MULTIPLE OUTPUTS IN PORT COST FUNCTIONS

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ABSTRACT

By describing the technical process, in this article we argue that cargo that arrives in many different forms are distinct outputs of a port, whose services require inputs that can be grossly defined as labor, space, facilities, and equipment. Then we show theoretically and empirically that the use of aggregate output in the presence of distinct outputs causes erroneous conclusions on marginal costs, on economies of scale, and on optimal industry structure.

1. INTRODUCTION

Port activity is complex and involves a large number of economic stakeholders. It is worth highlighting that what is known as port operation really encompasses a large number of smaller operations, most of which form the successive links of a chain in which the weakest link is the one that determines the strength of the chain as a whole. The fact that there are a large number of stakeholders and operations means that coordination becomes one of the essential keys to port efficiency.

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Port operations can be divided into three stages: ship-oriented services, cargo-oriented services and inter-modal connection. There are, therefore, two main users of the ports: the shipping lines on the waterside and the shippers on the landside.

Among the services provided in ports, there are those provided by the facilities (lighthouses and beacons, docks and quays, security of ships and cargo, etc.), cargo-handling services (loading–unloading ships, loading–unloading inland transport and goods planning in cargo terminals), other ship-oriented services (pilot guidance, towage, berthing), other ship- and/or cargo-oriented services (repairs, marking, forwarding and bulk breaking, storage), and other services like inspection, customs, police, etc.

In general, these functions are exercised by a range of both public and private bodies. Port authorities are the competent agency for facilities, the stevedore companies are the competent agents for cargo handling, ship- and cargo-oriented services (except pilot services) are usually provided by private companies, while pilot services, inspection, and the like are generally provided by the administration. The task of coordinating the different functions and companies usually befalls to the port authorities within each port.

The main private agencies operating in ports are the shipbrokers that coordinate most of the services required by ships, stevedore firms that take care of the cargo-handling operations, and freight forwarder companies that coordinate all the cargo services for shippers. They usually act as intermediaries between their clients, the owners of the cargo or shipping companies, and the service companies. However, the present concept of a port as concentrating traffic or as a logistics activity zone, is leading to the new figure of the logistics operator, with a global view of the entire transport operation from the cargo's point of origin to its destination. In this case, they charge for a complete service, very often door to door; therefore, the boundaries between the service providers and the services they offer are becoming increasingly blurred.

For synthesis, viewed as a whole, ports are factories designed to receive and dispatch cargo that arrives in many different forms. These movements are the outputs of a port, whose services require inputs that can be grossly defined as labor, space, facilities, and equipment. The technical process can be described as the search for the optimal combination of inputs to be able to move different combinations of outputs, which can be described either through a production (transformation) function, or through a cost function that represents the minimum expenditure necessary to produce those movements. In this chapter, we expose the reasons why cost functions estimated to describe port activities should be specified in a multiple output form

(Jara-Díaz, 1983) as opposed to the aggregate output approach, usually total tons moved or variations, e.g. Kim and Sachish (1986), Reker, Connell, and Ross (1990), Tongzon (1993), and Martínez-Budría (1996).

In the following section we present the basic elements of multioutput theory as developed by Baumol, Panzar, and Willig (1982) and a theoretical formulation of the problems caused by output aggregation in the context of ports. Then the technical analysis of input usage to produce the movements of an output mix in ports is presented, providing a case for a multioutput analysis instead of an aggregate output one. In the fourth section, some evidence from the literature is presented to verify the theoretical predictions. The final section concludes the chapter.

2. MULTIOUTPUT THEORY AND AGGREGATION

The cost function $C(W, Y)$ represents the minimum expenditure needed to produce outputs in Y, at factor prices W, which have been suppressed below for simplicity. The marginal cost of producing i keeping all other products constant is calculated as

$$\frac{\partial C}{\partial y_i} = Cm_i \tag{1}$$

The multioutput degree of economies of scale, S, is a technical property of the productive process, defined in the transformation or production functions. However, dual relations allow the calculation of S directly from the cost function as (Panzar & Willig, 1977)

$$S = \frac{C(Y)}{Y \nabla_y C(Y)} \tag{2}$$

S represents the maximum growth rate that the product vector can reach when productive factors increase by the same proportion. Therefore, the presence of increasing returns to scale ($S > 1$) implies that a proportional growth of all products induces a less than proportional growth of costs, i.e. a production expansion exhibits advantages from the point of view of costs. It is easy to verify that in the single output case S is given by the ratio between average cost C/Y and marginal cost and that increasing returns are present when average cost is decreasing with output.

