Northern* and the *South and East* coastlines. Spanish ports in Africa and in islands are excluded.

As far as we know, Núñez-Sánchez (2013) is the only work that calculates market power of Spanish ports although using the Lerner index obtained considering tons as output. The main drawback of that study is that it considers all cargo tons homogeneously, for example, that a port has the same revenue and monetary costs for a ton of containerized cargo as for a ton of bulk cargo. From Chapter 5 we know that marginal costs depend on the type of cargo, thus cargo is heterogeneous and each type must be considered separately. The main advantage of the Boone indicator is that it allows us to divide output into markets depending on each type of cargo.

The Chapter is organized as follows. Section 2 presents the methodology of the Boone indicator and the results for the different markets divided by cargo and sea frontage. Section 3 concludes.

6.2 Measuring market power in the Spanish port system

In this subsection we are interested in measuring the capacity of ports in setting prices above marginal costs. The Lerner index is the widely used measure of market power (Lerner,1934). However, ports are multioutput agents and we do not have disaggregated information about the different types of rates applied by ports depending of the different freight. Thus, we consider another method to measure competition that has been considered in other industry analysis, the Boone Indicator (*BI*).[1] The *BI* assumes that the most efficient port (that is, the one with lower marginal cost) will get higher market shares if the market is competitive. This effect is stronger the higher the level of competition in the market. The functional form of the *BI* is shown in equation (6.1).

$$\ln(MS)_{mit} = \alpha + \beta \ln(MC)_{mit} + u_{mit}, \tag{6.1}$$

where *MS* denotes market share, *MC* is the marginal cost, β is the *BI* and u is the error term. Also, sub-index m stands for the type of output, sub-index i stands for the port i and sub-index t stands for the year t. Parameter β is an elasticity and it is negative because it relates the market share with the marginal cost. It is implicitly assumed that reductions in marginal costs pass-through prices to some extent affecting market shares. The extent of such pass-through depends on the level of competition in the market. Thus, if $\beta = 0$ the marginal cost does not affect market shares and the extreme case of a monopoly is identified. Whereas a larger value of β, in absolute terms, means that the port, in

[1] See Boone (2000, 2001, 2004, 2008)

order to achieve a higher market share and because of competition, has to reduce more the marginal cost. Therefore, larger values of β are related to more competitive markets.[2]

The assessment of competition through the *BI* has the advantage that each particular merchandise can be taken as a single market. Besides, no more data are needed for its estimation. Table 6.1 reports information about the average market share and marginal cost for each output and port. Table 6.2 shows the results of the estimation of the BI.

[2] According to Van Leuvennsteijin et al. (2011) parameter β could take positive value in case there is some degree of coordination or collusion, or if the firms are competing in non-price variables such as quality.

Table 6.1 Average marginal costs and market shares per port and output

Port	MC_{y1}	MS_{y1} (in %)	MC_{y2}	MS_{y2} (in %)	MS_{y21} (in %)	MC_{y3}	MS_{y3} (in %)	MC_{y4}	MS_{y4} (in %)
A Coruña	0.42	3.44	n.a.	0.03	0.00	0.19	5.03	2.10	0.34
Alicante	0.99	1.08	0.23	0.85	0.01	2.74	0.08	0.64	1.08
Almería	0.50	3.65	n.a.	0.02	0.00	n.a.	0.18	0.16	3.70
Avilés	0.77	2.61	n.a.	0.03	0.00	1.13	0.44	n.a.	0.00
B. Algeciras	0.42	7.93	0.03	32.18	50.89	0.15	15.32	0.19	18.96
B. Cádiz	0.65	2.09	0.46	0.73	0.06	3.35	0.12	1.32	1.10
Baleares	0.99	6.41	1.37	0.77	0.01	2.79	1.16	0.09	20.65
Barcelona	0.83	8.66	0.14	15.20	8.99	0.96	7.64	0.63	11.64
Bilbao	0.63	5.48	0.24	4.33	0.12	0.31	12.25	3.25	0.61
Cartagena	0.27	3.13	0.67	0.51	0.06	0.05	13.66	4.06	0.32
Castellón	0.59	2.56	0.27	1.13	0.02	0.11	5.25	n.a.	0.00
Ceuta	3.34	0.93	3.32	0.06	0.00	2.43	0.58	0.13	8.08
Ferrol	0.32	6.02	n.a.	0.00	0.00	0.27	1.23	n.a.	0.03
Gijón	0.32	10.57	2.92	0.29	0.00	0.58	0.77	n.a.	0.08
Huelva	0.62	4.07	n.a.	0.05	0.00	0.17	11.37	n.a.	0.06
Las Palmas	0.50	4.16	0.12	8.90	10.47	0.92	3.35	0.46	6.00
Motril	1.17	0.60	n.a.	0.01	0.00	0.42	0.81	7.90	0.63
Málaga	0.71	1.20	3.66	1.12	1.51	3.83	0.06	0.27	2.51
SC Tenerife	0.80	3.26	0.29	2.35	0.28	0.61	5.11	0.10	18.69
Santander	0.87	3.16	n.a.	0.03	0.00	4.42	0.21	1.64	0.69
Sevilla	0.77	2.07	0.40	0.73	0.00	3.79	0.20	n.a.	0.05
Tarragona	0.59	7.05	1.77	0.75	0.56	0.22	12.62	n.a.	0.04
Valencia	0.39	7.83	0.06	29.35	26.91	1.00	2.44	1.89	2.17
Vigo	0.60	1.32	0.26	1.66	0.12	n.a.	0.05	1.09	0.62
Mean	0.85	-	0.95	-	-	1.38	-	1.52	-

Source: Own Elaboration

According to Table 6.1, there are clear differences between port market shares in each output that lead to different levels of concentration per output. We will, therefore, consider that each output is a different market in order to compute concentration indices and BI. For the *Containers* market we find that, the *five-firm concentration index*, C_5, is 83.41%, that is, the five largest ports (Bahía de Algeciras, Valencia, Barcelona, Las Palmas and Bilbao) concentrate the 83.41% of the total containerized tons. Focusing in the *Containers* market, there is a particular type of containers, the transshipment containers or containers in transit denoted *TContainers* in Table 6.2 and with port market shares denoted MS_{y21} in Table 6.1. It is notable to underline that this sub-market is the most concentrated market since its C_5, is 98.77% including Bahía de Algeciras, Valencia, Las Palmas, Barcelona and Málaga. Noting that Bahia de Algeciras and Valencia together reach a 77.80% market share. Similarly, the C_5 for the *Liquids* market is 65.22% accounting for the market shares of Bahía de Algeciras, Cartagena, Tarragona, Bilbao and Huelva. The *Passengers* market reach a $C_5 = 78.02\%$ including the market shares of Baleares, Bahia de Algeciras, Santa Cruz de Tenerife, Barcelona and Ceuta. Finally, the *Othercargo* market has a much lower C_5 equal to 42.04% accounting for the market shares of Gijón, Barcelona, Bahía de Algeciras, Valencia and Tarragona. Since the concentration index C_5 only gives a partial view of market concentration, we have computed the *Herfindahl-Hirschman Index*, HHI, for the five markets showing the same ranking across markets. [3] In particular, the highest HHI is that of the containers in transit market reaching a figure of 3,507, the *Containers* market has a HHI equal to 2,240, the second

[3] The *Herfindahl-Hirschman Index* is formally defined for each market m as $\sum_i^n (MS_{mi})^2$.

highest, followed by the *Passengers* market with $HHI = 1,401$, *Liquids* market is the third reaching a HHI of 1,021, and the less concentrated marked is the *Othercargo* market with a HHI of 585. According to the United States DOJ 2010 Merger Guidelines, the *TContainers* market is highly concentrated ($HHI > 2500$), the *Containers* market is considered moderately concentrated ($1500 < HHI < 2500$), while the other markets are unconcentrated ($100 < HHI < 1500$).

Table 6.2 includes two different samples for each market. The *extended* sample, denoted with sub-index *ext*, includes all ports that have reached at least a 0.1% market share.[4] Alternatively, the *reduced* sample, denoted by *red*, considers only ports that have reached at least a 5% market share. Note that the market shares used in the estimation of equation (6.1) are recalculated including only the ports in the corresponding sample. The *BI* estimation is done by using the STATA command *xtreg* which implements a *Generalised Least Squares* (GLS) estimation when the random effects methodology (denoted by RE) is applied; while a *Within Regression* estimation is applied when fixed effects (FE) are considered. The second column in Table 6.2 shows the estimation method chosen for each market after passing the corresponding Hausman test.[5]

[4] The minimum market share to obtain a reliable value of marginal cost.

[5] See Tables F.1 and F.2 in Appendix F for more information on the Hausman test results undertaken for the extended and reduced sample markets and for the the markets distinguishing per coastline.

Table 6.2 Boone Indicator estimates for different samples in each market

Market	Estimation Method	# of ports	# of obs.	BI	Std. Error
$Othercargo_{ext}$	RE	23	388	-0.0058	0.0165
$Othercargo_{red}$	RE	10	170	0.0119	0.0249
$Containers_{ext}$	FE	15	255	-0.9028***	0.0297
$Containers_{red}$	FE	6	102	-0.4759***	0.0904
$TContainers_{ext}$	RE	5	83	-1.6126***	0.1183
$TContainers_{red}$	RE	4	68	-1.2670***	0.0569
$Liquids_{ext}$	FE	18	303	-0.2376***	0.0411
$Liquids_{red}$	RE	10	170	-0.3069***	0.0439
$Passengers_{ext}$	RE	15	255	-0.7778***	0.0442
$Passengers_{red}$	RE	6	102	-0.6922***	0.0792

***, ** and * indicate that estimates are significantly different from zero at the 0.01, 0.05 and 0.10 levels, respectively

Table 6.2 shows a negative relationship between market shares and marginal costs in every market considered except for the reduced sample of the *Othercarco* market. Furthermore, all of the estimates are significant at the 1% level with the exception of the *Othercargo* market in both sample versions. Note that for each market with the *Liquids* market exception,[6] the reduced sample considered shows a lower *BI*, in absolute terms, in comparison to the extended sample.[7] This is consistent with the claim that, other things equal, an industry with more firms is more competitive. According to the estimates, we find that the most competitive market is that of *Containers* and in particular

[6] One possible explanation for the *liquids* market not following the rule is that it is the only market for which each sample version is estimated using a different method and then comparisons become more difficult to assess.

[7] It has been checked that the differences in the estimated *BIs* are statistically significant. In order to do so, we have run two-sample *t* tests on the equality of means implemented by the STATA command *ttesti*.

the sub-market of transshipment containers. The latter is the only one which is elastic in the relationship between marginal costs and market shares. The second most competitive is the *Passengers* market, followed by the *Liquids* market and the less competitive being the *Othercargo* market.

