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ORIGINAL ARTICLE

A dynamic view of the socioeconomic significance of ports

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Abstract This paper presents a methodology for the provision of a dynamic view on the economic role of ports by means of input–output analysis. The focus is on assessing the role of ports as a source of market expansion for firms located in the hinterland, particularly for export-oriented firms. Structural change in the economy is accounted for by incorporating a bi-proportional matrix adjustment technique in the general input–output framework. By assessing yearly impact changes encompassing a number of years, the outcome of the proposed methodology can serve as a decision support tool for transport policy decision makers, namely by incorporating results in predictive models making use of econometric techniques. Additionally, it allows ex-ante evaluations of port-related investments. By relying on data regularly collected by regional or national statistical offices, the proposed methodology provides a generally applicable and transparent framework for assessing the economic role of ports in their respective hinterland, while also allowing for comparisons between ports and across time. An application of the proposed methodology is illustrated by evaluating the economic significance of exports moving through the Portuguese port system.

Keywords Input–output analysis · Port socioeconomic impact studies · Maritime exports economic impacts · Port development · Economic growth · Dynamic analysis of port impacts

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Introduction

Ports are often considered to play a key role in regional economic development, particularly where growth is dependent on imports and exports (Moon 1995; Suykens and Van De Voorde 1998). Such role is typically assessed by means of port impact studies, most often through input–output analysis (Bryan et al. 2006; Dooms et al. 2015; Francou et al. 2007). On the one hand, port authorities have traditionally made use of such studies to demonstrate the contribution of ports to the regional economy, with the aim of increasing societal acceptance of port activity and motivate requests for public funding. On the other hand, the outcome of port impact studies—such as, for instance, the quantification of gross value added or employment directly attributable to port activity—has been used by government agencies responsible for port planning and development, to decide on capital budgeting, resource allocation, or the granting of regulatory permits allowing the implementation of port projects (Danielis and Gregori 2013; Dooms et al. 2015).

Criticisms to port economic impact studies

Despite their widespread use, the evaluation of the economic role of ports is fraught with difficulties and such studies have traditionally met with severe criticism. Some of the most frequent criticisms include:

- the lack of a unified approach, with differences in adopted methodologies rendering comparisons meaningless (Dooms et al. 2015);
- overestimation of impacts due to the inclusion of effects with unproven causality (De Jong and Van Wee 2007; Hall 2004; Mackie and Preston 1998);
- port impact studies, being commonly sponsored by port authorities, are often used as mere public relations tools, lacking scientific rigour (Waters 1977);
- static input–output analysis is unable to accommodate structural change in the economy and, therefore, is an inadequate tool for port planning purposes (Hall 2004; Waters 1977);
- procedures for assessing the economic and social impacts of ports are often obscure to most stakeholders and decision makers (Musso et al. 2007);
- most economic impact studies are commissioned to support a political position rather than to search for economic truth (Crompton 2006);
- structural changes in the economy have led port impact studies to become more accurate in estimating the relatively unimportant and declining direct employment and other benefits of cargo-handling activities, but at the same time they have become increasingly unreliable at estimating the much more significant and growing economic contributions that are represented by the cargo itself (Hall 2004).

Such criticisms have led to a loss of credibility of port authorities putting forward such studies, a decrease in stakeholder commitment (Dooms et al. 2015), and a generalized distrust of input–output analysis in being able to provide useful inputs to port planning policy makers (Hall 2004; Musso et al. 2007).

To overcome some of these criticisms, Dooms et al. (2015) formulate some general guidelines for a generally applicable and methodologically sound approach, which has been lacking thus far. The authors' approach focuses on local socioeconomic impact calculation (i.e. restricted to the port area). However—as acknowledged by the authors themselves—adopting a regional perspective, as emphasized by Notteboom and Rodrigue (2005), and determining the true extension of the benefits passed on to users in the hinterland, is more appropriate for strategic planning purposes. Moreover, only the adoption of a systemic perspective of port impacts and infrastructure investments allows for efficient port pricing and subsidizing schemes as noted, e.g. in Haralambides et al. (2001) and Santos et al. (2016).

The need for a dynamic view on socioeconomic impacts

It is widely accepted that a methodology providing useful guidance for port planning must be able to ascertain the incremental effects of changes in public investments (Chang 1978; Dooms et al. 2015; Waters 1977). Indeed, only a dynamic view on port impacts could enable the identification of the underlying causal mechanisms between port development and economic growth. In this regard, it is generally acknowledged, for instance, that the present socioeconomic significance of a port is the result of investments made over the course of a number of years in the past (Dooms et al. 2015). This makes it necessary for the analysis to encompass a minimum number of years, if the outcome of such analysis is to be used for planning purposes (Yochum and Agarwal 1988).

However, as stated above, one of the most relevant criticisms to port impact studies making use of input–output analysis derives from their static nature, particularly from the assumption of stable technology, industrial structure and demand characteristics (Waters 1977). Additionally, most port impact studies do not accommodate the changing nature of the relationship between ports and regional development (Hall 2004). Acknowledging such a drawback of conventional input–output analysis, Chang (1978) argues that periodic updating of impact studies helps in overcoming their static nature and in understanding the changing relationship between port and regional economy.