The incremental cost of product i, IC_i, is defined as the cost of adding that product to the line of production. This corresponds to

$$IC_i = C(y_1, y_2, \ldots, y_n) - C(y_1, y_2, \ldots, y_{i-1}, 0, y_{i+1}, \ldots, y_n) \tag{3}$$

This concept can be extended to a subset of products R, generating $IC_R(Y)$. The degree of economies of scale specific to subset R is defined as

$$S_R(Y) = \frac{IC_R(Y)}{\sum\limits_{j \in R} y_j \partial C(Y)/\partial y_i} = \frac{IC_R(Y)}{\sum\limits_{j \in R} y_j Cm_i(Y)} \tag{4}$$

The interpretation of $S_R(Y)$ is similar to that of S.

Two products are said to exhibit cost complementarity when the marginal cost of one of them diminishes as the other product increases, suggesting some form of advantage in joint production. Formally, this means that

$$C_{ij}(Y) = \frac{\partial^2 C(Y)}{\partial y_i y_j} \leq 0 \tag{5}$$

Economies of scope measures the relative cost increase that would result from the division of the production of Y into two different production lines T and $N-T$. The degree of economies of scope SC_T of subset of products T with relation to its complementary subset $N-T$ is defined as

$$SC_T(Y) = \frac{1}{C(Y)}[C(Y_T) + C(Y_{N-T}) - C(Y)] \tag{6}$$

If $SC_T(Y) > 0$, economies of scope are said to exist and it is cheaper to produce vector Y jointly than to produce vectors Y_T and Y_{N-T} separately. In other words, it is not advisable to specialize but to diversify production. It is easy to see that $-1 < SC < 1$.

It can be shown that scale and scope are related by

$$S_N(Y) = \frac{\alpha_T S_T(Y) + (1 - \alpha_T) S_{N-T}(Y)}{1 - SC_T(Y)} \tag{7}$$

with

$$\alpha_T = \frac{\sum\limits_{j \in T} y_j \partial C(Y) \Big/ \partial y_j}{\sum\limits_{j \in N} y_j \partial C(Y) \Big/ \partial y_j} \tag{8}$$

This means that, in the absence of economies of scope ($SC = 0$), S would be a weighted average of the specific economies of scale of each subset. The existence of economies of scope ($SC > 0$) favors the presence of overall economies of scale.

Now we can examine the case in which a multioutput production process in ports is viewed or analyzed by means of a cost function $\tilde{C}$ that has been estimated describing product as a single (aggregated) output $\tilde{Y}$, total tons moved per period. As shown in the next section, output in ports should distinguish the different types of cargo that are served. Let us define y_i as the volume of cargo type i. Then, Y is the output vector containing all y_i and $\tilde{Y} = \sum y_i$.

Under these circumstances, the estimated $\tilde{C}(\tilde{Y})$ is an implicit representation $\hat{C}$ of $C(Y)$ because (Jara-Díaz & Cortés, 1996)

$$\tilde{C}(\tilde{Y}) \equiv \tilde{C}\left[\tilde{Y}(Y)\right] \equiv \hat{C}(Y) \tag{9}$$

This is a very important relation, as from $\tilde{C}(\tilde{Y})$ only quantities like (1) and (2) can be calculated for different values of $\tilde{Y}$, unlike $C(Y)$ from which all elements (1)–(7) can be investigated. This has implications when it comes to calculate marginal costs and scale economies. First, and in a very evident way, the marginal cost estimate for each product would be

$$\frac{\partial \hat{C}}{\partial y_i} = \frac{\partial \tilde{C}}{\partial \tilde{Y}} \frac{\partial \tilde{Y}}{\partial y_i} = \frac{\partial \tilde{C}}{\partial \tilde{Y}} \tag{10}$$

which implies that the value of the additional resources necessary to move one additional volume unit of cargo i is equal for all cargo types. This suggests that the multioutput approach should be used whenever there are reasons to believe that marginal costs differ across products.

What is less evident, though, is the way in which the presence of economies of scope between the products in Y is "captured" when $\tilde{Y}$ is used, which is expressed in the following Theorem.