To give a more detailed analysis of port competition per output, we provide the BIs obtained when ports are classified according to the coastline they belong since ports located close are more likely to compete for cargo. In particular and for the purpose of the analysis we define two Spanish coastlines: i) *Northern* that includes A Coruña, Avilés, Bilbao, Ferrol SC, Gijón, Santander and Vigo ports. ii) *South and East* including Alicante, Almería, Bahía de Algeciras, Bahía de Cádiz, Barcelona, Cartagena, Castellón, Huelva, Málaga, Motril, Sevilla, Tarragona and Valencia ports. Spanish ports located in islands or in North Africa are not included. Market shares are conveniently computed taking into account the above classification where we only consider the extended sample per output (i.e. market shares larger than 0.1%) as defined above to run the analysis. Besides, the sub-market of transshipment containers is not divided into different locations since all the relevant ports are in the East coastline or in an island. Table 6.3 presents the results obtained for the *Northern* and the *South and East* coastlines.

Table 6.3 Boone Indicator estimates per coastline

Market	Estimation Method	# of ports	# of obs.	BI	Std. Error
Northern coastline					
$Othercargo_{ext}$	RE	7	119	-0.0409***	0.0130
$Containers_{ext}$	RE	3	51	-0.8854***	0.0413
$Liquids_{ext}$	FE	5	85	-0.0863	0.0927
$Passengers_{ext}$	RE	4	68	-0.4885***	0.0859
South and East coastline					
$Containers_{ext}$	FE	10	170	-0.9478***	0.0294
$Liquids_{ext}$	FE	9	150	-0.2480***	0.0550
$Passengers_{ext}$	RE	7	119	-0.8855***	0.0514
$Othercargo_{ext}$	RE	12	201	0.0166	0.0288

***, ** and * indicate that estimates are significantly different from zero at the 0.01, 0.05 and 0.10 levels, respectively

When markets are also distinguished by the location of ports, the estimated *BI* in Table 6.3 show that the *South and East* is more competitive than the *Northern* market with the exception of the *Othercargo* market that shows a positive *BI* for the *South and East* watershed. The rankings in competition are the same as those obtained for the extended sample in Table 6.2, from higher to lower competition: *Containers*, *Passengers*, *Liquids* and *Othercargo*. As indicated above the differences in the estimated *BIs* between the full sample and the samples per coastline and also the differences between different coastlines are statistically significant.

6.3 Conclusions

The objective of this Chapter is to provide an estimation of the market power in the Spanish port system. To do so, a Boone Indicator (*BI*) is estimated distinguishing for different markets and coastlines. The Boone Indicator requires information about market shares and marginal costs for a given output or market. We take advantage of the estimation of the corresponding cost functions for the different ports in Spain provided in Chapter 5 to compute marginal costs which are output specific. In this way, we provide market power estimates for different markets that correspond to the four outputs defined in the previous Chapters plus another sub-market defined by the transshipment containerized output. The results show that the most competitive market, that is, the one with the largest *BI* in absolute terms, is the transshipment containerized cargo sub-market, the containerized cargo market is in second place followed by the passenger and the liquid bulk transport markets. In addition, and to avoid the possible distortions derived by ports with low presence in some markets, market power estimations have been done for two types of samples, the extended sample and the reduced sample where the former includes all ports with market shares larger than 0.1% and the later only those with market shares above 5%. The extended samples present a higher level of competition except for the case of the liquids market; noting that for the rest of the merchandise the *BI* is not significant. Regarding the estimation of *BIs* by coastline, it is observed that the *south and east* coastline is more competitive than the *north* coastline, except for the market of the rest of the merchandise traffic. The main reason is that some of the ports located on the *north* coastline have solid bulk or non-containerized general cargo as their main cargo and most of the ports located on the *south and east* coastline have containerized cargo or petroleum cargo as their main activity.

An interesting extension for the future is to relate economic efficiency with the Boone Indicator. This is to empirically explore whether ports in more competitive markets are also more efficient. According to the Boone Indicator logic more competition would lead to lower marginal costs in order to keep or gain market share.

Chapter 7

Conclusions

The Spanish port system handles 80% of total Spanish cargo and up to 96% of cargo with other continents origin. It is, therefore, cardinal for Spain to gain competitiveness to achieve an efficient port system. This dissertation is aimed to assess the efficiency, both technical and economic, of the Spanish port system for the period 2002-2018, in order to identify which ports achieve a higher score and to understand the main port features that determine such efficiency. With this information in mind, an analysis of ports market power in the different markets they operate, according to the type pf cargo, is also carried out. In order to give a good measure of port technical efficiency, three different output oriented approaches are used in Chapter 4. One parametric, the Stochastic Frontier Analysis (SFA), and another non-parametric the Distance Envelopment Analysis under two different assumptions, either assuming constant or variable returns to scale, that is, DEA-CRS and DEA-VRS. Our first conclusion is that the rankings of port efficiency do not change very much by using different approaches. In fact, the Spearman's rank-order correlation coefficients found among the three rankings are positive and above 0.71. With respect to the ranking, Gijón, Bahía de Algeciras Ferrol SC and Valencia are the most efficient ports, while Vigo, Marín y Ría de Pontevedra and Vilagarcía de Aurosa are the most inefficient regardless the approach used. Furthermore, and focusing in efficiency levels, with find that the SFA approach indicates a decrease in technical efficiency in the period at an average rate of 0.86%, however, when using the non-parametric methodology there is an increase in efficiency at an average annual rate of 0.61% for DEA-CRS and 0.79 % for DEA-VRS. Another interesting conclusion is that the Spanish port system had small increasing returns to scale at the beginning of the period and it ends up showing decreasing returns to scale confirming the decreasing trend already found in Gonzalez & Trujillo (2008) for the period 1990-2002. Also, we find an average annual growth in technical progress of 1.77% between 2002 and 2018.

With respect to the determinants of technical efficiency, we find that terminals are an important feature in explaining port efficiency. The type of management matters and the sign of the effect depends on the type of cargo of the terminal. Ports with container terminals managed by private firms are significantly more efficient for any methodology employed. While those directly managed by ports have barely no effect. Similar results are found for general merchandise terminals with the difference that when the terminal is managed directly by ports the effect is negative and significant. Ports with passenger terminals are always less efficient regardless of the method used, although ports that have privately managed terminals have a larger negative impact. Finally, port terminals handling liquids have a positive and significant effect on port efficiency but only when a particular method is used.

Ports in islands are found to be more efficient only in case a DEA-VRS is used and ports in the Cantabric coast are more efficient than those in the Mediterranean coast according to the SFA method, while ports in the Atlantic coast are less efficient as compared with those in the Mediterranean coast in case a DEA with variable returns to scale is used. The access to complementary facilities has mixed results, an oil refinery nearby a port increases technical efficiency, while the use of railway access reduces it. The legislative reforms implemented in the years 2003, 2010 and 2011 have typically not significant effect on technical efficiency, therefore reinforcing the conclusion in Gonzalez & Trujillo (2008) and Díaz-Hernandez et al. (2008) works about the effect of laws with the purpose of implementing reforms in the Spanish port system. Only the 33/2010 law has a negative effect at 10% level of significance and only for the non-parametric methods, similarly the 2/2011 RD has a negative effect at 5% level of significance when the parametric approach is considered. Finally, port size does not affect technical efficiency regardless the method used in contrast to Martínez-Burdía (1996) and Bonilla et al. (2002) findings that largest ports had lower levels of efficiency and to Martínez-Burdía et al. (1999) and Coto-Millán et al. (2000) that concluded that the largest ports were the most efficient.

Chapter 5 estimates an stochastic short-run cost function in order to measure the level of economic efficiency of the Spanish port system and to find whether ports operate with levels of the quasi-fixed input –the squared meters of all types of port facilities like storage spaces, roads and other spaces of port authorities,– above the optimal level. We find that the economic efficiency of Spanish port system for 2002 was 0.8457 and 0.7961 for 2018 with an average of 0.8251 in the period and average annual reduction in economic efficiency of 0.38 %. The most economically efficient ports are Motril, Avilés, Almería, Sevilla, Ferrol SC and Ceuta; while Valencia, Barcelona, Bahía de Algeciras, Vigo, Tarragona, and Las Palmas are the least efficient ports. In addition, total costs are shown to decrease over time, therefore, some technical progress is attained coinciding with the result in Rodríguez-Álvarez & Tovar (2012). We also conclude that there is overcapitalization in the Spanish port system in line with the conclusions obtained in Rodríguez-Álvarez & Tovar (2012).

As happens with the analysis of technical efficiency, the results of the second stage show that the type of management matters for container and passenger terminals. Container terminals managed by the port authority have a positive effect in economic efficiency, while when managed by a private company their effect is negative but not significant. For the case of passenger terminals, the effect is reversed, privately managed terminals have a positive effect on efficiency, while those directly managed by port authorities have a negative one. Finally, for the rest of terminals, their effect on port efficiency is negative regardless of the type of management. Both the use of a railway connection and the existence of the oil refinery close to the port also reduce economic efficiency. Ports located in islands are more efficient and those located in the Cantabric coastline are more efficient than Mediterranean coast ports. Regarding the effect of the legislative reforms in the period, both the reforms of the years 2003 and 2010 have not significantly affected economic efficiency, while that of 2011 had a negative effect. Finally, the most overcapitalized ports and those with greater level of mechanization index are less efficient.

It is interesting to note that among the most technically efficient ports are those with the largest number of non-passenger privately managed terminals which have a positive effect on efficiency, (Valencia with eighteen, B. de Algeciras eight, Gijón seven and Ferrol five). These ports are the leaders in handling non-containerized cargo, Gijón is in first place, B de Algeciras is the second, Valencia the third and Ferrol the sixth. Similarly, B. de Algeciras and Valencia are the two top ports in number of tons of containerized cargo. However, B. de Algeciras and Valencia are among the less economically efficient. These two ports only have non-passenger privately managed terminals that now have a negative effect (except container terminals that have no significant effect) on economic efficiency and this may explain the change in the ranking. They are the third and the second in number of workers and Valencia is the largest in terms of meters of berths. We believe that fixed costs are explaining this because when we look at marginal costs, both are the two ports with the lowest marginal cost regarding container cargo (B. de Algeciras has marginal cost equal to 0.03 and Valencia 0.06 while the average in the Spanish port system is 0.95) and among those with low marginal costs of non-containerized merchandise (B. de Algeciras has marginal cost equal to 0.42 and Valencia 0.39 below the average in the Spanish port system of 0.85). As a conclusion, top ports in terms of non-passenger privately managed terminals and in terms of cargo handled excluding liquids and passengers have the facilities required to attract cargo and behave efficiently in technical terms. However, the same ports are unable to adjust their short-run costs to a more efficient combination of inputs despite their low marginal costs.