An alternative to periodic updating of static studies, as proposed by Chang (1978), would be to resort to an approach making use of dynamic input–output analysis, where capital stock items are incorporated in the model through the use of capital coefficients, in order to calculate the impacts for the coming years (for details on the dynamic input–output model, the reader is referred to Miller and Blair 2009). However, dynamic input–output analysis is incapable of providing results which approach smoothly those of the static analysis, and is inadequate for describing the actual process of economic development and change (Kurz and Salvadori 2000). As such, this paper shares the view of Chang (1978) and proposes a methodology which provides a dynamic view of the economic significance of a port, by yearly updating static input–output analysis. Given the possibility of structural change in the economy during the time period under review, a bi-proportional matrix adjustment technique—in particular the RAS approach—is incorporated in the proposed methodology, as suggested by Moon (1995).

The role of exports in economic growth

A last point to clarify concerns the definition of the impacts to be calculated, in order to determine the socioeconomic significance of ports.

While many port impact studies still focus their attention on the impacts directly attributable to industry located within the port's geographical boundaries (Bryan et al. 2006), many ports have lost their industrial role due to containerization and increasing mechanization, having become mere transit points (Dooms et al. 2015; Gripaios and Gripaios 1995). On the other hand, the main mission of a maritime commercial port is to facilitate trade and act as an element in a value-driven chain system (Notteboom and Rodrigue 2005). Taking these two facts into account, it seems more appropriate to investigate the role of ports in regional economic development by assessing the economic benefits associated with the cargo moving through them (i.e. by assessing the impacts deriving from market expansion of port users) rather than focusing attention on the port industry per se. In other words, taking into account that ports are essentially trade-facilitating infrastructures, the focus should be on investigating their role as a source of reduced transportation costs, thus ensuing industry expansion in the hinterland by determining the benefits associated with the cargo itself (Boske and Cuttino 2003). Moreover, research consistently shows that the economic benefits for port user industries—i.e. exporting and importing firms—far surpass those of the port industry (Yochum and Agarwal 1988; Hall 2004).

Additionally, the political and economic justification for the expansion or improvement of transport infrastructures is always the demand from firms wishing to make use of the port as part of their supply chain (Randall 1988). To put it differently, it is always the demand from port users that ultimately serves to justify resource allocation in port expansion, and not the direct activity of cargo-handling services or other port-related industry or services per se. Thus, when judging the merits of a given port project, it seems appropriate to focus the attention on the socioeconomic impacts associated with the cargo handled at the ports, rather than on the direct impacts of the cargo-handling activities and related services.

Lastly, a clarification must be made concerning the type of cargo to be considered in impact calculations. While establishing the linkage between imports and economic growth entails a distinction to be made between competitive and non-competitive imports (Moon 1995), highly significant positive correlation between an economic growth variable and some variant of export growth has been observed in a considerable amount of research making use of *ordinary least squares* regression on cross-sectional and time series data (Michaely 1977; Balassa 1978; Heller and Porter 1978; Tyler 1981; Feder 1983; Kavoussi 1984). Indeed, some authors warn against the possible negative impacts of ports on regional economic development due to facilitating imports, which can thus compete more effectively with local producers, with a deleterious impact on regional employment (Goss 1990). In turn, concerning exports, there is general consensus regarding the positive effects, deriving from increased port development and increased port efficiency, on market expansion and economic development (Davis 1983; Dooms et al. 2015; Goss 1990;

Yochum and Agarwal 1988). For this reason, while acknowledging the need to incorporate the effect of imports in a future development, the methodology proposed in this paper focuses on the role of exports, moving through ports, on regional economic development.

Additionally, it should be noted that while the aim here is to assess the role of cargo moving through ports in economic growth, this does not equate to saying that all firms exporting through the port would cease to exist should the port become unavailable. Rather, it is admitted here that a significant part of such firms would find alternative routes to other shipping points for their trade flows should the port under analysis become unavailable (Davis 1983; Hall 2004). On the other hand, it should also be mentioned that, at least in the long-run, port unavailability would have some deleterious consequences on the economic activity in the hinterland. However, the direct quantification of such negative impact is not the aim here, but rather to provide policy makers with a dynamic view on the linkage between port development and economic growth.

By providing a dynamic view on the economic benefits deriving from export production moving through ports, the proposed methodology should allow for a better understanding of the role of port investments in market expansion for export-oriented firms.

The proposed methodology makes use of data collected from public agencies in a systematic manner, applied to all ports in a given region, thereby avoiding the introduction of subjective judgments by researchers, such as those seen in port impact studies, ascertaining the degree of dependence of firms on the existence of ports (see, for instance, Artal-Tur et al. 2015). This allows the fulfilment of the requirements voiced by Dooms et al. (2015) concerning the need for a generally applicable framework, aiming at increasing transparency and a clear definition of methods in calculating the economic benefits of ports. Moreover, the proposed methodology provides a dynamic view of ports' economic role, enabling a more valuable interpretation of data and related predictions. Predictive models—e.g. by making use of the results of our methodology for purposes of econometric modelling, as suggested by Francou et al. (2007)—can also prove valuable as a decision support tool for policy decision makers concerned with port planning and development.

Organization of the paper

The paper is organized in the following manner: the following section is a literature review, including research focusing on port socioeconomic impacts, as well as research addressing methodological issues in impact studies in general. Thereafter, our methodology is presented, including the data collection process and an overview of the RAS method. The section that follows presents an application of the proposed methodology to a port system and finally we present our conclusions and directions for future research.

Literature review

While research on the economic impacts of the port industry, including discussion of methodological aspects is available (e.g. Bryan et al. 2006; Chang 1978; Dooms et al. 2015; Gripaios and Gripaios 1995; Waters 1977), literature concerning the formal quantification of port impacts on regional development is scarce. Additionally, given that such assessments are usually conducted for a single port and over a limited range of impacts, the role of ports in economic development has been difficult to assess (Rodrigue et al. 2013).