Theorem. The existence of economies of scope between products in T and $N-T$ induces decreasing average costs in $\tilde{C}(\tilde{Y})$ (single output scale economies).

Proof. First note that

$$\tilde{Y}_T \equiv \tilde{Y}(Y_T) = \sum_{i \in T} y_i \text{ and } \tilde{Y}_{N-T} \equiv \tilde{Y}(Y_{N-T}) = \sum_{i \notin T} y_i \tag{11}$$

which implies that

$$\tilde{Y}_T = \theta_T \tilde{Y} \text{ and } \tilde{Y}_{N-T} = (1 - \theta_T)\tilde{Y} \tag{12}$$

where $\theta_T \in (0,1)$ is the proportion of the volume of products in T with respect to the total. From Eqs. (6) and (12) the existence of economies of scope between products in T and $N-T$ implies that

$$\hat{C}(Y_T) + \hat{C}(Y_{N-T}) = \tilde{C}(\theta_T \tilde{Y}) + \tilde{C}\left[(1 - \theta_T)\tilde{Y}\right] > \tilde{C}(\tilde{Y}) \tag{13}$$

Without losing generality we assume that

$$\frac{\tilde{C}(\theta_T \tilde{Y})}{\theta_T \tilde{Y}} > \frac{\tilde{C}\left[(1-\theta_T)\tilde{Y}\right]}{(1-\theta_T)\tilde{Y}} \tag{14}$$

As known, if $a/b > c/d$ with a, b, c, and d positive, then $a/b > a+c/b+d$. Applying this and imposing (13) we get

$$\frac{\tilde{C}(\theta_T \tilde{Y})}{\theta_T \tilde{Y}} > \frac{\tilde{C}(\theta_T \tilde{Y}) + \tilde{C}\left[(1-\theta_T)\tilde{Y}\right]}{\theta_T \tilde{Y} + (1-\theta_T)\tilde{Y}} = \frac{\tilde{C}(\theta_T \tilde{Y}) + \tilde{C}\left[(1-\theta_T)\tilde{Y}\right]}{\tilde{Y}} > \frac{\tilde{C}(\tilde{Y})}{\tilde{Y}} \tag{15}$$

As $\theta_T \in (0,1)$, this shows that average costs are decreasing. Note that condition (14) is general, as if inequality was the opposite the proof is similar for $\tilde{C}\left[(1-\theta_T)\tilde{Y}\right]/(1-\theta_T)\tilde{Y}$.

Q.E.D.

This is quite an important result, as the presence of scope in $C(Y)$ would turn into scale when analyzed from $\tilde{C}(\tilde{Y})$, overestimating true economies of scale and reinforcing the identification of a port activity as a natural monopoly.

3. PORT PRODUCTION

3.1. Port Operation

Sea transport, like all productive processes, has undergone profound technological changes over recent decades, aimed at increasing productivity. This has been attained by reducing the cost of the operation that, like any transport operation, it can be divided into two parts: the monetary tariffs and the cost of the time of the operation, which in the case of cargo, can be objectively quantified. This technological advance could not occur solely in a single link of the transport chain; it has to be accompanied by all the other links. Hence, the new kinds of specialized ships have meant that new, more efficient port terminals and cargo-handling equipment had to be designed to make port operations faster. To this end, cargoes have to be transported in standard formats so that it can be handled by standard equipment used in all ports. This cargo standardization process means that the cost of the process is more dependent on how the cargo is packed than on the nature of the product. The container and the pallet are the best-known forms of standardizing cargo-handling operations.

The productive factors necessary for the port operation are a sheltered dock, mechanical equipment for loading (unloading) the ship, physical space and mechanical equipment for handling and distributing the cargo on land after the ship has been unloaded (before loading), and equipment for loading (unloading) the cargo onto terrestrial transport and personnel, both for managing the necessary infrastructure and mechanical resources used and for operating this equipment.

In summary, physical capital is required in infrastructure for ships, cargo, and terrestrial transport; in cranes and other forms of unloading ships, in forklift trucks, and other means of moving the cargo in the terminal, in computer and communication systems; and personnel to manage the infrastructure and cranes and stevedores for the cargo-handling equipment. There is also a need for a range of intermediate inputs like electricity, fuel, water, communication services, office material, spare parts, etc.