In Chapter 6 an estimation of the market power in the Spanish port system using the Boone Indicator is provided, distinguishing for the four different output markets and two coastlines to better grasp port competition. The analysis also includes the transshipment containerized cargo sub-market. In addition, and to avoid the possible distortions derived by ports with low presence in some markets, market power estimations have been done for two types of samples, the extended sample and the reduced sample where the former includes all ports with market shares larger than 0.1% and the later only those with market shares above 5%. The results show that the most competitive market, that is, the one with the largest *BI* in absolute terms, is precisely the transshipment containerized cargo sub-market. The containerized cargo market is in second place followed by the passenger and the liquid bulk transport markets. The extended samples present a higher level of competition except for the case of the liquids market; noting that for the rest of the merchandise the *BI* is not significant. Regarding the estimation of *BIs* by coastline, it is observed that the *south and east* coastline is more competitive than the *north* coastline, except for the market of the rest of the merchandise traffic. The main reason is that some of the ports located on the *north* coastline have solid bulk or non-containerized general cargo as their main cargo and most of the ports located on the *south and east* coastline have containerized cargo or petroleum cargo as their main activity. We leave for future research to empirically explore whether ports in more competitive markets are also more efficient. Boone Indicator logic assumes that more competition would lead to lower marginal costs in order to keep or gain market share.

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Appendix A

Chapter 1 Appendix

A.1 Ports included in each port authority

Table A.1 Ports included in each port authority

Port authority (PA)	Port
A Coruña	• A Coruña
Alicante	• Alicante
Almería	• Almería • Carboneras
Avilés	• Avilés
Bahía de Algeciras	• Algeciras • Tarifa
Bahía de Cadiz	• Cabezuela - Puerto Real • Cádiz • Santa María • Zona Franca

Table A.1 continued from previous page

Port authority	Port
Baleares	• Alcudia • Ibiza • Mahón • Palma de Mallorca • Cala Sabina
Barcelona	• Barcelona
Bilbao	• Bilbao
Cartagena	• Cartagena
Castellón	• Castellón
Ceuta	• Ceuta
Ferrol - San Cibrao	• Ferrol • San Cibrao
Gijón	• Gijón
Huelva	• Huelva
Las Palmas	• Arrecife • Las Palmas • Rosario
Málaga	• Málaga
Marín y Ría de Pontevedra	• Marín y Ría de Pontevedra
Melilla	• Melilla
Motril	• Motril
Pasaia	• Pasaia

Table A.1 continued from previous page

Port authority	**Port**
Santa Cruz de Tenerife	• La Estaca • Los Cristianos • SS de la Gomera • Santa Cruz de la Palma • Santa Cruz de Tenerife
Santander	• Santander
Sevilla	• Sevilla
Tarragona	• Tarragona
Valencia	• Gandia • Sagunto • Valencia
Vigo	• Vigo
Villagarcía de Arousa	• Villagarcía de Arousa

Source: Own elaboration from Table 3.5 of Statistical Yearbooks of EPPE 2002-2018

A.2 Primeras y segundas mercancías para cada autoridad portuaria en 2018

Table A.2 Primeras y segundas mercancías para cada autoridad portuaria en 2018

Autoridad Portuaria	Miles de toneladas	Primera mercancía	% del total	Operadores	Segunda mercancía	% del total	Operadores
A Coruña	15,292	Productos petrolíferos	35.06	Repsol Petróleo SA y CLH SA	Cereales y harina	9.51	Galigrain y Unión Fenosa
Alicante	3,161	Contenedores	39.39	APA en el Muelle nº11	Minerales no metálicos	35.09	Ditecpesa SA y Medifer CGL
Almería	6,965	Carbón	51.03	Holcim SA y Endesa Generación SA	Minerales no metálicos	24.06	APA en el Muelle Pechina
Avilés	4,968	Minerales metálicos	24.40	AGP, Bergué M., AZSA, C.Tudela Veguín SA, Alvargónzalez SA, Marpin y Algeposa	Productos químicos	15.81	Fertiberia SL, ArcelorMittal SA e I. Química del Nalón SA

Cuadro A.2 continuación de la página anterior

Autoridad Portuaria	Miles de toneladas	Primera mercancía	% del total	Operadores	Segunda mercancía	% del total	Operadores
B. Algeciras	105,544	Contenedores	59.09	TCA, APM TA y TTI-Algeciras	Productos petrolíferos	11.48	CEPSA (San Roque), CLH Alg. y Vopak TASA
B. Cádiz	3,802	Cereales y harina	23.37	Puma Energía Esp	Asfalto	16.01	H. Vilafranquina SA e Istamelsa
Baleares	16,207	Tara Ro-Ro	41.54	APB	Productos alimenticios	9.88	APB
Barcelona	65,895	Contenedores	52.80	APM y BEST	Productos químicos	9.61	Enagas SA, Relisa, Terquimsa, Decal, CLH SA, Sadesa, Demigrasa y Tradebe PS

Cuadro A.2 continuación de la página anterior

Autoridad Portuaria	Miles de toneladas	Primera mercancía	% del total	Operadores	Segunda mercancía	% del total	Operadores
Bilbao	35,583	Productos petrolíferos	31.60	Esergui SA, Acideka SA y FCC Ámbito SL	Contenedores	19.13	Noatum CTB SA
Cartagena	33,732	Productos petrolíferos	49.22	Terliq, Carthago, Saras Energía SA, CLH SA, Felguera IH, CGLZ SA, LBC Tanks, Ilboc SA, Masol Cartagena, Enagas T SAU, Bungue Ibérica y Repsol	Cereales y harinas	7.59	FOMDESA SA

Cuadro A.2 continuación de la página anterior

Autoridad Portuaria	Miles de toneladas	Primera mercancía	% del total	Operadores	Segunda mercancía	% del total	Operadores
Castellón	21,108	Productos petrolíferos	42.25	BP España Oil SA, Infinita Renovables SL y Masol	Minerales no metálicos	27.17	Lafarge Asland SA, PortsurCastellón, Elite Cements SL y Cemex España SA
Ceuta	1,711	Productos petrolíferos	48.74	APC	Tara Ro-Ro	26.15	APC
Ferrol S.C.	13,664	Carbón	34.62	Endesa Generación SA	Minerales metálicos	31.18	Alúmina Aluminio SA
Gijón	19,654	Carbón	37.82	EBHI SA	Cemento	6.64	Cementos Tudela Vegín SA
Huelva	32,767	Productos petrolíferos	50.3	Cepsa, Enagas SA y APH	Líquidos no petrolíferos	26.36	Atlantic Cooper SA, Decal España SA y Cepsa

Cuadro A.2 continuación de la página anterior

Autoridad Portuaria	Miles de toneladas	Primera mercancía	% del total	Operadores	Segunda mercancía	% del total	Operadores
Las Palmas	24,322	Contenedores	50.28	TMA SL, La Luz TC SA, Operaciones Portuarias Canarias SA	Productos petrolíferos	27.87	Oryx, BP, Petrologic, Aegean y Cepsa
Málaga	3,207	Contenedores	29.04	Noatum Container Terminal	Cemento	21.73	Cemensol, Transcemasa y Financiera y Minera
M.R. Pontevedra	2,514	Contenedores	37.38	Perez y Torres y Cía SL	Cereales y harina	23.33	Ceferino Nogueira SA
Melilla	868	Tara Ro-Ro	38.85	APM	Contendores	19.82	APM

Cuadro A.2 continuación de la página anterior

Autoridad Portuaria	Miles de toneladas	Primera mercancía	% del total	Operadores	Segunda mercancía	% del total	Operadores
Motril	2,820	Productos petrolíferos	40.42	Motrileña de líquidos, Secicar, Transgranada y CLH	Tara Ro-Ro	11.56	Navieras Armas SL y FordeReedereiSee tourisk Iberia SLU
Pasaia	3,809	Productos siderúrgicos	45.51	Consignaciones Toro y Betolaza SA	Vehículos y piezas	13.44	APP
SC Tenerife	12,348	Productos petrolíferos	36.39	Terminales Canarios SL	Contenedores	29.38	Boluda Terminal Marítima de Tenerife SLU y Terminal de Contenedores de Tenerife SA
Santander	5,957	Productos químicos	13.37	LCB	Vehículos y piezas	12.73	GSW y Aceraisa

Cuadro A.2 continuación de la página anterior

Autoridad Portuaria	Miles de toneladas	Primera mercancía	% del total	Operadores	Segunda mercancía	% del total	Operadores
Sevilla	4,413	Contenedores	22.28	UTE Batán y Terminales Marítima del Gualdaquivir SL	Productos siderúrgicos	17.11	Holcim España SA y CPOP
Tarragona	31,995	Productos petrolíferos	57.08	Repsol Butano SA, Terminales Químicos SA, Asfaltos Españoles SA y Basf Española SA	Cereales y harina	12.18	Bergué y Cía SA y Silos de Tarragona SA
Valencia	76,426	Contenedores	75.74	TVC OP SA, Noatum Container Terminal Valencia y Intersagunto Terminal SL	Material de construcción	11.75	Silos y Almacenajes de Valencia SA, Terminal Marítima Servicesa SA, Temagra SL, Borax España SA y Silesa

Cuadro A.2 continuación de la página anterior

Autoridad Portuaria	Miles de toneladas	Primera mercancía	% del total	Operadores	Segunda mercancía	% del total	Operadores
Vigo	4,136	Contenedores	64.51	Terminales Marítimas de Vigo SL	Vehículos y piezas	18.76	Kaleido, Progeco, Perez Torres & Cía, Algacargo y Bergué Marítima
Vilagarcía A.	1,208	Madera	15.66	Tudela Veguín SA y Nynas SA	Cereales y harina	13.02	Finsa y Foresa

Fuente: Tabla 3.1.2 y 4.5.2 del Anuario Estadístico de Puertos del Estado, memorias anuales del 2018 para cada autoridad portuaria y elaboración propia.

A.3 Evolución de la utilización de la capacidad del sistema portuario español

Table A.3 Evolución de la utilización de la capacidad del sistema portuario español

		2012		2015		2018	
Tipo de terminal	Capacidad Máx. Teórica	Tráficos	% Capacidad Máx.	Tráficos	% Capacidad Máx.	Tráficos	% Capacidad Máx.
Granel líquido	315.7	161.7	51.22%	176.1	55.79%	188.9	59.82%
Granel sólido	202.9	88.6	43.66%	96	47.3%	102.4	50.45%
Mercancía general y polivalente	145.2	62.8	40.56%	71.1	45.9%	81.3	52.52%
Contenedores	341.8	162.1	47.44%	159.3	46.6%	191	55.89%
Total Sistema	1015.2	475.2	46.81%	502.4	49.49%	563.6	55.51%

Fuente: Plan de Infraestructuras y Vivienda (2012-2014), Tabla 7 y Anuarios estadísticos de EPPE. Capacidad máxima teórica y tráficos en millones de toneladas.