Waters (1977) calls attention to some of the major shortcomings of port impact studies, and argues that the static nature of input–output analysis—including the assumption of stable technology—makes it an inadequate tool for port planning. To this, Chang (1978) responds that, while impact studies are static, periodic updating of such studies helps in understanding the changing relationship between the port and the regional economy. Acknowledging the limitations of conventional dynamic input–output analysis, including its incapability both in providing results which approach smoothly to those of the static analysis and in describing the actual process of economic development and change (Kurz and Salvadori 2000), this paper shares the view of Chang (1978) and proposes a methodology that provides a dynamic view of the economic significance of a port by making use of yearly updating of static input–output analysis.

Francou et al. (2007) acknowledge that port economic impact studies, made for a single year, cannot be used for planning. However, when such studies are available at different points in time, they can be useful in assessing the merits of an investment plan, or to check the validity of the benefit predictions resulting from other approaches such as, for instance, cost–benefit analysis. The methodology proposed in this paper is in line with Francou et al. (2007), as regards the need for a dynamic view on the economic significance of ports, when the aim is to use the results as inputs to port planning.

Yochum and Agarwal (1988) and Warf and Cox (1989) attempt to provide a dynamic point of view on port impacts by making use of two static studies, for the same port, under the same methodology. This provides a more valuable interpretation of the results—namely by relating changes in impacts to port investments made in previous years—and attempted predictions, for instance, by combining impact studies results with econometric modelling techniques. Our methodology is largely in line with that proposed by the referred authors, in that it enables a quantitative yearly analysis of the benefits of ports. However, our paper deviates from the view of Yochum and Agarwal (1988) and Warf and Cox (1989) in that, here, the economic benefits of ports are assessed in terms of market expansion for port users, rather than focusing the analysis on the port industry *per se*. Furthermore, Yochum and Agarwal (1988) and Warf and Cox (1989) call attention to the errors associated with the dynamic input–output analysis, given its inadequacy to account for external factors such as changes in business productivity, changes in regulation and currency exchange rates. Despite the fact that this observation was made some 20 years ago, the deficiencies of the dynamic input–output model are yet to be solved in a satisfactory manner. To overcome this, yearly updating of impact analysis makes use of a bi-proportional matrix adjustment technique as in Moon (1995).

Moon (1995) assesses the adequacy of input–output analysis as a predictive tool for port planning. The author uses the RAS technique to project the input coefficient matrix and obtain a forecast of the economic impact of a port. Similarly to Moon (1995), our methodology also uses the RAS approach to incorporate structural change. However, while Moon (1995) assesses the economic significance of ports by focusing on the impacts on port industry, we take the view of Goss (1990), Gripaios and Gripaios (1995), Hall (2004) and Randall (1988), who argue that the most significant economic benefits from ports leak to users in inland locations.

Indeed, most port economic impact studies are based on expenditure surveys. Such surveys assess the expenditures made by the suppliers of transport services. This results in an estimate of regional income that is generated by port-related expenditures. However, Waters (1977) calls attention to a significant drawback of the expenditure approach, made clear through an analysis of the increasing dominance of containerization. As the author states, the direct expenditure per ton of cargo at port level has decreased significantly, a fact which, at first sight, might suggest a decrease in the impact of ports on the regional economy. However, containerization has decreased the through cost of handling in transportation, resulting in the expansion of competitive markets for many products, both foreign and domestic. The increased competition has held prices down and increased the number and volume of products available for consumption. This has led to a real increase in regional incomes, while direct employment—i.e. employment in ports—per ton, has declined. As such, an appreciation of a port's economic significance based solely on the direct impacts of port industry is deemed insufficient.

Indeed, already in 1995, Gripaios and Gripaios (1995) argued that, as a consequence, inter alia, of containerization and increasing mechanization, ports were no longer vast and interrelated arrays of industrial complexes making extensive use of labour. Additionally, more recent research shows that the impacts of direct port activity, particularly employment per ton of cargo, have been consistently decreasing due to, among other factors, the adoption of automated cargo-handling systems and technology in ports, re-location of former port-related industries and shifts from local to international inputs (Dooms et al. 2015; Hall 2004; Musso et al. 2000).

While agreeing with Gripaios and Gripaios (1995) with respect to the changing nature of the port industry, with the resulting decrease in direct impacts, this paper deviates from the referred authors with respect to the role of ports in economic development. The continued decrease in the direct impacts of the port industry, resulting from structural changes in the port industry (Musso et al. 2000) does not necessarily mean that ports play a less significant role in the economic development, as claimed by Gripaios and Gripaios (1995). In fact, precisely the opposite seems to be the case, with the increasing economic significance of a port's hinterland, as argued by Goss (1990) and Hall (2004). This paper aligns with the view of Goss (1990) and Hall (2004), and proposes a methodology for assessing the economic significance of ports by focusing on port users, namely, in terms of their market expansion. Such market expansion is evaluated in terms of the temporal evolution of exports moving through the port.

Lastly, Hall (2004) calls attention to the fact that very few countries or regions collect or compile socioeconomic impact studies conducted for seaports in a systematic way. The difficulties associated with the data collection process, for determining direct impacts, are overcome in the methodology proposed here by making use, exclusively, of data on cargo moving through ports, which is yearly collected by regional or national statistical offices.

Next section presents the proposed methodology, including a brief overview of input–output analysis and the RAS technique, as well as the data collection process.