These are heterogeneous, rather than a single uniform process, each of which will combine these factors in a different manner depending on the cargo carried by the ship. The most widely accepted classification of cargoes is into liquid bulk, solid bulk, and general cargo. But this classification is too general to explain the complex operations of modern ports. So we need a sub-classification for each of these categories and a brief description of the operation, with the emphasis on both the specialized and the multipurpose inputs.

3.2. Port Cargoes

3.2.1. Liquid Bulks: Oil and Derivatives, Liquid Gases

Loading and unloading is done by pipes running directly between the tank and the ship's hold. This is the kind of cargo that uses the least amount of port inputs, as these are limited to a sheltered dock (sometimes, they even use sheltered waters, rather than a dock), the pipes, which are connected by the employees of the shipper or the receiving company, and the storage tanks, which may be public or private.

3.2.2. Solid Bulk: Cereals, Minerals, Cement Clinker, etc.

There are different techniques for handling solid bulks, which can be divided into two groups: those that use specialized facilities and those that use multipurpose facilities and equipment. For the former group, we have specialized facilities like pneumatic loader and conveyor belts and, on the other hand, multipurpose cranes. The pneumatic loader is used for loading (unloading) cereals and cement clinker, and conveyor belts are used for unloading (loading) minerals. In both cases, there is a direct connection between the places where the cargo is to be stored and the ship, requiring specialized docks and, for minerals, large dedicated areas. Stevedores play a relatively small part in operations of this kind.

The multipurpose cranes are used for unloading (loading) cereals and clinker, coupling a special device called a bucket, to the crane, to scoop up the cargo. In this case, the infrastructure requirement is the same (depending solely on the ship) but the demand for stevedore work is notably greater as workers have to pile up the bulk in the ship's holds. If the cargo first has to be unloaded onto the dock as well, then this demand is greater still as it will then require another operation to load the said cargo onto a truck, train, etc. With regard to handling bulk cargoes on land, there are two options. First of all, the solid bulk is placed in a hopper and transferred to the trucks that will take it to the prepared silos. This way, the speed of the operation will depend on the availability of inland transport and the capacity of those receiving the grain. At other times, the crane will unload the bulk directly onto the dock, from where it will later be loaded onto trucks as these arrive. In this latter case, cranes are used less, as their job is finished once the bulk cargo is unloaded from the ship, although more personnel is required for handling the bulk from the dockside to the truck. Here, of course, the efficiency of the operation will depend on how fast the port workers act and the reception capacity of the client the cargo is being delivered to.

The decision to use special facilities or multi-purpose equipment will depend on the volume of traffic. There is a minimum threshold of solid bulk that will pay back the investment with a reasonable return. So, the volume of bulks and the solution chosen for the problem of coordinating between sea and land transport will vary the demand for factors.

3.2.3. General Cargo in Containers and Carried on Container Ships

Container loading and unloading operations are very different from other cargoes. For a port to handle large volumes of containers, it needs specific facilities: port terminals with large storage spaces, gantry cranes for loading (unloading) the container onto the ship, and equipment for moving the containers within the terminal and for loading them on to modes of land transport. The port hinterland trade structure can also determine the need for space and other inputs. If there is a pronounced imbalance between the arrival and departure of cargo in the hinterland, there will be a need for large flows of empty containers that, in turn, will determine the productive technique used.

Availability of storage area will determine the height to which containers can be stacked and there is a sustainable ratio between the input of area and the input of labor, mechanical equipment on the ground, and energy to power these. So, if the price of the area of land is relatively low in comparison with the other inputs, then the goods can be stacked to a lower height and, in this case only a few containers with have to be moved (in average value) to dispatch the container required. On the other hand, if the price of the land is relatively high in comparison with the other inputs, this will change the optimum demand, forcing managers to stack to a greater height and, therefore, face higher costs for the inputs of personnel, equipment to move the containers on land and intermediate inputs. Furthermore, managing a container terminal requires a costly specialized computer system.

Another option for container handling is to transport them to the shipside on a rolling platform (or from the ship to the storage area) using tractors or mobile platforms. In this case, more multipurpose equipment can be used as these tractors or mobile platforms can also be used for handling containers to be transported in Roll-on Roll-off ships and also for moving general, non-containerized cargo.

