Shipowner preferences and user charges: allocating port infrastructure costs

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Abstract

The main aim of this paper is to present a pricing mechanism appropriate for allocating common maritime infrastructure cost which would allow not only a fair and efficient allocation, but also, a solution which would take into account demand characteristics assuring a realistic interpretation of market’s behaviour. The proposed solution concept is that of the “ratio equilibrium”. Its main qualities consist in guaranteeing a balanced budget, and being – from a strategic point of view – a stable solution. In other words, no port user will be discouraged from using the infrastructure by the assignment of a cost-share that is too high. This latter feature adds a competitive element into the calculations and can be considered as an innovative feature of this analysis. A numeric example is presented. © 2000 Elsevier Science Ltd. All rights reserved.

1. Introduction

The Green paper published in 1997 by the European Commission details the approach the EU intends to follow with regards to sea ports and maritime infrastructure. Among other issues, it introduces the principle of “charging the user” for the benefits he/she gains from using the
maritime infrastructure, excluding from this regime only a specific type of infrastructure: that which is not aimed at serving a specific segment of the market (nautical access to a port, berths and navigation aids). The Green paper states that the latter could be defined as a public good and, therefore, it would be economically justifiable to finance it with public means.

The subsequent document published in 1998 by the EU, the White paper on “principles of fair payment for transport infrastructure” (for all transport modes), does not analyse in as much detail the issues relating to port infrastructure. It limits itself to reaffirming the principle that the “user must pay” and it does not recall the exemption made for general use infrastructure.

The factor generally used in distinguishing between infrastructure that can be identified with a public good, and that which cannot, is the possibility of a common and general use, by one or by a plurality of agents, that would not generate a reduction in the consumption of other users (non-rivalry) and the fact that it would be too costly to exclude users from the consumption benefits associated with it (non-excludability). However, in the case of the nautical access to a port, under the assumption of no congestion, the absence of rivalry in consumption holds. The access of a vessel can be limited by the port authority and the users are easily identifiable, and therefore, excludable. ¹

The public good definition given by the EU seems to be dictated not by the intrinsic characteristics of the “good” itself, but by political considerations. These are mainly related to the impact that an “unqualified and abrupt” application of the user pay principle, associated with treating port access as a private good, would have on a number of geographically concentrated ports, ² some of which are “important gateways to European trade” (EU, 1997, p. 21), and on the generated inland waterway traffic. Other possible reasons, not explicitly referred to could be the impact on the economy of the interested region, the positive externalities generated by the port location, the value added generated by its presence, etc. ³ However, by stating that “there is no a priori reason why maritime access should be treated any differently from other port infrastructure” (EU, 1997, p. 21) the document does not exclude the possibility that, in the future – possibly after the implementation of such policies in areas where this is “more urgent and easier to achieve” (EU, 1997, p. 21) – the cost recovering principle could be reflected in the pricing policies related to this type of infrastructure or that ad hoc schemes could be adopted. ⁴

It is the objective of this paper to provide an original framework to determine the optimal extent of specific port access infrastructure ⁵ and, in particular, how its associated cost could be fairly divided among its users without producing a deficit budget. ⁶ The issue is addressed in two stages. In the first stage a public good provision problem is considered. Taking into account the

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¹ The goods that are excludable but not rival are inherently not public goods but can instead be defined “club goods”, a concept originally introduced by Buchanan (1965). Furthermore, should congestion be present, the nautical access to the port would be defined a “private good”, just as berths. The latter, in fact, are both excludable and rival.

² A number of European ports, mainly those located on the northern coast of Europe, are located on estuaries or are river ports, subject to silting and where the provision of maritime access requires substantial outlays.

³ These considerations could, under specific assumptions, justify public intervention in the supplying of the infrastructure.

⁴ This could be the rationale behind the lack, in the White paper (Commission of the European Communities, 1998), of specific reference to this type of infrastructure.

⁵ The application could be extended to other types of infrastructure as well.

⁶ Efficiency, in this context, refers to the condition of total recovery of the overall cost.
user’s willingness to pay for the infrastructure and its cost structure the optimal level of public good is determined, while in the second stage, taking the infrastructure as given, the allocation of its associated cost is determined, accounting for shipowners’ preferences. This latter feature adds a competitive element into the calculations, and can be considered an innovative feature since previous approaches disregard it completely.

The proposed solution concept is that of the “ratio equilibrium”. Its main qualities consist in guaranteeing a balanced budget and a stable solution. In other words, no port user will be discouraged from using the infrastructure by the assignment of a cost share that is too high.