Appendix B

Chapter 2 Appendix

B.1 Recieved literature on Spanish ports efficiency

Table B.1 Papers about the Spanish port system

Authors	Data	Model	Variables	Objectives	Results
Martínez-Burdía (1996)	27 Port Authorities from 1985 to 1989	Cost function	Outputs: -Tons of merchandise added -Number of passengers Inputs: -Labor expenses -Total expenses in capital	To find a representative cost function for the Spanish port system	• Large scale economies • Ports that belong to *Juntas de Puertos* are less efficient than the rest • Larger ports are less efficient
Baños-Pino et al. (1999)	27 Port Authorities from 1985 to 1997	Stochastic cost function and Stochastic distance function	Outputs: -Tons of merchandise added -Income obtained from leases Inputs: -Number of workers -Net tangible assets -Intermediate consumption	To measure the degree of over-capitalization in the Spanish port system	• There is over-capitalization in the Spanish port system

Table B.1 continued from previous page

Authors	Data	Model	Variables	Objectives	Results
Martínez-Burdía et al. (1999)	27 Port Authorities from 1993 to 1997	DEA	Outputs: -Tons of merchandise added -Income obtained from leases Inputs: -Labor expenses -Intermediate consumption	To analyse relative port efficiency	• Port authorities of greater complexity offer higher comparative efficiency levels
Coto-Millán et al. (2000)	27 Port Authorities from 1985 to 1989	Stochastic cost function	Outputs: -Tons of merchandise added Inputs: -Labor expenses -Total expenses in capital -Linear meters of berths with depth higher than 4m	To analyse port economic efficiency	• The most efficient ports are those which are smaller in size and managed under a more centralized regime

Table B.1 continued from previous page

Authors	Data	Model	Variables	Objectives	Results
Bonilla et al. (2002)	24 Port Authorities from 1995 to 1998	DEA	Outputs: -Tons of solid bulk -Tons of liquid bulk -Tons of general merchandise not containerized -Tons of general merchandise containerized Inputs: -Net tangible assets	To analyse port efficiency	• There are large ports not included among the most efficient

Table B.1 continued from previous page

Authors	Data	Model	Variables	Objectives	Results
Jara-Díaz et al. (2005)	3 terminals from 1991 to 1999	Cost function	Outputs: -Tons of general merchandise not containerized -Tons of general merchandise containerized -Tons of Ro-Ro merchandise Inputs: -Labour expenses –Depreciation of capital	To identify the optimal price policies and the advantage of increasing production	• Container traffic shows the smallest marginal cost • All firms have scope economies

Table B.1 continued from previous page

Authors	Data	Model	Variables	Objectives	Results
González- Serrano & Trujillo (2008)	9 Port Authorities from 1990 to 2002	Stochastic distance function	Outputs: -Tons of solid bulk -Tons of liquid bulk -Tons of general merchandise not containerized -Tons of general merchandise containerized -Number of passengers Inputs: -Number of workers -Linear meters of berths with depth higher than 4m -Surface in square meters.	To analyse the legislative reforms effect on technical efficiency	• Legislative reforms do not affect technical efficiency but increase technical progress

Table B.1 continued from previous page

Authors	Data	Model	Variables	Objectives	Results
Díaz-Hernández et al. (2008)	21 Port Authorities from 1994 to 1998	DEA	Outputs: -Tons of solid bulk -Tons of general merchandise not containerized -Tons of general merchandise containerized Inputs: -Number of workers -Cranes	To evaluate the introduction of new technologies and the effect of legislative reforms.	• Ports that improve the most are those with higher containerized cargo and private ownership of cranes

Table B.1 continued from previous page

Authors	**Data**	**Model**	**Variables**	**Objectives**	**Results**
Rodríguez-Álvarez et al. (2011)	3 port terminals from 1991 to 1998	Cost function	Outputs: -Tons of general merchandise not containerized -Tons of general merchandise containerized -Tons of Ro-Ro merchandise Inputs: -Labour expenses –Depreciation of capital	To analyse whether uncertainty affects total cost	• Demand uncertainty affects port total cost • The most efficient terminals are those wit h the higher containerized cargo index

Table B.1 continued from previous page

Authors	Data	Model	Variables	Objectives	Results
Tovar & Wall (2012)	3 port terminals from 1991 to 1998	Cost function	Outputs: -Tons of general merchandise not containerized -Tons of general merchandise containerized -Tons of Ro-Ro merchandise Inputs: -Labour expenses –Depreciation of capital	To analyse whether uncertainty affects total cost	• Demand variability affects port total cost • Scope and scale economies are higher with demand uncertainty

Table B.1 continued from previous page

Authors	Data	Model	Variables	Objectives	Results
Rodríguez-Álvarez & Tovar (2012)	26 Port Authorities from 1993 to 2007	Cost function	Outputs: -Tons of solid bulk -Tons of liquid bulk -Tons of general merchandise not containerized -Tons of general merchandise containerized -Number of passengers Inputs: -Number of workers -Depreciation of capital	To analyse the effects of regulatory changes on economic efficiency	• Reforms introduced in 1992 and 1997 improved economic efficiency • The 2003 reform reduced economic efficiency

Table B.1 continued from previous page

Authors	Data	Model	Variables	Objectives	Results
Coto-Millán et al. (2015)	Operators data from 2002 to 2011	Stochastic distance function	Outputs: Annual earnings of maritime companies Inputs: -Number of workers -Net tangible assets -Intermediate consumption	To analyse regulation, competition, crisis and technical efficiency of companies that operate in Spanish ports	• Port terminals and logistic operators have the higher technical efficiency • Stevedoring companies are the less efficient • The 2003 reform improved technical efficiency but was countered by the economic crisis

Table B.1 continued from previous page

Authors	Data	Model	Variables	Objectives	Results
Tovar & Wall (2015)	26 Port Authorities from 1993 to 2002	Stochastic distance function	Outputs: -Tons of solid bulk -Tons of liquid bulk -Tons of general merchandise not containerized -Tons of general merchandise containerized -Number of passengers Inputs: -Number of workers -Surface in square meters -Net tangible assets -Intermediate consumption	Whether ports can increase traffic while reducing inputs	• Variable inputs can be reduced while increasing outputs

Table B.1 continued from previous page

Authors	Data	Model	Variables	Objectives	Results
Coto-Millán et al. (2016)	26 Port Authotiries from 1986 to 2012	Stochastic distance function	Outputs: -Tons of solid bulk -Tons of liquid bulk -Tons of general merchandise not containerized -Tons of general merchandise containerized -Number of passengers Inputs: -Number of workers -Linear meters of berths with depth higher than 4m -Net tangible assets	To analyse the impact of public regulation on the efficiency of the Spanish port system	• There are scale economies • Reforms introduced in 1997 and 2003 improved technical efficiency.

Table B.1 continued from previous page

Authors	Data	Model	Variables	Objectives	Results
Pérez et al. (2020)	27 Port Authotiries from 2001 to 2011	Stochastic distance function	Outputs: -Tons of total bulk cargo (including solid and liquid bulk) -Total tons of general merchandise (including containerized merchandise, conventional cargo and fishing) Inputs: -Number of stevedoring workers -Linear meters of berths with deep higher than 4 m -Cranes	To analyse the impact of public regulation on the efficiency of the Spanish port system	• The larger and more specialized ports are more highly efficient

B.2 Received literature on other country or region ports efficiency

Table B.2 Papers considering non-Spanish port systems

Authors	Data	Model	Variables	Objectives	Results
Chang (1978)	Data of Mobile port from 1953 to 1973	Production function	Outputs: -Annual earnings Inputs: -Number of workers -Net tangible assets	Determine whether Mobile's Port needs an expansion of its facilities	• Mobile's Port should expand its facilities
Roll & Hayuth (1993)	20 P.A.	DEA	Outputs: -Tons of solid bulk -Tons of general merchandise not containerized -Tons of general merchandise containerized -Number of vessels Inputs: -Number of workers -Total expenses in capital	Present non-parametric approach	• Non-parametric approach suited to calculate technical efficiency

Table B.2 continued from previous page

Authors	Data	Model	Variables	Objectives	Results
Liu (1995)	28 British P.A.from 1983 to 1990	Stochastic production frontier function	Outputs: -Annual earnings Inputs: -Labour expenses -Net tangible assets	Analyze whether privatization ownership improves the perfomance of port activities	• Large and intensive capital ports have a positive impact on efficiency • There are not clear-cut pattern of efficiency in favour of one type of ownership

Table B.2 continued from previous page

Authors	Data	Model	Variables	Objectives	Results
Notteboom et al.(2000)	The 36 largest containers terminals on Europe in 1994	Bayesian stochastic frontier function	Outputs: -TEUs of containerized merchandise Inputs: -Linear meters of berths with deep greater than 4m -Hectares of surface -Cranes	Investigate technical efficiency of the major European containers terminals.	• The most efficient container terminals comply with the follow characteristics: located in the north, high size and located at hub ports.

Table B.2 continued from previous page

Authors	Data	Model	Variables	Objectives	Results
Tongzon (2001)	4 Australian P.A. and 12 international in 1996	DEA	Outputs: -TEUs of containerized merchandise Inputs: -Number of workers -Hectares of surface -Linear meters of berths with deep greater than 4m -Square meters of surface	To apply DEA method to provide an efficiency measurement	• Port size is not the key determinant of port efficiency.
Valentine & Grey (2001)	31 P.A. in 1998	DEA	Outputs: -Tons of merchandise added Inputs: -Linear meters of berths with deep greater than 4m -Square meters of surface	To analyse whether ownership structure is important for port efficiency.	• Simple organizational structures are the most efficient. • Structure of ownership has not influence in efficiency.

Table B.2 continued from previous page

Authors	Data	Model	Variables	Objectives	Results
Cullinane et al. (2002)	15 major Asian container ports from 1989 to 1998	Stochastic production frontier function	Outputs: -TEUs of containerized merchandise Inputs: -Linear meters of berths with deep greater than 4m -Hectares of surface -Net tangible assets	To analyse the effescts of different administrative and ownership structures	• Privatization and desregulation improve productive efficiency. • Larger ports or terminals are more efficients.
Estache et al. (2002)	11 mexican P.A. from 1996 to 1999	Stochastic production frontier function	Outputs: -Tons of merchandise added Inputs: -Number of workers -Square meters of surface	To analyse the effects of reforms carried out in the 1990's on Mexico	• Reforms generate larger short-run improvements in the average performance of the sector.

Table B.2 continued from previous page

Authors	Data	Model	Variables	Objectives	Results
Barros (2003)	6 portuguese P.A. from 1999 to 2000	DEA	Outputs: -Tons of solid bulk -Tons of liquid bulk -Tons of general merchandise not containerized -Tons of general merchandise containerized -Tons of Ro-Ro merchandise -Number of vessels -Annual earnings Inputs: -Number of workers -Net tangible assets	To analyse technical and allocative efficiencies of Portuguese P.A. in order to investigate if state's policy is achieving its aims.	• The organisational governamental environment forces the seaports to achieve efficiency in their operational activities.