3.2.4. General Cargo in Containers and Transported in Roll-on Roll-off Ships

There are two techniques for moving containers in Roll-on Roll-off ships. In one of them, the container is placed on a platform that is towed onto the ship with a tractor. In the port of destination, the operation is reversed. The other way is to drive the truck straight onto the ship with the container. The former method allows greater flexibility and the use of multipurpose mechanical equipment as the tractors used are the same ones as those described in the handling of containers to be carried on container ships and for moving general, non-containerized cargo, on pallets for example, which are loaded on the same mobile platform as the ones used for carrying containers.

3.2.5. General Non-Containerized Cargo

There are different forms for shipping general non-containerized cargo: in individual units like rolls of paper; with a pre-slung system like iron or wood; on pallets (the most widespread form) and, particularly, cars. In all these cases, handling requires the use of medium-sized cranes for loading (unloading) the ship and sometimes mobile, wheeled cranes that, although they are not specifically devoted to port work, as they are also designed for building roads, or building works in general, they do give the investment in cranes greater flexibility and adapt it more to the volumes of cargo. Forklift trucks are also needed for moving cargo on the dockside, apart from the stevedores. But there are differences in handling techniques, depending on the cargo to be handled, although the ship's port infrastructure requirements are the same for the techniques described above and will depend exclusively on the technical specifications of the ship in question.

If the cargo is transported in individual units, such as rolls of paper, specific fittings are used both on the cranes and on the forklift trucks that handle the merchandise on land, because the cargo is fragile, and they also require a labor force with a certain degree of specialist training. These two kinds of mechanical equipment are the same as those used for other kinds of non-containerized cargoes, i.e. medium capacity cranes. Docks with nearby cold store facilities are usually used for handling perishable goods.

Another form of transporting merchandise is the pre-slung system, designed for putting units of cargo (like wood and iron) together in bundles or batches to facilitate their handling, to hook them up to the cranes and to move them from one place to another.

In the case of cars carried as cargo, generally on special ships, they are unloaded by the stevedores by driving the cars off the ship and performance and efficiency will depend on the availability of parking areas and how close these are to the ship.

3.3. Common and Specialized Inputs

As we have seen, there are inputs that are used for all kinds of goods and there are others that are good specific, although this is related with total and relative volumes as well. In multipurpose terminals, the inputs are common to the different kinds of outputs that are moved, that is, the same infrastructure, the same cranes and the same stevedores are used whatever the cargo: containers or pallets, individual units, pre-slung and Roll-on Roll-off. They can even use the same facilities for loading solid bulk cargoes. This kind of terminal is a good option for small ports, where the volume of traffic does not justify specialized terminals. Large volumes make a case for a greater degree of inputs' specialization, but this is never absolute because, even in large ports with highly specialized terminals, there are inputs that are used generally for all kinds of cargo.

These resources that are common to all terminals, regardless of the kind of goods handled and the volume of traffic, include, at least the following: lighthouses and shipping services, breakwaters, road networks, buildings, infrastructure, mechanical equipment and loading/unloading equipment management personnel, most of the cargo-handling personnel and the inspection, customs, port security services, etc.

Furthermore, there are resources that are used for several different kinds of cargo. For example, the general cargo docks are generally used for loading (unloading) both pallets and loose or pre-slung goods. In this case, the stevedores, cranes, and landside resources are all common. The first two are used for handling solid bulk if there are no special facilities. Tractors and platforms are used for most road traffic, whether it is transported on pallets or in containers and, in some ports, they are also used for moving containers on the dockside before they are loaded (unloaded) by crane.

On the other hand, we have specialized inputs used for certain goods. In the case of general perishable goods, with temperature and/or humidity requirements, the only specific input will be the cold storage facilities. The most significant example of specialized inputs, however, is that of container terminals, where, first of all, the berths are specific, depending on the draught and length needed by the container ship. There also require spacious and dedicated areas close to the docks for handling and storage. Moreover, the cranes for loading (unloading) the ship are specialized cranes, normally gantry cranes that are more powerful and faster than the cranes used for handling other cargoes. The mechanical equipment for handling and dispatching (receiving) containers on land is also specialist equipment, such as trastainers and more versatile machinery like the reach stacker and the spreader forklift. These mechanical resources are specially designed for handling containers, thus making the operation faster and more efficient, which, at the same time, guarantees the security of the operation. The operation also has to be carried out by employees specially trained in the use of this kind of machinery, both to attain the best possible efficiency and because the machinery is complex.