The paper is as follows. Section 2 offers a review of the main literature on various pricing systems and their advantages and drawbacks. Section 3 presents the issues related to the provision of an efficient level of a public good and of determining the set of core allocations among which to choose the appropriate one. It also explains the concept and the implications of the ratio equilibrium solution. Section 4 illustrates, with a specific example, the calculations needed to implement the selected pricing mechanism. The results, although based on a number of simplifying assumptions, demonstrate the validity of the instrument presented and allow to compare the outcomes of different pricing mechanisms. The last section contains concluding remarks.

2. Review of the literature

While earlier port pricing literature advocated marginal cost pricing as an appropriate pricing policy, more recent literature highlight its shortcomings. The problem with this standard methodology was first asserted by Heggie (1974) and later by Bromwich (1978). To ensure the economic viability of a port, pricing should be based on the long run cost and not on “the economist’s short run pricing principles” (Bromwich, 1978, p. 228). The major reason was that the sum of marginal costs are not even close to a budget that takes into account the writing-off of the infrastructure. Also Walters (1974) remarked that the main problem with applying marginal cost pricing in a port is that the presence of economies of scale will systematically cause this pricing policy to generate losses, since marginal cost is well below average cost. The standard second best solution to such a problem would be to apply Ramsey prices, adding a mark-up to marginal costs so as to meet the budget constraint and assuring a minimal deviation from demand under the first best, marginal cost pricing, solution. Finally, in a more recent paper Talley (1994) states that “in attempting to apply marginal cost pricing to ports, a practical problem arises – the inability of ports to determine the marginal costs of their services” (Talley, 1994, p. 62), and mentions several reasons. It is clear that this problem inevitably carries over to the application of Ramsey pricing.

A number of pragmatic alternatives to the pricing problem of shared capacity have been proposed as alternative to marginal cost pricing. The objective of these rules is not to determine an optimal solution in which the net benefits to the consumers and the provider of the infrastructure are maximised, but to provide an operational and workable instrument to set prices. Of course the ease of computation and the limited data requirements come at the expense of a certain amount of welfare.

A first formulation of this concept is due to Lindahl (1919) and to further contributions by Kaneko (1977).
A commonly used way to set prices for jointly used infrastructure is the fully distributed cost (FDC) method. The distinguishing feature of FDC pricing consists in the allocation of shared costs without strong reference to economically meaningful criteria. It is a form of average cost pricing in which the common cost is distributed according to the relative share of output of the service in total output. This method is frequently used because the data can be found easily in port accounts, but it ignores price efficiency and the calculated prices are arbitrary and lack a conceptual foundation.

A second pragmatic approach is based on concepts of cooperative game theory. The key ideas of this method were introduced by Shapley (1953) and Faulhaber (1975). The focus is on guaranteeing that there will be no cross-subsidy between the different users of the shared infrastructure. The “Shapley value” is a complex formula that, when applied to joint cost, is assured to provide subsidy-free cost allocations. This Shapley value takes on a more workable form – that Moulin (1994) proposes to call “Serial cost sharing formula” – when the cost of producing the infrastructure has the specific feature that it depends solely on the capacity needs of the biggest user. A well known example is the “Airport game”: it is self-evident that the cost of a runway is only contingent on the biggest aeroplane that is to be serviced.

Bergantino and Coppejans (1997) applied this serial cost sharing method to the nautical access to the port of Antwerp. While the results were encouraging, some of the properties of the calculated fees structure, which might have been desired in other contexts, did not seem to be ideal in a port-environment characterised by strong competition. In particular, the property of symmetry, i.e. the solution fees “treats equals equally”, represent a major shortcoming. This property, justified at first glance, is unrealistic in a context where two ships, with the same relevant dimension, cannot always be charged equally on the account of different price sensitivity/elasticity. In other words, this method does not include preferences in the allocation of common infrastructure costs.

Another set of solution concepts that assumes demand for the good independent of prices is the so-called “axiomatic approach”. This is used to determine the prices of the output of a multi-product firm by allocating the full cost of production of all the outputs to the users assuming them to be insensitive to prices. The key feature of this method is that the pricing principle is simply the combination of a set of desirable characteristics or “axioms” such as “balancing the budget”, “consistency”, “population monotonicity”. A number of authors have illustrated this approach, however, for the purpose of this study, it is interesting to focus on the empirical application of the axiomatic approach presented by Talley (1994). He is the first to apply it to pricing

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8 Other possibilities are the share in total revenue, the share in total attributable cost etc. For a detailed analysis of the FDC method, see Braeutigam (1980).