Table B.2 continued from previous page

Authors	Data	Model	Variables	Objectives	Results
Cullinane & Song (2003)	5 port operators in Korea	Stochastic production frontier function	Outputs: -Annual earnings Inputs: -Labour expenses -Net tangible assets -Buildings and infrastructure	To Asses the efficiency of Korea's port sector liberalization policy.	• The implementation of privatization and deregulation affect positively to the productive efficiency.
Barros & Athanassiou (2004)	4 Portuguese and 2 Greek P.A. from 1998 to 2000	DEA	Outputs: -Tons of solid bulk -Tons of liquid bulk -Tons of general merchandise containerized -Number of vessels Inputs: -Number of workers -Net tangible assets	To find the best practices that will lead to improved performance in European ports	• Privatization and competition allow improve productivity.

Table B.2 continued from previous page

Authors	Data	Model	Variables	Objectives	Results
Barros (2005)	10 Portuguese P.A. from 1990 to 2000	Stochastic cost frontier function	Outputs: -Tons of merchandise added -Number of vessels Inputs: -Labour expenses -Total expenses in capital	To identify the best practices in the management of Portuguese P.A.	• Portuguese P.A. are failing in the purpose of improve port efficiency.
Lin & Lih (2005)	27 international containers ports from 1999 to 2002	Production function and DEA	Outputs: -TEUs of containerized merchandise Inputs: -Linear meters of berths with deep greater than 4m -Hectares of surface -Cranes -Stevedores equipment	To compare two approaches to measure technical efficiency.	• Values of parametric method are higher. • Localization and administrative structure do not affect efficiency.

Table B.2 continued from previous page

Authors	Data	Model	Variables	Objectives	Results
Tongzon & Heng (2005)	25 container terminals and ports.	Stochastic production frontier function	Outputs: -TEUs of containerized merchandise Inputs: -Linear meters of berths with deep greater than 4m -Hectares of surface -Cranes	To identify the relationship between ownership structure and port efficiency.	• Landlord improves operative efficiency.

Table B.2 continued from previous page

Authors	Data	Model	Variables	Objectives	Results
Cullinane et al.(2006)	The 30 best container ports in 2001.	Stochastic production frontier function DEA	Outputs: -TEUs of containerized merchandise Inputs: -Linear meters of berths deepest than 4m -Hectares of surface -Cranes	To compare two approaches to measure technical efficiency	• High levels of technical efficiency are associated with scale, greater private-sector participation and with transshipment as opposed to gateway ports.

Table B.2 continued from previous page

Authors	Data	Model	Variables	Objectives	Results
Cheon et al. (2010)	100 ports in 1991 and 138 ports in 2004.	DEA	Outputs: -TEUs of containerized merchandise Inputs: -Linear meters of berths with deep greater than 4m -Square meters of surface -Cranes	To evaluate how institutional reforms have influenced to efficiency.	• Ports have gained efficiency. • The improvement in PTF comes from the ownership structure and the practices in asset management
Bang et al. (2012)	14 containers lines of the 20 most important in the world on 2008	DEA	Outputs: -TEUs of containerized merchandise -Annual earnings Inputs: -Net tangible assets	To measure relative efficiency of the shipping companies.	• Linear shipping with greater capacity, higher vessels, higher ratio of leased vessels and with alliance are financially more efficient.

Table B.2 continued from previous page

Authors	Data	Model	Variables	Objectives	Results
Chang & Tovar (2014)	7 Chilean ports and 7 Peruvian ports from 2004 to 2010.	Distance function	Outputs: -Tons of solid bulk -Tons of general merchandise containerized -TEUs of containerized merchandise -Tons of Ro-Ro merchandise Inputs: -Number of workers -Net tangible assets	To check whether political reforms have achieved their objectives.	• The greater flexibility of the Chilean port reform allowed that these terminals achieved better performance than Peruvian ports

Table B.2 continued from previous page

Authors	Data	Model	Variables	Objectives	Results
De Oliveira & Cariou (2014)	200 containers ports from 2004 to 2010	DEA	Outputs: -TEUs of containerized merchandise Inputs: -Linear meters of berths with depth higher than 4m -Square meters of surface -Cranes	To investigate whether inter-port competition impacts port efficiency.	• Increasing inter-port competition decreases port efficiency

Table B.2 continued from previous page

Authors	Data	Model	Variables	Objectives	Results
SchØyen & Odeck (2015)	6 Norwegian ports and 14 Nordic and British ports from 2009 to 2014.	DEA	Outputs: -TEUs of containerized merchandise Inputs: -Linear meters of berths with depth higher than 4m -Hectares of surface -Cranes	To determine the elements that explain productivity improvement of the six largest Norwegian seaports.	• The productivity growth is due to technical efficiency. • There is not evidence about differences between Norwegian ports as one group and Nordic and British ports as a second group.

Table B.2 continued from previous page

Authors	Data	Model	Variables	Objectives	Results
Serebrisky et al. (2015)	63 containers terminals from 1999 to 2009	Stochastic production frontier function	Outputs: -TEUs of containerized merchandise Inputs: -Linear meters of berths with depth higher than 4m -Square meters of surface -Cranes	To analyze the determinants and progress of technical efficiency in Latin American and Caribbean seaports.	• Privatization and Landlord model explain the higher gains of efficiency

Table B.2 continued from previous page

Authors	Data	Model	Variables	Objectives	Results
Pérez et al. (2016)	40 containers terminals from 2000 to 2010.	Stochastic production frontier function	Outputs: -TEUs of containerized merchandise Inputs: -Linear meters of berths with depth higher than 4m -Square meters of surface -Cranes	To investigate whether changes in LAC port industry have improved port efficiency during the last decade.	• Container terminals located at Mercosur countries are more efficient. • Container terminals located ai transshipment ports are less efficient. • Ports with higher number of terminals are more efficient.

Appendix C

Chapter 3 Appendix

C.1 Number of terminals per type and port during the period 2002-2018

Figures in parentheses indicate the period in which the corresponding number of terminals is operative.

Table C.1 Number of terminals per type and port during the period 2002-2018

Port	TPRC	TPBC	TPRL	TPBL	TPRMG	TPBMG	TPRP	TPBP
A Coruña	0	0	1	0	2 (02-06) 3 (07-14) 4 (15-18)	0	0 (02-06) 1 (07-18)	1 (02-06) 0 (07-18)
Alicante	1 (02-07) 2 (08-09) 1 (2010) 0 (11-18)	0 (02-09) 1 (10-18)	2 (02-11) 1 (12-18)	0 (02-11) 1 (12-18)	1	0	0 (02-07) 1 (08-18)	2 (02-13) 1 (14-18)
Almería	0	0	1 (02-05) 0 (06-18)	0	3 (02-05) 2 (06-18)	0	0	1
Avilés	0	0	1	0	2	0	0	0
B. Algeciras	2 (02-09) 3 (10-18)	0	1 (02-06) 2 (07-11) 3 (12-18)	0	2 (02-11) 1 (12-14) 2 (15-18)	0	0	3 (02-07) 2 (08-18)

Table C.1 continued from previous page

Port	TPRC	TPBC	TPRL	TPBL	TPRMG	TPBMG	TPRP	TPBP
B. Cádiz	1 (02-16) 2 (17-18)	0	1 (02-12) 0 (13-18)	0	1 (02-05) 2 (06-12) 1 (13-18)	0	0	1 (02-05) 3 (06-18)
Baleares	0	0	2 (02-10) 1 (11-18)	0	3	1	0	5 (02-09) 6 (10-12) 7 (13-14) 8 (14-18)
Barcelona	2 (02-11) 3 (12) 2 (13-18)	0	2 (02-07) 1 (08-18)	0	5 (02-07) 6 (08-18)	0	0	1
Bilbao	1	0	3	0	2 (02-08) 1 (09-14) 0 (15-18)	0	0	1 (02-05) 2 (06-18)
Cartagena	0	0 (02-17) 1 (2018)	1 (02-04) 2 (05) 3 (06-18)	0	0 (02-05) 1 (06-11) 2 (12-18)	0	0	1

Table C.1 continued from previous page

Port	TPRC	TPBC	TPRL	TPBL	TPRMG	TPBMG	TPRP	TPBP
Castellón	0 (02-10) 1 (11-18)	0	2 (02) 3 (03-06) 2 (07-13) 1 (14-15) 2 (16-18)	0	2	0	0	0
Ceuta	0	0	0	0	0	0	0	2 (02-14) 1 (15-18)
Ferrol-SC	0 (02-10) 1 (11-18)	0	1 (02-11) 2 (12-18)	0	2 (02-05) 3 (06-09) 2 (10-13) 1 (14-15) 2 (16-18)	0	0	0
Gijón	1	0	3 (02-17) 2 (18)	0	3 (02-06) 4 (07-18)	1 (02-06) 0 (07-18)	0 (02-09) 1 (10-14) 0 (15-18)	0 (02-15) 1 (16-18)

Table C.1 continued from previous page

Port	TPRC	TPBC	TPRL	TPBL	TPRMG	TPBMG	TPRP	TPBP
Huelva	0	0	5 (02) 4 (03-07) 5 (08-09) 6 (10) 5 (11-18)	2 (02-12) 1 (13-18)	0 (02) 1 (03) 2 (04-06) 1 (07-12) 0 (13-14) 1 (15-18)	1 (02) 0 (03-18)	0	0
Las Palmas	5 (02-06) 6 (07-12) 4 (13-16) 3 (17-18)	0	2 (02-05) 1 (06-14) 2 (15-17) 1 (18)	0 (02-05) 1 (06-17) 0 (18)	4 (02-04) 5 (05-07) 4 (08) 5 (09-15) 6 (16-17) 7 (18)	3	2 (02-04) 3 (05-13) 2 (14-2018)	5 (02-04) 4 (05-18)
Málaga	0	0	4 (02-07) 3 (08-17) 2 (18)	0	1 (02-11) 2 (12-18)	0	0	1 (02-06) 2 (07-10) 1 (11-16) 0 (16-18)

Table C.1 continued from previous page

Port	TPRC	TPBC	TPRL	TPBL	TPRMG	TPBMG	TPRP	TPBP
MR Pontevedra	1	0	0	0	1 (02-05) 2 (06-14) 3 (15-18)	1	0	0
Melilla	0	0	0 (02-03) 1 (04-18)	0	1	0	0	1 (02-07) 2 (08-11) 1 (12-18)
Motril	0	0	0	0	2	0	0 (05-09) 1 (10-15) 2 (16-18)	0
Pasaia	0	0	0	1 (02-04) 0 (05-18)	2 (02-16) 1 (17-18)	0	0	1 (02-07) 0 (08-18)
SC Tenerife	1 (02-11) 2 (12-18)	0	1	0	2 (02-08) 1 (09-18)	0	1 (02-16) 2 (17-18)	6
Santander	0	0	3	0	4 (02-09) 5 (10-18)	0	0	1