Input–output analysis and bi-proportional matrix adjustment techniques

Theoretical background

Let $\mathbf{x}$ be a column vector of dimension n containing the total gross output of each sector, while $\mathbf{I}$ is the identity matrix, $\mathbf{A}$ is the matrix of input coefficient and $\mathbf{f}$ is the vector of exogenous demand. Equation (1), where $\mathbf{L}$ is the Leontief inverse or total-requirements matrix, allows the estimation of output requirements $\mathbf{x}$, following a given exogenous demand $\mathbf{f}$:

$$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{f} = \mathbf{Lf} \tag{1}$$

Admitting that matrix $\mathbf{A}$ is derived from input–output data of year t, while the aim is to assess the impacts of a given demand occurring at time $t \pm s$, Eq. (1) can be changed to:

$$\mathbf{x}(t+s) = [\mathbf{I} - \mathbf{A}(t)]^{-1}\mathbf{f}(t+s) = \mathbf{L}(t)\mathbf{f}(t+s) \tag{2}$$

Using Eq. (2) it is admitted that no significant structural change has occurred in the economy between the years t and $t + s$, and, therefore, that matrix $\mathbf{A}$ remains valid for year $t + s$. Although some literature suggests that input–output tables may remain useful for a number of years (Carter 1970), Miller and Blair (2009) warn that the use of outdated tables can produce considerable error. However, the methodologies for producing input–output tables describing relationships between inputs and outputs for a particular economy, commonly entail the undertaking of large-scale surveys to firms. In general, this process is very expensive and time-consuming, often leading to a significant time lapse between the release of two consecutive input–output tables, usually in the order of five or more years.

The inexistence of input–output tables for a considerable period of time poses the problem of updating the last known technical coefficient matrix.

A common procedure for updating input coefficient, by filling in missing data, is to use a bi-proportional matrix adjustment technique (Leontief 1941; Stone et al. 1942; Stone 1961, 1962; Stone and Brown 1962).

To illustrate the application of a bi-proportional adjustment technique, consider a known square matrix $\mathbf{Z}$, corresponding to a matrix of input–output transactions for a given year, possibly obtained through industry surveys. Additionally, consider an unknown 'target' matrix $\mathbf{Z}^*$ corresponding to another year, for which only the margins (the row and column sums) are known. The objective is to estimate a matrix $\tilde{\mathbf{Z}}$ which has the same dimension, mathematical properties and margins as $\mathbf{Z}^*$:

$$\sum_{i=1}^{n} Z_{ij}^{*} = \sum_{i=1}^{n} \tilde{Z}_{ij} \tag{3}$$

$$\sum_{j=1}^{n} Z_{ij}^{*} = \sum_{j=1}^{n} \tilde{Z}_{ij} \tag{4}$$

Bi-proportional adjustment techniques allow determining $\tilde{\mathbf{Z}}$ by making use of the structure of $\mathbf{Z}$, once the row and column totals of $\mathbf{Z}^*$ are known.

A particular matrix adjustment technique, commonly referred to as the RAS approach, originally proposed by Stone (1962) and Stone and Brown (1962) is used here. For details on the RAS approach, the reader is referred to Lahr and de Mesnard (2004), Miller and Blair (2009), Stone (1962) and Stone and Brown (1962).

The RAS approach presents two main advantages when compared to competing matrix adjustment techniques. First, it is a simple algorithm, ensuring a non-negative solution. Second, the amount of data required is minimal, compared to its output. In particular, for an economy consisting of n sectors, this technique generates an estimate of the n^2 technical coefficients from $3n$ pieces of information for the target year. In particular, such pieces of information are: total gross outputs, $\mathbf{x}$; total intermediate sales, $\mathbf{u}$; and total intermediate purchases, $\mathbf{v}$.

The RAS algorithm can succinctly be written as:

$$\tilde{\mathbf{A}}(t+s) = \hat{\mathbf{r}}A(t)\hat{\mathbf{s}}, \tag{5}$$

where $\tilde{\mathbf{A}}$ is the estimated input coefficient matrix and $\hat{\mathbf{r}}$ and $\hat{\mathbf{s}}$ are the row and column modifiers, respectively.

Once matrix $\tilde{\mathbf{A}}$ has been estimated, the impacts deriving from a given exogenous demand in the target year can be calculated in the usual manner, as in Eq. (1), by substituting $\mathbf{L}$ by $\mathbf{L} = (I - \tilde{\mathbf{A}})^{-1}$.

Data collection

In port economic impact studies, the collection of data on primary impacts is one of the most critical steps and also one of the most relevant sources of error. At least two considerable difficulties are commonly faced in this process. First, the researchers must identify the firms whose business is related to the port. If for some firms, such as stevedoring companies, this is a relatively straightforward process, for other firms, of smaller dimension or in a remote location from the port, the task is more difficult. Second, after the identification process is concluded, the researchers must ascertain the degree of dependency of such firms on the port. This introduces further difficulty and subjectivity (Yochum and Agarwal 1988; Crompton 2006; Hall 2004).

If the data to be used are collected in a systematic and transparent manner by an independent public agency in a yearly fashion for all ports within the region, then the subjectivity in the data collection process is largely, if not entirely, surpassed.

The necessary data for the application of the proposed methodology are: (i) the exports value and volume by productive sector moving through each port for each target year, (ii) total gross outputs, total intermediate sales and total intermediate purchases for the target year, and (iii) an input–output table for a year that is as close as possible to the target year. All such data are usually available from national or regional statistical offices. Our approach greatly increases the reliability of comparisons, not only between ports, but also across time, when data for different years are used (for instance, when the study is used to evaluate the outcome of a port investment plan).

Next section illustrates the application of the proposed methodology for the Portuguese port system.