Solid bulk is handled in special facilities when large volumes are involved. These include specific dock and surface infrastructures and mechanical equipment for transporting the bulk from ship to shore. The specific inputs for handling cereals are the pneumatic loaders, the technical specifications of which will depend on the volume of bulk to be handled, and the Silos on the dockside. Minerals, on the other hand, require large areas on the dockside and specially designed conveyor belts. For relatively small volumes of bulk, hoppers are used for receiving and dispatching, and these are used solely for a specific kind of good.

Finally, liquid bulk is transferred with underground pipelines connecting the ship's tanks with the shoreside tanks that are used exclusively for storing the goods safely. One example of this is the tanks and pipelines used for oil products.

4. EMPIRICAL EVIDENCE

For synthesis, the technical elements provided in the previous section show that there are technical reasons to expect different marginal costs for distinct types of cargo moved within a port, which, as argued earlier, are a cause for a multioutput analysis of port production. In what follows we present empirical evidence regarding the type of bias induced by aggregate output approaches in port activities, including one example on infrastructure port services and another on cargo-handling activities.

Infrastructure port services related to planning and management of port facilities in Spanish ports were analyzed by Martínez-Budría (1996) using a Cobb–Douglas specification within an aggregate output approach, obtaining significantly large economies of scale ($\hat{S} = 3.47$). Data covers 26 Spanish ports during a period of 5 years (1985–1989), including information from the port authorities. Using an expanded data set for the same ports (11 years, 1985–1995) Jara-Díaz, Martínez-Budría, Cortes, and Basso (2002) examined the same sector under a multioutput view. The dependent variable, total annual cost (TC) for infrastructure and its administration, includes labor (GL), amortization (GK), and other expenses (GI), directly obtained from port reports. The explanatory variables include four kinds of cargo in the multioutput case, and three indices for input prices. The output components represent port activities, and they include the movement of containerized general cargo (CGC), non-containerized general cargo (NCGC), dry bulk (DB), and liquid bulk (LB). The multioutput function was estimated using a quadratic specification, which allowed for scope analysis.

As the aggregate output cost function reported by Martínez-Budría (1996) has less information and used a more restricted form than the multioutput model presented in Jara-Díaz et al. (2002), we estimated a new version of the aggregate output cost function using the same quadratic specification and data base used in the latter (see Appendix A). Results of the two directly comparable models are shown in Table 1.

At the mean of the observations, the multioutput approach revealed different marginal costs for each of the four products (minimum and maximum averages by port in parenthesis): 427 (278−647) for CGC, 500 (335−613) for NCGC, 125 (75−220) for LB, and 183 (143–246) for DB, all in pesetas/ton.

Table 1. Cost Structure in the Multioutput and Aggregate Output Analysis of Infrastructure Services of Spanish Ports[a].

Approach	Multioutput[b]				Aggregate Output
Output	CGC	NCGC	DB	LB	Total tons
Marginal cost (pesetas/ton)	427	500	183	125	255
Scale economies		1.69			3.09

[a]Quadratic cost function and input expenditure equations used in both models estimated using the SURE procedure. Period 1985–1995, 26 ports authorities, and 286 observations.
[b]*Source:* Jara-Díaz et al. (2002).

It is fairly evident that the relative order of the marginal costs figures by product reflects the technical discussion presented in Section 3: the lowest for liquid bulk and the largest for NCGC. The aggregate output analysis gave a single value of 255 pesetas/ton using the quadratic specification.

When it comes to analyzing scale economies, the importance of the theorem proved in Section 2 becomes apparent. Jara-Díaz et al. (2002) obtained a figure of 1.69 for the degree of scale economies at the mean. They also studied economies of scope calculating SC using Eq. (6) for three partitions of output: liquid bulk versus the rest (SC_{LB}), general cargo from liquid and dry bulk (SC_{GC}), and CGC versus the rest (SC_{CGC}). The three positive values indicated the presence of economies of scope between the corresponding subsets, reflecting the convenience of using common infrastructure if all port services are to be produced. We have estimated a value of 3.09 for the degree of economies of scale economies at the mean using the aggregate output quadratic cost function. These values are according to the theorem.