Table C.1 continued from previous page

Port	TPRC	TPBC	TPRL	TPBL	TPRMG	TPBMG	TPRP	TPBP
Sevilla	0 (02-03) 1 (04-18)	0	3 (02-03) 1 (04-07) 2 (08-18)	0	3 (02-03) 1 (04-06) 2 (07-13) 1 (14-18)	0	0	0 (02-06) 1 (07) 0 (08-15) 1 (16) 0 (17-18)
Tarragona	0 (02-03) 1 (04-18)	0	7 (02-06) 5 (07-18)	0	4 (02-10) 5 (11-12) 4 (13-18)	0	0	1 (02-04) 0 (05-12) 1 (13-18)
Valencia	1 (02-05) 2 (06) 3 (07-10) 4 (11-18)	0	3 (02-03) 4 (04-05) 5 (06-18)	0	8 (02-06) 9 (07-09)	0	2 (02-03) 1 (04-06) 3 (07-10) 2 (11-18)	1 (02-10) 0 (11-13) 1 (14-18)
Vigo	1	0	0 (02-13) 1 (14-18)	0	0 (02-12) 2 (13-18)	0	0 (02-09) 1 (10-18)	1 (02-2010) 2 (11-18)
V. Aurosa	0	0	2	0	1	0	0	0

Source: Own Elaboration

Appendix D

Chapter 4 Appendix

D.1 Detailed information about port access to railway

Table D.1 Detailed information about port access to railway

Port	Railway Access
A Coruña	Yes, except for the year 2003
Alicante	Only in the years 2006, 2010, 2011 and from 2015 to 2018
Almería	Only in 2016
Avilés	Yes
Bahía de Algeciras	Only from 2014 to 2018
Bahía de Cádiz	Only from 2002 to 2008
Baleares	No
Barcelona	Yes
Bilbao	Yes
Cartagena	Only from 2003 to 2004 and from 2006 to 2010
Castellón	Only for the years 2006, 2010 and 2011
Ceuta	No
Ferrol-San Cibrao	Only from 2002 to 2006 and in 2009
Gijón	Yes
Huelva	Yes, except for the year 2013
Las Palmas	No
Málaga	Only from 2002 to 2008 and from 2013 to 2014
Marín y Ría de Pontevedra	Yes
Melilla	No
Motril	No
Pasaia	Yes
Santa Cruz de Tenerife	No
Santander	Yes
Sevilla	Yes
Tarragona	Yes
Valencia	Yes
Vigo	Only from 2009 to 2011 and in 2016
Villagarcía de Aurosa	Only in the year 2002 and from 2004 to 2009

Source: 3.1.16 " Classification of goods by transport facilities used when entering or leaving the port (in tonnes)" from statistics yearbooks published in the web-page of Puertos del Estado.

D.2 Technical efficiency per port and year using SFA

Table D.2 Technical efficiency per port and year using SFA

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Average
A Coruña	0.3141	0.3105	0.3069	0.3034	0.2998	0.2963	0.2927	0.2892	0.2857	0.2822	0.2787	0.2752	0.2717	0.2682	0.2648	0.2613	0.2579	0.2858
Alicante	0.2911	0.2876	0.2841	0.2806	0.2771	0.2736	0.2701	0.2666	0.2632	0.2597	0.2563	0.2529	0.2495	0.2461	0.2427	0.2393	0.2360	0.2633
Almería	0.6977	0.6952	0.6927	0.6902	0.6877	0.6852	0.6826	0.6801	0.6775	0.6749	0.6723	0.6696	0.6670	0.6643	0.6617	0.6590	0.6563	0.6773
Avilés	0.4841	0.4807	0.4772	0.4738	0.4703	0.4668	0.4633	0.4598	0.4563	0.4527	0.4492	0.4457	0.4421	0.4386	0.4350	0.4315	0.4279	0.4562
B. Algeciras	0.7536	0.7515	0.7494	0.7473	0.7451	0.7430	0.7408	0.7386	0.7364	0.7342	0.7319	0.7297	0.7274	0.7251	0.7229	0.7205	0.7182	0.7362
B. Cádiz	0.2902	0.2867	0.2832	0.2796	0.2762	0.2727	0.2692	0.2657	0.2623	0.2588	0.2554	0.2520	0.2486	0.2452	0.2418	0.2384	0.2351	0.2624
Baleares	0.3635	0.3599	0.3563	0.3526	0.3490	0.3454	0.3418	0.3382	0.3346	0.3310	0.3274	0.3238	0.3203	0.3167	0.3131	0.3095	0.3060	0.3347
Barcelona	0.6500	0.6473	0.6445	0.6417	0.6389	0.6361	0.6333	0.6304	0.6276	0.6247	0.6218	0.6189	0.6159	0.6130	0.6101	0.6071	0.6041	0.6274
Bilbao	0.4150	0.4114	0.4078	0.4042	0.4006	0.3970	0.3934	0.3898	0.3862	0.3826	0.3790	0.3754	0.3718	0.3682	0.3645	0.3609	0.3573	0.3862
Cartagena	0.3933	0.3897	0.3861	0.3825	0.3789	0.3753	0.3717	0.3680	0.3644	0.3608	0.3572	0.3536	0.3500	0.3464	0.3428	0.3392	0.3356	0.3644
Castellón	0.3433	0.3397	0.3361	0.3325	0.3289	0.3253	0.3218	0.3182	0.3146	0.3110	0.3075	0.3039	0.3003	0.2968	0.2933	0.2897	0.2862	0.3147
Ceuta	0.3576	0.3540	0.3504	0.3468	0.3432	0.3396	0.3360	0.3324	0.3288	0.3252	0.3216	0.3181	0.3145	0.3109	0.3073	0.3038	0.3002	0.3289
Ferrol SC	0.6605	0.6578	0.6551	0.6524	0.6496	0.6469	0.6441	0.6413	0.6385	0.6357	0.6328	0.6300	0.6271	0.6242	0.6213	0.6184	0.6155	0.6383
Gijón	0.9505	0.9501	0.9496	0.9491	0.9486	0.9481	0.9476	0.9471	0.9466	0.9461	0.9456	0.9451	0.9446	0.9440	0.9435	0.9430	0.9424	0.9466
Huelva	0.3447	0.3411	0.3375	0.3339	0.3303	0.3267	0.3231	0.3195	0.3160	0.3124	0.3088	0.3053	0.3017	0.2982	0.2946	0.2911	0.2876	0.3160
Las Palmas	0.3143	0.3108	0.3072	0.3036	0.3001	0.2965	0.2930	0.2895	0.2860	0.2824	0.2789	0.2754	0.2720	0.2685	0.2650	0.2616	0.2581	0.2861
Málaga	0.2813	0.2778	0.2743	0.2708	0.2674	0.2639	0.2605	0.2570	0.2536	0.2502	0.2468	0.2434	0.2400	0.2367	0.2333	0.2300	0.2267	0.2538
MP Pontevedra	0.2471	0.2437	0.2403	0.2370	0.2336	0.2303	0.2270	0.2237	0.2204	0.2171	0.2139	0.2107	0.2074	0.2043	0.2011	0.1979	0.1948	0.2206
Melilla	0.1848	0.1818	0.1787	0.1757	0.1727	0.1698	0.1668	0.1639	0.1610	0.1581	0.1553	0.1524	0.1496	0.1468	0.1441	0.1414	0.1387	0.1613
Motril	na	na	na	0.2495	0.2461	0.2428	0.2394	0.2360	0.2327	0.2294	0.2261	0.2228	0.2195	0.2162	0.2130	0.2098	0.2066	0.2278
Pasaia	0.3428	0.3392	0.3356	0.3320	0.3284	0.3248	0.3212	0.3176	0.3141	0.3105	0.3069	0.3034	0.2998	0.2963	0.2927	0.2892	0.2857	0.3141
SC Tenerife	0.2491	0.2457	0.2424	0.2390	0.2356	0.2323	0.2290	0.2257	0.2224	0.2191	0.2158	0.2126	0.2094	0.2062	0.2030	0.1988	0.1966	0.2226
Santander	0.4324	0.4289	0.4253	0.4217	0.4182	0.4146	0.4110	0.4074	0.4038	0.4002	0.3966	0.3930	0.3894	0.3858	0.3822	0.3786	0.3749	0.4038
Sevilla	0.3054	0.3018	0.2983	0.2947	0.2912	0.2877	0.2841	0.2806	0.2771	0.2737	0.2702	0.2667	0.2632	0.2598	0.2564	0.2529	0.2495	0.2773
Tarragona	0.3858	0.3822	0.3786	0.3750	0.3714	0.3678	0.3642	0.3605	0.3569	0.3533	0.3497	0.3461	0.3425	0.3389	0.3353	0.3317	0.3281	0.3569
Valencia	0.6055	0.6025	0.5995	0.5965	0.5935	0.5904	0.5874	0.5843	0.5812	0.5781	0.5750	0.5718	0.5687	0.5655	0.5624	0.5592	0.5560	0.5810
Vigo	0.1989	0.1958	0.1926	0.1895	0.1865	0.1834	0.1803	0.1773	0.1743	0.1713	0.1684	0.1654	0.1625	0.1596	0.1568	0.1539	0.1511	0.1746
Vilagarcía A	0.1566	0.1538	0.1510	0.1482	0.1454	0.1427	0.1400	0.1373	0.1346	0.1320	0.1293	0.1268	0.1242	0.1217	0.1192	0.1167	0.1142	0.1349
Average	0.4067	0.4035	0.4003	0.3926	0.3894	0.3862	0.3830	0.3799	0.3767	0.3735	0.3703	0.3671	0.3640	0.3608	0.3604	0.3573	0.3541	0.3784