Application of the proposed methodology

The methodology developed above was applied to the Portuguese port system for the years between 2005 and 2014.

As detailed above, economic benefits are appreciated here in terms of market expansion of firms, by assessing the evolution, through time, of the economic significance of exports moving through ports. To this end, data for each economic sector, on the value and volume of exports moving through each port were collected for each of the four main Portuguese ports: Leixões, Lisbon, Setubal and Sines. Quantification of investments in ports and related infrastructure is not the subject of this paper. However, results obtained using the present methodology, combined with the knowledge of the timing and size of such investments, should allow a clarification of the linkage between such investments and regional economic growth, namely, regional gross value added and employment.

Economic and industrial features of the Portuguese port system

The Portuguese port system consists of seven main ports: Viana do Castelo, Leixões, Aveiro, Figueira da Foz, Lisbon, Setúbal and Sines. These ports constitute the Portuguese port range, understood as a multi-port gateway system, being characterized by a relatively low level of interport competition (Santos et al. 2015; Santos and Guedes Soares 2017). While the Portuguese port system mainly serves a geographic hinterland in close proximity to the ports, its influence is gradually extending towards neighbouring regions in Spain, in what constitutes a typical example of a port regionalization process (Santos and Guedes Soares 2017).

The vast majority of traffic moving through Portuguese ports concerns international trade, which amounts to approximately 85% of the total traffic. Together, the Portuguese ports handle approximately 60% of the country’s international trade, in terms of volume, and approximately 30% in terms of value. Tables 1, 2, 3 and 4 provide an overview of both imports and exports handled

Table 1 Imports volume in Portuguese ports (million tons). *Source* INE, Statistics Portugal, International Trade Statistics (2005–2014, 2015)

Port	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Viana do Castelo	0.308	0.278	0.276	0.218	0.160	0.253	0.147	0.113	0.159	0.427
Leixões	7.914	7.761	8.070	8.603	7.523	7.396	8.318	7.578	7.829	8.179
Aveiro	2.391	2.235	1.734	1.719	1.220	1.791	1.577	1.443	1.690	1.891
Figueira da Foz	0.350	0.448	0.475	0.499	0.518	0.715	0.651	0.710	0.924	0.448
Lisboa	7.271	6.418	7.166	6.853	6.364	6.604	6.573	5.642	5.543	6.242
Setúbal	3.408	2.830	3.010	2.267	2.329	2.503	2.427	1.836	2.229	3.357
Sines	18.364	19.478	18.383	17.086	16.828	15.970	16.495	17.657	20.375	18.903
Portugal[a]	40.863	40.150	39.716	37.871	35.616	35.817	36.781	35.590	39.217	41.069

[a] All ports, including minor ports not listed in the table

Table 2 Exports volume in Portuguese ports (million tons). *Source* INE, Statistics Portugal, International Trade Statistics (2005–2014, 2015)

Port	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Viana do Castelo	0.065	0.088	0.102	0.114	0.108	0.172	0.272	0.330	0.289	0.306
Leixões	2.465	2.700	2.924	3.304	2.977	2.948	4.073	4.971	4.958	5.250
Aveiro	0.828	1.027	1.362	1.620	1.447	1.380	1.350	1.494	1.875	2.148
Figueira da Foz	0.485	0.608	0.676	0.635	0.655	0.644	1.002	1.040	1.037	1.206
Lisboa	2.489	2.903	2.967	2.868	2.545	2.744	3.017	2.788	3.630	3.426
Setúbal	1.909	2.102	2.381	2.646	2.488	3.426	3.540	3.568	4.209	5.061
Sines	2.518	3.745	3.259	3.538	3.139	4.619	4.942	6.287	10.455	10.876
Portugal[a]	10.817	13.232	13.712	14.780	13.379	15.998	18.306	20.739	26.750	28.634

[a] All ports, including minor ports not listed in the table

through the main Portuguese ports in the period 2005–2014. Port of Sines is by far the most significant Portuguese port in terms of international trade, accounting for approximately 40% of total throughput between 2005 and 2014, followed by the port of Leixões (approximately 20%) and the port of Lisbon (15%). While the port of Sines is also the most significant port in terms of value of international trade, most definitely since 2010, a large share of the cargo handled is liquid bulk cargo (mainly products for the petroleum industry), whereas the most significant cargo both for Leixões and Lisbon is containerized cargo, which has typically a much higher value per ton than the typical liquid bulk cargo.

Figure 1 shows the most significant sectors, in terms of exports through the Portuguese ports, for the years 2005, 2010 and 2014. It can be seen that the manufacturing sector is the most significant, having accounted for approximately 78% of Portuguese exports handled by Portuguese ports in 2005, a share which rose to approximately 86% in 2014.

Table 3 Imports value in Portuguese ports, c.i.f., 2014 constant prices (million euros). *Source* INE, Statistics Portugal, International Trade Statistics (2005–2014, 2015)

Port	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Viana do Castelo	92.4	121.2	125.7	126.8	74.2	113.6	55.6	20.6	30.9	155.5
Leixões	4427.9	4769.6	5145.9	6339.5	4086.9	4946.8	6271.7	5743.0	5679.0	5627.4
Aveiro	1110.0	1169.9	1025.3	1219.8	457.3	743.2	826.9	718.0	783.8	808.3
Figueira da Foz	67.1	76.6	54.8	219.4	57.7	84.5	79.0	67.3	89.5	65.0
Lisboa	3787.8	3611.3	4642.5	5009.8	3841.4	4462.5	4665.1	3645.9	3421.2	3641.1
Setúbal	2453.1	2198.6	2387.8	1693.7	1660.5	1721.5	1633.5	1002.6	1198.2	2009.2
Sines	4518.7	5733.1	5680.6	6719.3	4647.7	6399.4	7614.9	7965.9	9144.3	7816.1
Total	16,457.0	17,680.3	19,062.6	21,328.3	14,825.8	18,471.5	21,146.5	19,163.3	20,346.9	20,122.5