A second country-wise study that can be used for comparison of the two approaches is Martínez-Budría and Díaz-Hernández (2006) that analyzed cargo handling in Spain using a multiproduct approach. The outputs analyzed in this study were defined according to how the merchandise is handled: *CGC*, *NCGC*, and solid (dry) bulk cargoes that are handled without special facilities (*DB*). Likewise the two factors considered are labor and cranes. The data from the Spanish Ports' Annual Reports have been used to get the quantities of cargo moved by each port and year included in the sample. Other data sources were a questionnaire presented to the *SEED*s (Sociedad Estatal de Estiba y Desestiba) that provided information on the labor factor, basically concerned with labor costs and hours worked by stevedores. The Annual Reports of each port and the information received from crane operators companies in ports provided the hours worked by

Table 2. Cost Structure and Technical Change in the Multioutput and Aggregate Output Analysis of Cargo Handling in Spanish Ports[a].

Approach	Multioutput[b]			Aggregate Output
Output	CGC	NCGC	DB	Total tons
Marginal cost (pesetas/ton)	488	593	292	403
Scale economies		1.071		1.34
Average technical change (%)		3.66		2.53

[a]Normalized quadratic cost function and input expenditure equations used in both models estimated using the SURE procedure. Period 1990–1998, 21 cargo-handling firms, 158 observations.
[b]*Source:* Martínez-Budría and Díaz-Hernández (2006).

cranes and permitted the calculation of total expenses on this item. Twenty-one Spanish ports observed from 1990 to 1998 were included in this study. However, as some *SEEDs* were created during the study period, the number of observations for each port varies. The above-mentioned sources were used to build a data panel with 158 annual observations. The normalized quadratic cost system was used to estimate the multioutput cost function. Table 2 shows the results including the calculation of the rate of technical change.[1] Using the same data and specification, we estimated an aggregate output cost function, shown in Appendix B. Marginal costs and scale economies are shown in Table 2 for the two models.

These results again show differences for marginal costs across products, which justify the multiproduct approach, and the relative order fits the intuition suggested by our discussion in the previous section. The overall degree of scale economies shows nearly constant returns. On the other hand, economies of scope exist for all partitions involving single output production, which means that it is less costly to produce the three products jointly than to do it with two firms, one producing either of the three outputs and the other producing the other two (at the mean). The marginal cost figure at the mean for the aggregate output approach was 403 pesetas/ton and the estimated degree of scale economies was $S = 1.34$, i.e. increasing returns were found. According to the theorem in Section 2, this is again explained by the presence of economies of scope detected when the process is correctly analyzed. It is worth noting that the estimate for the average rate of technical change drops to 2.53 with the aggregate output view, underestimating the effect of technology.

Finally, a very specific analysis made by Jara-Díaz, Tovar, and Trujillo (2005) on three cargo-handling firms in the port of Las Palmas show the

Table 3. Cost Structure in the Multioutput and Aggregate Output Analysis of Cargo Handling Firms in Las Palmas Port[a].

Approach	Multioutput[b]			Aggregate Output[c]
Output	CGC	NCGC	RR	Total tons
Marginal cost (pesetas/ton)	745	1974	1056	715.9
Scale economies		1.64		1.96

[a]Quadratic cost function and input demand equations estimated with the SURE procedure. Period 1991–1999 (monthly), three firms, and 264 observations.
[b]*Source:* Jara-Díaz et al. (2005).
[c]*Source:* Jara-Díaz et al. (2006).

same qualitative effects as those shown here. In that study, other cost items were included in addition to labor and equipment (intermediate inputs, land, and other capital items). Different marginal costs were detected among containers, Roll-on Roll-off cargo (*RR*), and general cargo. These are shown in Table 3, along with increasing returns that were detected at a disaggregated level ($S = 1.64$). The presence of economies of scope for all partitions once again turns into an overestimated value $S = 1.96$ when the aggregate analysis was used (Jara-Díaz, Tovar, & Trujillo, 2006).

Besides illustrating empirically the bias in scale economies induced by the aggregate output analysis under the presence of economies of scope, proved in our theorem, there is another point that merits attention. The statistical results from the aggregate analysis are quite satisfactory (see Appendices A and B), which might induce the acceptance of these results if there was no alternative specification, with all the implications on optimal industry structure and potential regulatory policies.