D.3 Technical efficiency per port and year using DEA-CRS

Table D.3 Technical efficiency using DEA with constant returns to scale

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Average
A Coruña	0.4920	0.4805	0.5063	0.5822	0.5393	0.5440	0.4399	0.4051	04045	0.3962	0.4337	0.3837	0.4048	0.4693	0.4561	0.5051	0.5123	0.4679
Alicante	0.1692	0.1823	0.1619	0.1717	0.1742	0.1757	0.1330	0.1142	0.1137	0.1152	0.1147	0.1103	0.1233	0.1357	0.1915	0.2039	0.1834	0.1514
Almería	0.4845	0.5135	0.5523	0.5679	0.5075	0.5221	0.4568	0.3329	0.4293	0.4011	0.4464	0.4019	0.4193	0.4729	0.4154	0.4888	0.5396	0.4678
Avilés	0.3285	0.3758	0.4049	0.3992	0.4793	0.4484	0.3960	0.3183	0.3626	0.4053	0.4177	0.3758	0.3883	0.4142	0.4033	0.3766	0.3830	0.3928
B. Algeciras	1	0.9599	1	0.9441	0.9745	1	0.7248	0.6918	0.7516	0.7967	0.9229	0.9754	1	0.9730	1	0.9643	1	0.9223
B. Cádiz	0.1620	0.1691	0.1909	0.2069	0.2045	0.2578	0.1602	0.1273	0.1283	0.1345	0.1299	0.1378	0.1442	0.1326	0.1397	0.1554	0.1499	0.1606
Baleares	0.2528	0.2631	0.2991	0.3349	0.3634	0.3669	0.3370	0.2931	0.3112	0.3047	0.3080	0.3193	0.3359	0.3499	0.3947	0.4161	0.4487	0.3352
Barcelona	0.3581	0.3655	0.4041	0.4477	0.4841	0.5183	0.5138	0.4665	0.4678	0.4637	0.4310	0.4430	0.4861	0.4756	0.4776	0.5655	0.6249	0.4702
Bilbao	0.4599	0.4868	0.5613	0.5770	0.6909	0.7123	0.6906	0.6030	0.5732	0.5139	0.4746	0.4928	0.5119	0.5549	0.5340	0.6131	0.6346	0.5697
Cartagena	0.8025	0.7765	0.8837	0.9975	0.8814	0.8140	0.7867	0.6204	0.5815	0.6582	0.8937	0.8836	0.9701	1	0.9448	1	0.9696	0.8508
Castellón	0.7820	0.6695	0.7433	0.8561	0.6912	0.5647	0.5900	0.4484	0.4900	0.5003	0.4843	0.5115	0.6082	0.6455	0.6715	0.7361	0.8777	0.6394
Ceuta	0.3527	0.3190	0.3133	0.3085	0.3576	0.3874	0.4421	0.4104	0.3834	0.3905	0.3911	0.3653	0.3534	0.3382	0.3624	0.3655	0.3690	0.3653
Ferrol SC	0.7156	0.6848	0.7426	0.7111	0.7154	0.6962	0.7438	0.6426	0.5235	0.6112	0.7196	0.7043	0.7363	0.7449	0.7395	0.8226	0.8229	0.7104
Gijón	0.9625	0.8983	0.9210	1	0.9642	0.9655	0.8347	0.6139	0.6160	0.6024	0.6890	0.7230	0.7984	0.7973	0.8225	1	0.9517	0.8330
Huelva	0.7897	0.8719	0.7787	0.8539	0.8672	0.8799	0.9208	0.7420	0.7776	0.9436	1	0.9158	0.9510	0.9465	1	1	0.9917	0.8959
Las Palmas	0.2887	0.3186	0.3452	0.3603	0.3711	0.3799	0.3350	0.2615	0.2783	0.3079	0.3024	0.2629	0.2699	0.3141	0.3114	0.3360	0.3272	0.3159
Málaga	0.1510	0.1522	0.1454	0.2232	0.2785	0.2795	0.1997	0.1017	0.1104	0.2052	0.1916	0.1150	0.1050	0.1176	0.1433	0.1458	0.1548	0.1659
MP Pontevedra	0.2480	0.2171	0.2108	0.2020	0.1852	0.1888	0.1581	0.1564	0.1736	0.1663	0.1692	0.1761	0.1823	0.1970	0.2036	0.2053	0.1951	0.1905
Melilla	0.1323	0.1226	0.1202	0.1340	0.1380	0.1218	0.1727	0.1892	0.1975	0.2000	0.2314	0.2272	0.2278	0.2429	0.2625	0.2567	0.2277	0.1885
Motril	na	na	na	0.4272	0.3896	0.3663	0.3170	0.2589	0.2537	0.2824	0.2368	0.2364	0.2482	0.2535	0.2743	0.2653	0.3122	0.2944
Pasaia	0.3073	0.3413	0.3298	0.3157	0.3212	0.3062	0.2881	0.2196	0.2362	0.1980	0.1944	0.1908	0.2303	0.2501	0.2320	0.2083	0.2273	0.2586
SC Tenerife	0.5521	0.5649	0.5738	0.5852	0.5848	0.5892	0.5230	0.4539	0.4640	0.4494	0.4502	0.4303	0.4122	0.4208	0.4204	0.3848	0.3661	0.4838
Santander	0.2536	0.2416	0.2696	0.2912	0.2577	0.2768	0.2531	0.1990	0.2309	0.2405	0.2441	0.2319	0.2517	0.2708	0.2440	0.2828	0.3035	0.2555
Sevilla	0.3112	0.3174	0.2644	0.2897	0.3170	0.2790	0.2490	0.2454	0.2328	0.2412	0.2428	0.2424	0.2416	0.2644	0.2833	0.2610	0.2613	0.2673
Tarragona	0.8054	0.7848	0.8163	0.8032	0.8084	0.9310	0.7387	0.6543	0.6735	0.6690	0.6721	0.5604	0.6490	0.6872	0.6603	0.7265	0.6679	0.7240
Valencia	0.6573	0.6816	0.7039	0.6874	0.6861	0.6939	0.6969	0.7143	0.8158	0.7770	0.7939	0.6987	0.7114	0.7540	0.7198	0.7313	0.7840	0.6922
Vigo	0.1350	0.1401	0.1381	0.1364	0.1378	0.1454	0.1276	0.0949	0.1013	0.1063	0.0999	0.0985	0.0965	0.1021	0.0985	0.1005	0.1033	0.1154
Vilagarcía A	0.2062	0.2272	0.2019	0.2099	0.2126	0.2166	0.1205	0.1018	0.0826	0.0821	0.0932	0.0827	0.0956	0.1050	0.1037	0.1153	0.1203	0.1398
Average	0.4504	0.4491	0.4660	0.4866	0.4851	0.4867	0.4410	0.3743	0.3845	0.3987	0.4207	0.4035	0.4076	0.4439	0.4468	0.4726	0.4826	0.4411

D.4 Technical efficiency per port and year using DEA-VRS

Table D.4 Technical efficiency using DEA with variable returns to scale

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Average
A Coruña	0.4924	0.4810	0.5067	0.5932	0.5436	0.5446	0.4409	0.4073	04080	0.4014	0.4459	0.3945	0.4156	0.4816	0.4669	0.5161	0.5249	0.4744
Alicante	0.1692	0.1823	0.1619	0.1717	0.1742	0.1757	0.1330	0.1142	0.1137	0.1152	0.1147	0.1103	0.1233	0.1357	0.1915	0.2039	0.1834	0.1514
Almería	0.5148	0.5457	0.5840	0.6509	0.5662	0.5825	0.5105	0.3736	0.5025	0.4697	0.5211	0.4695	0.4850	0.5417	0.4760	0.5607	0.6150	0.5276
Avilés	0.3285	0.3758	0.4050	0.3993	0.5181	0.4897	0.4290	0.3184	0.3627	0.4518	0.4848	0.4479	0.4598	0.4910	0.4818	0.4438	0.4454	0.4313
B. Algeciras	1	0.9680	1	0.9467	0.9794	1	0.7466	0.7573	0.7901	0.8035	0.9280	0.9858	1	0.9912	1	0.9872	1	0.9343
B. Cádiz	0.1789	0.1838	0.2120	0.2280	0.2269	0.2916	0.1807	0.1436	0.1426	0.1529	0.1435	0.1400	0.1458	0.1326	0.1412	0.1564	0.1528	0.1737
Baleares	0.4027	0.4302	0.4616	0.5310	0.5899	0.6134	0.5721	0.5035	0.5144	0.5183	0.5339	0.5423	0.5979	0.6143	0.6771	0.7167	0.7624	0.5636
Barcelona	0.5350	0.5766	0.6175	0.7169	0.8009	0.8315	0.8169	0.7682	0.7509	0.7761	0.8156	0.8240	0.8751	0.9040	0.9027	1	1	0.7948
Bilbao	0.5155	0.5365	0.6204	0.6340	0.7629	0.7884	0.7537	0.7025	0.6694	0.6017	0.5466	0.5649	0.5837	0.6321	0.6077	0.6860	0.7104	0.6421
Cartagena	0.8084	0.7821	0.9094	1	0.8826	0.8150	0.7869	0.6206	0.5833	0.6592	0.8937	0.8858	0.9701	1	0.9449	1	0.9788	0.8542
Castellón	1	0.8279	0.8852	1	0.8057	0.6113	0.6380	0.4754	0.5251	0.5352	0.5216	0.5547	0.6634	0.7033	0.7354	0.8069	0.9498	0.7199
Ceuta	0.3527	0.3190	0.3133	0.3085	0.3576	0.4814	0.5843	0.4104	0.3834	0.3905	0.3911	0.3653	0.3534	0.3382	0.3624	0.3655	0.3690	0.3792
Ferrol SC	0.8688	0.7984	0.8588	0.8515	0.8291	0.7726	0.7935	0.6684	0.5385	0.6320	0.7456	0.7583	0.7928	0.8092	0.8096	0.9086	0.9031	0.7845
Gijón	0.9685	0.9041	0.9210	1	0.9708	0.9703	0.8672	0.6406	0.6936	0.6770	0.7757	0.8075	0.8652	0.8356	0.8382	1	0.9712	0.8651
Huelva	0.8143	0.9199	0.7993	0.8704	0.8785	0.8911	0.9566	0.7462	0.7962	0.9476	1	0.9163	0.9578	0.9521	1	1	1	0.9084
Las Palmas	0.3759	0.3903	0.4007	0.4110	0.4100	0.4090	0.3696	0.3199	0.3381	0.3755	0.3523	0.3349	0.3518	0.3979	0.4140	0.4260	0.4398	0.3833
Málaga	0.1510	0.1522	0.1454	0.2232	0.3138	0.3184	0.1997	0.1017	0.1104	0.2052	0.1916	0.1150	0.1050	0.1176	0.1433	0.1458	0.1548	0.1703
MP Pontevedra	0.2480	0.2171	0.2108	0.2020	0.1852	0.1888	0.1581	0.1564	0.1736	0.1663	0.1692	0.1761	0.1823	0.1970	0.2036	0.2053	0.1951	0.1905
Melilla	0.1323	0.1226	0.1202	0.1340	0.1380	0.1218	0.1727	0.1892	0.1975	0.2000	0.2314	0.2272	0.2278	0.2429	0.2625	0.2567	0.2277	0.1885
Motril	na	na	na	0.4272	0.3896	0.3663	0.3170	0.2589	0.2537	0.2824	0.2368	0.2364	0.2482	0.2535	0.2743	0.2658	0.3126	0.2945
Pasaia	0.3073	0.3614	0.3359	0.3169	0.3224	0.3062	0.2881	0.2196	0.2362	0.1980	0.1944	0.1908	0.2303	0.2501	0.2320	0.2083	0.2273	0.2603
SC Tenerife	0.5622	0.5757	0.5869	0.5985	0.6004	0.6033	0.5425	0.4729	0.4813	0.4663	0.4636	0.4419	0.4216	0.4297	0.4386	0.4151	0.3970	0.4999
Santander	0.2541	0.2464	0.2780	0.3162	0.2722	0.2884	0.2548	0.2024	0.2323	0.2408	0.2444	0.2339	0.2523	0.2714	0.2462	0.2866	0.3093	0.2606
Sevilla	0.3112	0.3174	0.2644	0.2897	0.3170	0.2790	0.2490	0.2454	0.2328	0.2412	0.2428	0.2424	0.2416	0.2644	0.2833	0.2610	0.2613	0.2673
Tarragona	0.8823	0.8551	0.8942	0.8659	0.8704	1	0.8246	0.7162	0.7361	0.7394	0.7769	0.6449	0.7541	0.7972	0.7679	0.8446	0.7793	0.8088
Valencia	0.6841	0.7056	0.7342	0.7589	0.8346	0.8693	0.7746	0.7337	0.8243	0.8401	0.8588	0.8217	0.8168	0.8789	0.8941	0.9295	1	0.8211
Vigo	0.1350	0.1433	0.1385	0.1364	0.1480	0.1568	0.1381	0.1005	0.1086	0.1068	0.0999	0.0985	0.0965	0.1021	0.0985	0.1005	0.1033	0.1183
Vilagarcía A	0.2062	0.2272	0.2019	0.2099	0.2126	0.2166	0.1205	0.1018	0.0826	0.0821	0.0932	0.0827	0.0956	0.1050	0.1037	0.1153	0.1203	0.1398
Average	0.4889	0.4869	0.5025	0.5283	0.5322	0.5351	0.4864	0.4096	0.4207	0.4384	0.4649	0.4505	0.4755	0.4954	0.5000	0.5289	0.5392	0.4872