Table 4 Exports value in Portuguese ports, f.o.b., 2014 constant prices (million euros). *Source* INE, Statistics Portugal, International Trade Statistics (2005–2014, 2015)

Port	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Viana do Castelo	30.1	61.2	110.8	100.8	97.4	124.6	180.0	210.6	223.6	275.9
Leixões	2709.9	2831.1	2063.6	2252.2	1998.4	2126.6	3043.1	3764.8	3574.7	3574.2
Aveiro	405.9	464.6	1132.9	1219.5	1261.8	1138.0	1123.6	1198.8	1407.8	1410.1
Figueira da Foz	252.5	320.9	349.1	352.6	314.0	328.8	450.8	484.3	472.3	549.3
Lisboa	2299.6	2574.6	2066.9	2407.0	1843.9	1873.2	2234.0	2106.5	2709.3	2489.4
Setúbal	2350.7	2923.2	3018.3	3123.2	2154.2	3675.8	3953.5	3499.8	3116.8	3795.3
Sines	1180.2	1860.5	1825.4	2064.4	1263.5	2434.9	3338.4	4331.8	6864.5	6456.4
Total	9228.8	11,036.1	10,567.0	11,519.7	8933.1	11,702.0	14,323.5	15,596.5	18,369.0	18,550.6

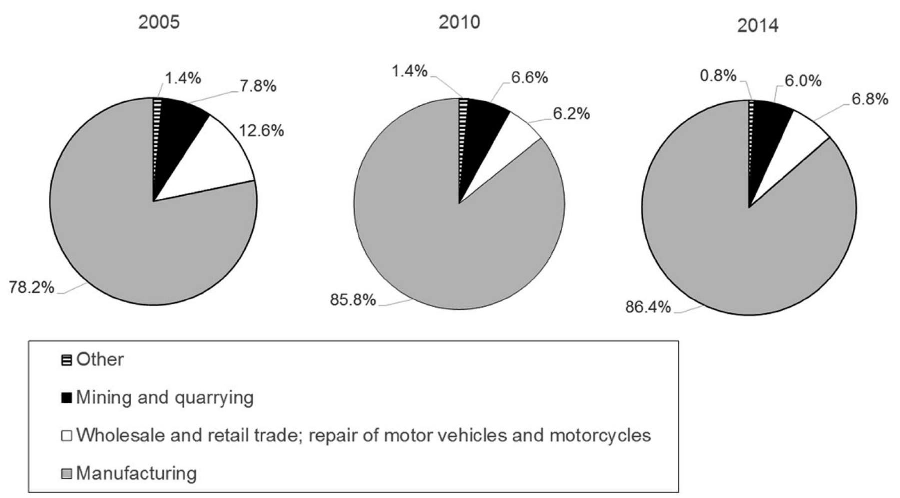

Fig. 1 Portuguese maritime exports by economic sector, for the years 2005, 2010 and 2014. *Source* INE, Statistics Portugal, International Trade Statistics (2005–2014, 2015)

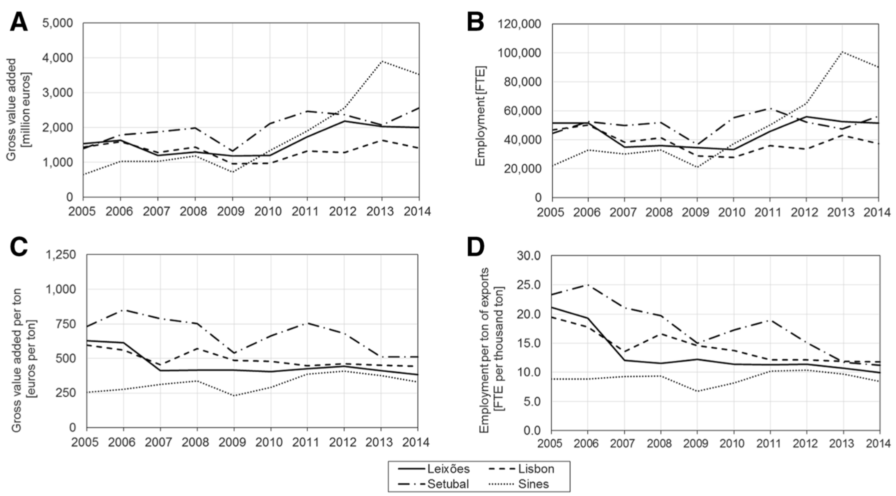

Fig. 2 Economic impacts of maritime exports through the main Portuguese ports

Economic significance of the Portuguese maritime exports

The economic significance of exporting activity is presented for the four main Portuguese ports: Leixões, Lisbon, Setúbal and Sines. Figure 2 shows the economic impacts of exports moving through these ports. One of the most striking features observable in Fig. 2 is the sharp decrease in 2009, affecting all Portuguese maritime exports, most likely a result of the 2008–2009 financial crisis.