5. CONCLUSIONS

The main contribution of this paper to the literature is to show that there are various important reasons to prefer the multioutput analysis to the aggregate output view as the most appropriate approach to study the supply side of port production. First, we have proved theoretically that the presence of scope is captured as scale when no distinction among different products is made, inducing biased estimates of scale and erroneous conclusions on optimal industry structure when the aggregate output view is adopted. Second, we have provided technical reasons to expect relevant marginal cost differences among the various types of cargo moved within a port, which is a cause for multioutput analysis. Finally, empirical evidence was presented to verify the theoretical properties. This also shows that good statistical properties of an aggregate output cost function are no guarantee of a correct analysis of industry structure. The technical aspects should be understood as well.

NOTES

1. The rate of technical change is given by $\overset{\circ}{T} = 1/C\partial C(W, Y, t)/\partial t$, where W is the input price vector, Y the output vector, and t the time trend introduced to capture the technical change.

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APPENDIX A. PARAMETER ESTIMATES OF THE AGGREGATE OUTPUT COST FUNCTION FOR INFRASTRUCTURE SERVICES IN SPANISH PORTS

Parameter	Estimate	*t*-Statistic
Aggregate cargo (*C*)	255.7	9.142
Labor price (WL)	136.9	4.410
Capital price (WK)	2729.9	15.672
Intermediate input (WI)	2.61E + 06	23.829
C*C	−1.31E−03	−10.392
WL*WL	−0.037	−5.301
WK*WK	−0.038	−5.628
WI*WI	−260259	−23.873
WL*WK	−0.3623	−2.038
WL*WI	47.246	2.608
WK*WI	373.71	4.280
*C**WL	0.0263	4.332
*C**WK	0.4022	7.255
*C**WI	26.837	13.412
dALGEGIRAS	3.27E + 0.6	21.354
dALICANTE	2.93E + 0.6	17.373
dALMERIA	2.54E + 0.6	13.991
dBARCELONA	0.99E + 0.5	61.764
dBILBAO	0.77E + 0.5	34.483
dCADIZ	4.16E + 0.6	27.441
dCARTAGENA	2.40E + 0.6	13.532
dCASTELLON	2.56E + 0.6	13.322
dCEUTA	2.35E + 0.6	16.395
dEL FERROL	2.01E + 0.6	11.046
dGIJON	5.75E + 0.6	27.191
dHUELVA	4.03E + 0.6	26.793
dCORUÑA	2.50E + 0.6	14.113
dLAS PALMAS	4.65E + 0.6	31.233

APPENDIX A. (*Continued*)

Parameter	Estimate	*t*-Statistic
dMALAGA	3.36E + 0.6	20.852
dMELILLA	2.41E + 0.6	11.857
dPMALLORCA	3.76E + 0.6	27.241
dPASAJES	3.83E + 0.6	26.126
dPONTEVEDRA	2.34E + 0.6	11.778
dTENERIFE	4.22E + 0.6	30.972
dSANTANDER	3.82E + 0.6	25.331
dSEVILLA	4.06E + 0.6	22.424
dTARRAGONA	4.07E + 0.6	28.292
dVALENCIA	5.31E + 0.6	31.493
dVIGO	3.74E + 0.6	23.485
dVILLAGARCIA	1.84E + 0.6	8.859

Notes: The variable dALGECIRAS and those that follow are binary variables denoting port; all are included as no constant was used. For discussion of the estimation procedure, see Jara-Diaz et al. (2002); 286 observations, R^2 cost function: 0.978, R^2 labor expenditure equation: 0.817, R^2 intermediate input expenditure equation: 0.855, and R^2 capital expenditure equation: 0.801.

APPENDIX B. PARAMETER ESTIMATES OF THE AGGREGATE OUTPUT COST FUNCTION FOR CARGO HANDLING IN SPANISH PORTS

Parameter	Estimate	*t*-Statistic
Labor price (WL)	159.75	7.11
Aggregate cargo (*C*)	11.49	14.28
Trend (*t*)	−0.88	−9.04
WL*WL	−28.18	−8.26
WL*C	48.80	5.03
t*t	0.26	2.27
WL*t	−6.08	−3.99
C*t	0.56	3.67
C*C	−0.17	−2.72
Constant	43.33	14.73

Notes: R^2 quadratic cost function: 0.884 and R^2 labor expenditure equation: 0.908.