Appendix E

Chapter 5 Appendix

E.1 Evolution of the shares of the total cost components

Table E.1 Evolution of the shares of the total cost components

Year	s_i	s_k	s_l
2002	0.2471	0.3935	0.3595
2003	0.2573	0.3829	0.3598
2004	0.2637	0.3864	0.3500
2005	0.2592	0.3910	0.3498
2006	0.2755	0.3812	0.3433
2007	0.2870	0.3784	0.3346
2008	0.2988	0.3781	0.3232
2009	0.2808	0.3972	0.3221
2010	0.2861	0.4006	0.3133
2011	0.2913	0.4141	0.2945
2012	0.2797	0.4432	0.2771
2013	0.2688	0.4571	0.2742
2014	0.2625	0.4683	0.2692
2015	0.2754	0.4571	0.2675
2016	0.2717	0.4627	0.2656
2017	0.2821	0.4606	0.2573
2018	0.2782	0.4599	0.2619

E.2 Total investment in the Spanish port system in constant euros of 2018

Table E.2 Total investment in the Spanish port system in constant euros of 2018

Year	Total investment
2002	1,002,494,031
2003	1,209,212,811
2004	1,283,189,053
2005	1,346,981,999
2006	1,594,473,604
2007	1,489,820,879
2008	1,653,798,058
2009	1,439,734,235
2010	1,283,162,947
2011	852,624,245
2012	541,054,117
2013	492,216,995
2014	530,785,919
2015	676,508,716
2016	447,644,744
2017	455,196,339
2018	358,100,000

E.3 Economic efficiency per port and year

Table E.3 Economic efficiency per port and year

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Average
A Coruña	0.8723	0.8695	0.8667	0.8638	0.8609	0.8579	0.8548	0.8517	0.8485	0.8453	0.8420	0.8386	0.8352	0.8317	0.8281	0.8245	0.8208	0.8478
Alicante	0.9056	0.9035	0.9014	0.8992	0.8970	0.8947	0.8924	0.8901	0.8877	0.8852	0.8827	0.8801	0.8775	0.8749	0.8721	0.8694	0.8665	0.8871
Almería	0.9539	0.9528	0.9518	0.9507	0.9496	0.9484	0.9473	0.9461	0.9448	0.9436	0.9423	0.9410	0.9397	0.9383	0.9369	0.9355	0.9341	0.9445
Avilés	0.9923	0.9921	0.9919	0.9917	0.9915	0.9913	0.9911	0.9909	0.9907	0.9905	0.9903	0.9900	0.9898	0.9896	0.9893	0.9891	0.9888	0.9906
B. Algeciras	0.7143	0.7088	0.7031	0.6974	0.6915	0.6856	0.6796	0.6735	0.6674	0.6611	0.6548	0.6484	0.6419	0.6353	0.6286	0.6219	0.6150	0.6664
B. Cádiz	0.8952	0.8929	0.8906	0.8882	0.8857	0.8832	0.8807	0.8781	0.8754	0.8727	0.8699	0.8671	0.8642	0.8613	0.8583	0.8553	0.8522	0.8748
Baleares	0.8089	0.8050	0.8009	0.7968	0.7926	0.7883	0.7840	0.7795	0.7750	0.7704	0.7658	0.7610	0.7562	0.7513	0.7463	0.7413	0.7361	0.7741
Barcelona	0.6745	0.6684	0.6621	0.6558	0.6494	0.6429	0.6363	0.6297	0.6229	0.6161	0.6092	0.6022	0.5952	0.5880	0.5808	0.5735	0.5661	0.6220
Bilbao	0.8018	0.7977	0.7936	0.7893	0.7850	0.7805	0.7761	0.7715	0.7669	0.7621	0.7573	0.7524	0.7475	0.7424	0.7373	0.7321	0.7268	0.7659
Cartagena	0.8342	0.8306	0.8271	0.8234	0.8197	0.8159	0.8121	0.8081	0.8041	0.8001	0.7959	0.7917	0.7874	0.7831	0.7786	0.7741	0.7695	0.8033
Castellón	0.9029	0.9007	0.8985	0.8963	0.8940	0.8917	0.8893	0.8869	0.8844	0.8819	0.8793	0.8767	0.8740	0.8713	0.8685	0.8656	0.8627	0.8838
Ceuta	0.9257	0.9241	0.9224	0.9207	0.9189	0.9171	0.9152	0.9133	0.9114	0.9095	0.9074	0.9054	0.9033	0.9012	0.8990	0.8968	0.8945	0.9109
Ferrol SC	0.9494	0.9483	0.9471	0.9459	0.9447	0.9434	0.9421	0.9408	0.9395	0.9381	0.9368	0.9353	0.9339	0.9324	0.9309	0.9293	0.9277	0.9392
Gijón	0.8915	0.8892	0.8867	0.8843	0.8817	0.8792	0.8765	0.8738	0.8711	0.8683	0.8655	0.8626	0.8596	0.8566	0.8535	0.8503	0.8471	0.8704
Huelva	0.7911	0.7868	0.7824	0.7780	0.7735	0.7689	0.7642	0.7594	0.7545	0.7496	0.7446	0.7395	0.7343	0.7291	0.7237	0.7183	0.7128	0.7536
Las Palmas	0.7606	0.7558	0.7509	0.7459	0.7408	0.7357	0.7304	0.7251	0.7197	0.7142	0.7086	0.7030	0.6972	0.6914	0.6855	0.6795	0.6734	0.7187
Málaga	0.8467	0.8434	0.8401	0.8367	0.8332	0.8297	0.8261	0.8224	0.8187	0.8149	0.8110	0.8071	0.8030	0.7990	0.7948	0.7906	0.7862	0.8179
Motril	na	na	na	0.9924	0.9922	0.9920	0.9919	0.9917	0.9915	0.9913	0.9911	0.9909	0.9907	0.9904	0.9902	0.9900	0.9898	0.9911
SC Tenerife	0.8738	0.8711	0.8683	0.8654	0.8625	0.8596	0.8565	0.8535	0.8503	0.8471	0.8438	0.8405	0.8371	0.8337	0.8302	0.8266	0.8229	0.8496
Santander	0.8789	0.8763	0.8736	0.8709	0.8681	0.8652	0.8623	0.8593	0.8563	0.8532	0.8501	0.8469	0.8436	0.8403	0.8369	0.8334	0.8299	0.8556
Sevilla	0.9451	0.9438	0.9426	0.9413	0.9400	0.9386	0.9372	0.9358	0.9344	0.9329	0.9314	0.9298	0.9283	0.9267	0.9250	0.9233	0.9216	0.9340
Tarragona	0.8202	0.8165	0.8126	0.8087	0.8047	0.8007	0.7965	0.7923	0.7880	0.7837	0.7792	0.7747	0.7701	0.7655	0.7607	0.7559	0.7510	0.7871
Valencia	0.6585	0.6521	0.6456	0.6391	0.6325	0.6258	0.6190	0.6121	0.6052	0.5981	0.5910	0.5838	0.5766	0.5692	0.5618	0.5543	0.5468	0.6042
Vigo	0.7538	0.7489	0.7439	0.7388	0.7336	0.7283	0.7229	0.7175	0.7120	0.7064	0.7007	0.6949	0.6891	0.6831	0.6771	0.6710	0.6648	0.7110
Average	0.8457	0.8425	0.8393	0.8425	0.8393	0.8360	0.8327	0.8293	0.8259	0.8223	0.8188	0.8152	0.8115	0.8077	0.8039	0.8001	0.7961	0.8251

Appendix F

Chapter 6 Appendix

F.1 Hausman test results

Table F.1 Hausman test results for the extended and reduced sample

Market	FE	RE	χ^2	p-value	Selected Estimation
$Othercargo_{ext}$	-0.0023	-0.0058	2.37	0.1239	RE
$Othercargo_{red}$	0.0135	0.0119	0.30	0.5855	RE
$Containers_{ext}$	-0.9028	-0.9174	24.38	0.0000	FE
$Containers_{red}$	-0.4759	-0.5766	17.82	0.0000	FE
$TContainers_{ext}$	-1.5617	-1.6126	0.71	0.3993	RE
$TContainers_{red}$	-1.0015	-1.2670	3.37	0.0665	RE
$Liquids_{ext}$	-0.2376	-0.2714	59.32	0.0000	FE
$Liquids_{red}$	-0.3071	-0.3069	0.00	0.9824	RE
$Passengers_{ext}$	-0.7640	-0.7778	1.60	0.2055	RE
$Passengers_{red}$	-0.7234	-0.6922	1.79	0.1809	RE

Table F.2 Hausman test results for the different coastlines

Market	FE	RE	χ^2	p-value	Selected Estimation
Northern coastline					
$Othercargo_{ext}$	-0.0410	-0.0409	0.04	0.8450	RE
$Containers_{ext}$	-0.8808	-0.8854	0.79	0.3750	RE
$Liquids_{ext}$	-0.0863	-0.1301	46.70	0.0000	FE
$Passengers_{ext}$	-0.4987	-0.4885	0.40	0.5261	RE
South and East coastline					
$Othercargo_{ext}$	-0.0132	-0.0166	0.91	0.3404	RE
$Containers_{ext}$	-0.9478	-0.9572	7.91	0.0049	FE
$Liquids_{ext}$	-0.2480	-0.2719	15.89	0.0001	FE
$Passengers_{ext}$	-0.8888	-0.8855	0.23	0.6335	RE