Another salient feature of results presented in Fig. 2 is that, although Port of Sines shows the highest share in terms of international trade, exports handled at this port show the smallest value added and employment per ton. This is due to the fact that the majority of cargo handled at this port is liquid bulk cargo, which typically corresponds to a lesser value added per ton. In contrast with port of Sines, the port of Setúbal shows the highest value in terms of value added per ton and employment per ton. This is due to the fact that this port is used by local automotive industry for exporting. Indeed, sector 29 of the Statistical Classification of Economic Activities in the European Community (NACE), revision 3 (*manufacture of motor vehicles, trailers, semi-trailers and parts and accessories for motor vehicles*) alone accounts for approximately 50% of the total value of goods exported through the port of Setúbal.

Results therefore show that some of the ports handling the highest cargo volumes do not correspond to those generating more added value or employment per ton of cargo. This can provide port planners with valuable inputs as to which ports should be given higher priority in terms of expansion and development of associated infrastructures such as road and rail networks in the respective hinterland. In particular, the ports of Leixões and Sines seem to play an increasing role in terms of employment and gross value added. In contrast, the port of Lisbon seems to be lagging behind in both these aspects. Exports moving through the port of Setúbal, while also playing an important role in terms of employment and gross value added, could have a more limited potential to further increase socioeconomic impacts, given that a considerable share of those exports pertain to a limited number of local automotive manufacturers, therefore lacking the cargo diversity observed, for instance, in the port of Leixões. Therefore, it could be argued that the port of Leixões, in the northern part of the country, and Sines, in the south, should be given the highest priority in terms of infrastructure development.

Error analysis

At least two potential sources of error can be identified when applying the proposed methodology: the treatment of the input data (mainly for data reconciliation purposes), and the adequacy of the RAS approach to accommodate structural change. These two sources of potential error are addressed below.

Aggregation bias

Several factors determine the aggregation level of input–output tables, including computational expense, or whether it is important or not to distinguish individual sectors, and data availability (Miller and Blair 2009). Concerning data availability, the proposed methodology acknowledges that there may be differences between the level of aggregation of matrices $\mathbf{Z}$ (the known inter-industry transactions matrix), and vectors $\mathbf{x}$, $\mathbf{u}$ and $\mathbf{v}$ (i.e. the known output, row and column totals for the unknown matrix $\bar{\mathbf{Z}}^*$). Such discrepancy makes it necessary to aggregate some of the data, in order to make the necessary computations possible. However, such aggregation introduces some error (Morimoto 1970). Let $\mathbf{S}$ be the aggregation

Table 5 Aggregation bias

	Aggregated outputs			Outputs from aggregated model			Aggregation error			Aggregation error as a percent of gross output		
	1999	2005	2008	1999	2005	2008	1999	2005	2008	1999	2005	2008
A	4.208	4.138	4.051	5.134	4.932	4.783	0.926	0.794	0.732	−18.037	−16.099	−15.304
B	1.147	1.221	1.332	1.158	1.247	1.351	0.011	0.026	0.019	−0.950	−2.085	−1.406
C	27.822	27.531	28.299	29.351	28.421	28.627	1.529	0.890	0.328	−5.209	−3.131	−1.146
D	3.630	3.913	5.253	3.567	4.061	5.170	−0.063	0.148	−0.083	1.766	−3.644	1.605
E	2.436	2.725	2.974	2.376	2.667	2.894	−0.060	−0.058	−0.080	2.525	2.175	2.764
F	2.801	3.173	3.622	2.785	3.207	3.548	−0.016	0.034	−0.074	0.575	−1.060	2.086
G	6.985	6.210	6.356	7.205	6.368	6.389	0.220	0.158	0.033	−3.053	−2.481	−0.517
H	7.376	7.544	8.148	7.133	7.529	7.910	−0.243	−0.015	−0.238	3.407	0.199	3.009
I	1.711	1.913	1.389	1.669	1.909	1.348	−0.042	−0.004	−0.041	2.516	0.210	3.042
J	7.247	7.326	6.825	7.297	7.526	7.068	0.050	0.200	0.243	−0.685	−2.657	−3.438
K	4.343	6.314	5.842	4.229	6.303	5.801	−0.114	−0.011	−0.041	2.696	0.175	0.707
L	2.050	1.864	2.151	1.977	1.818	2.031	−0.073	−0.046	−0.120	3.692	2.530	5.908
M	9.828	10.715	10.577	9.613	10.984	10.670	−0.215	0.269	0.093	2.237	−2.449	−0.872
N	6.929	7.376	7.622	6.882	7.498	7.464	−0.047	0.122	−0.158	0.683	−1.627	2.117
O	1.000	1.000	1.079	1.000	1.000	1.079	0.000	0.000	0.000	0.000	0.000	0.000
P	1.397	1.136	1.123	1.387	1.139	1.113	−0.010	0.003	−0.010	0.721	−0.263	0.898
Q	2.222	2.257	2.339	2.229	2.253	2.353	0.007	−0.004	0.014	−0.314	0.178	−0.595
R	2.818	2.538	2.310	2.857	2.619	2.300	0.039	0.081	−0.010	−1.365	−3.093	0.435
S	3.269	3.171	3.282	3.274	3.174	3.279	0.005	0.003	−0.003	−0.153	−0.095	0.091

Table 6 RAS-generated output multiplier error analysis

	$\tilde{m}(o)_j$ [1999 → 2005]	$m(o)j$ [2005]	$e(o)_j$ (%) [1999 → 2005]	$\tilde{m}(o)_j$ [1999 → 2008]	$m(o)_j$ [2008]	$e(o)_j$ (%) [1999 → 2008]	$\tilde{m}(o)_j$ [2005 → 2008]	$m(o)_j$ [2008]	$e(o)_j$ (%) [2005 → 2008]
A	1.637	1.699	3.674	1.732	1.805	4.077	1.739	1.805	3.658
B	1.637	1.804	9.247	1.741	1.767	1.496	1.755	1.767	0.660
C	1.631	1.723	5.342	1.660	1.696	2.142	1.664	1.696	1.886
D	2.135	2.052	−4.054	2.402	2.515	4.505	2.441	2.515	2.942
E	1.839	1.629	−12.883	1.910	1.854	−2.980	1.922	1.854	−3.629
F	2.121	2.023	−4.865	2.055	2.053	−0.093	2.055	2.053	−0.098
G	1.623	1.665	2.565	1.635	1.650	0.930	1.636	1.650	0.868
H	1.771	1.769	−0.083	1.794	1.761	−1.877	1.791	1.761	−1.722
I	1.612	1.734	6.993	1.629	1.676	2.777	1.629	1.676	2.784
J	1.762	1.688	−4.374	1.758	1.772	0.750	1.768	1.772	0.225
K	1.482	1.502	1.310	1.450	1.473	1.564	1.453	1.473	1.334
L	1.365	1.387	1.591	1.295	1.279	−1.306	1.273	1.279	0.449
M	1.808	1.759	−2.805	1.776	1.774	−0.081	1.775	1.774	−0.017
N	1.611	1.733	7.077	1.602	1.721	6.944	1.601	1.721	6.952
O	1.317	1.333	1.191	1.368	1.371	0.181	1.364	1.371	0.474
P	1.171	1.187	1.371	1.186	1.193	0.575	1.184	1.193	0.753
Q	1.415	1.473	3.916	1.458	1.512	3.565	1.451	1.512	4.043
R	1.679	1.674	−0.292	1.705	1.753	2.740	1.724	1.753	1.664
S	1.657	1.831	9.466	1.640	1.680	2.404	1.647	1.680	1.981
Mean absolute percentage error			4.373			2.157			1.902

matrix. Additionally, let **x** be the total output of the original unaggregated model, calculated as per Eq. (1), and let **x*** be the output of the aggregated model, such that $\mathbf{x}^* = (\mathbf{I} - \mathbf{A}^*)^{-1}\mathbf{f}^*$, where **A*** is the aggregated input coefficient table and **f*** is the aggregated final demand component. The total aggregation bias, τ, is then calculated as:

$$\tau = \mathbf{x}^* - \mathbf{S}\mathbf{x} \quad (6)$$

Table 5 shows the aggregation error for the case study at hand for each economic sector.

It can be seen that the average error is low for all the years in analysis. In particular, the average error amounts to approximately 2.7% for 1999, 2.3% for 2005 and 2.4% for 2008. This indicates that, while there are exceptions in terms of the error introduced in individual sectors, the overall error introduced by the aggregation process may not be significant for the economy under analysis. An evaluation of the closeness of $\tilde{\mathbf{Z}}$ to Z^* is possible for those years for which Z^* is available. Such evaluation allows the assessment of the adequateness of the RAS procedure to accommodate possible structural change in the economy.

Accuracy of the RAS-generated Leontief inverse matrices

Let $m(o)_j$ denote the output multiplier of sector j, associated with the known target year coefficient table **A**, and let $\tilde{m}(o)_j$ represent the output multiplier for sector j, associated with the RAS-generated coefficient table, $\tilde{\mathbf{A}}$. Then, a vector of percentage errors, expressing each difference $[m(o)_j - \tilde{m}(o)_j]$ as a percentage of $m(o)_j$ indicates the closeness between the estimated and the true multipliers. Table 6 shows such percentages for the case study at hand.

Table 6 shows that the RAS approach is capable of accommodating structural change in the economy, with a mean absolute percentage error of less than five percent. Such results indicate that, for the economy at hand, the updating of the input coefficient matrices might be dispensed altogether without a significant error being introduced in computations. However, given the aim of providing a generally applicable framework (also applicable when structural change may have a significant role), the matrix adjustment technique is maintained, as an element of the proposed methodology as in Moon (1995).

Conclusions

This paper presents a methodology for assessing the economic significance of ports. By evaluating the economic benefits derived from cargo itself, the proposed methodology provides a closer adherence to the true role of ports as trade facilitators, and to the current trends towards port regionalization, as opposed to the common practice in port impact studies, which tend to focus on the impacts of the port industry itself.

Such an approach allows accommodating the changing nature of the shipping and port industry, where the importance of ports as industrial complexes is continually decreasing while at the same time, the economic significance of cargo moving through them is increasing.

Moreover, by providing a dynamic view on the economic impacts associated with the usage of ports—i.e. impacts calculated for a number of years under the same approach—the methodology proposed in this paper allows one to ascertain the incremental effects of investments made in ports and related infrastructure. Such results can provide valuable inputs to port policy makers, particularly when combined with econometric forecasting techniques.

Additionally, by extending the analysis to encompass a number of years, the proposed methodology allows the proposal of causal explanations for the observed dynamics, both at system level, and at port level.

Lastly, the fact that data are obtained from public agencies which specialize in collecting the necessary data in a uniform and systematic manner dispenses with the need for expensive surveys which constitute one of the most important sources of error in port impact studies.

Our methodology focuses on the role of exports in regional economic development. Considerable research has been published providing evidence on the link between exports and economic growth.

Application of our methodology to the Portuguese port system allows the identification of ports contributing the most to regional economic growth through a number of years, and the identification of those ports which should be given the highest priority in terms of infrastructure development. In particular, it could be argued that port planners should give the highest priority to the port of Leixões in the northern part of the country, and Sines, in the south. The contribution of exports to regional economic growth, from these two ports, shows a considerable increase in the period 2005–2014.

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