9 Supposing there are n users and the capacity needed for user i is “y_i”, this cost function can be algebraically formulated as c = c(max,y_i) for i = 1 to n.


11 For instance, a 40 ft. BULK carrier is more price-sensitive than a CARGO ship of the same dimensions.

12 While the first axiom is self-explanatory, the last two need some interpretation. “consistency” implies that all outputs with the same allocated costs are to be priced the same while “population monotonicity” implies that when the set of agents (e.g. shipowners) using a common capacity (e.g. a berth) increases, none of the previous participants should be made worse-off by paying a higher share of the total costs. The reader is referred to Thomson (1983), Mirman et al. (1982) and Talley (1994).

in a maritime environment. He justifies his approach on three main considerations: the characteristics of the approach itself, the fact that ports can be identified with multi-product firms whose services show a relatively price inelastic demand, and finally, that after careful selection of the desired axioms or properties the resulting cost allocation rule would need limited data requirements and computational efforts. He concluded that Moriarty’s rule – allocation of a common cost among units that share it in proportion to exclusive capacity (stand alone) costs – embraces the desired properties for ports localised in the geographical area object of his study. He also highlights the advantages of this methodology with respect to alternative capacity rules based on game theory algorithms, which are more costly to apply. However, the extension of this approach to areas where ports cannot enjoy captive markets and have to face competitive pressures, faces the same limitation as the previous solution concept. Both these approaches are penalised by the lack of relevance allocated to users’ preferences.

3. Theoretical framework

3.1. Providing an efficient level of a public good

Although the EU decision to define a number of port services as public goods might have stemmed from political considerations, it is not the aim of the paper to take a position in this respect. In the remainder of the paper, the infrastructure guaranteeing access to a port will be considered as a public good. We begin by considering an ex-ante situation in which the infrastructure has not yet been built and the problem is to determine the efficient amount of public good. In order to approach this issue we make some assumptions: the specific type of public good can be produced in any continuous amount, the cost of providing the infrastructure is strictly convex, which in our context, implies that the marginal cost of providing one foot of draught increases more than linearly.

The well known condition for efficiency in the case of continuous provision of a public good – the sum of the marginal rates of substitution (MRS) equals the marginal cost of provision – under the assumption that the utility functions of the economic agents are quasi-linear, will typically determine one, and only one, efficient level of the public good.

Considering two agents (shipowners) each operating a ship of different type (BULK and CARGO, respectively) these results and assumptions can be translated in: willingness-to-pay,
\( b(y) \), a cost function \( c(y) \), and two goods of which, one public, \( y \), and one private (monetary), \( x \). The “price” of the public good can be identified with a share in the cost of providing the public good itself.

Defining \( u_i(\cdot) \) as agents’ utility functions (i.e. shipowners’ utilities), we have the following:

\[
\begin{align*}
\tag{1}
&u_{\text{CARGO}}(y, x_{\text{CARGO}}) = b_{\text{CARGO}}(y) - x_{\text{CARGO}}, \\
&u_{\text{BULK}}(y, x_{\text{BULK}}) = b_{\text{BULK}}(y) - x_{\text{BULK}},
\end{align*}
\]

where the first and the second order conditions are:

\[
\begin{align*}
\tag{3}
&\frac{\partial b_i(y)}{\partial y} \geq 0, \\
\tag{4}
&\frac{\partial^2 b_i(y)}{\partial y^2} \leq 0.
\end{align*}
\]

The cost function, \( c(y) \), which respects the assumptions previously made, is characterised by the following:

\[
\begin{align*}
\tag{5}
&c(0) = 0, \\
\tag{6}
&\frac{\partial c(y)}{\partial y} > 0, \\
&\frac{\partial^2 c(y)}{\partial y^2} > 0.
\end{align*}
\]

In this case, the conditions for an efficient provision of a public good \(^{20}\) are:

\[
\text{MRS}_{\text{BULK}} + \text{MRS}_{\text{CARGO}} \equiv \text{MC}.
\]

This is equivalent to saying:

\[
\begin{align*}
\tag{8}
&\frac{\partial u_{\text{BULK}}(y, x_{\text{BULK}})/\partial y}{\partial u_{\text{BULK}}(y, x_{\text{BULK}})/\partial x_{\text{BULK}}} + \frac{\partial u_{\text{CARGO}}(y, x_{\text{CARGO}})/\partial y}{\partial u_{\text{CARGO}}(y, x_{\text{CARGO}})/\partial x_{\text{CARGO}}} \\
&= -\left( \frac{\partial b_{\text{BULK}}(y)}{\partial y} + \frac{\partial b_{\text{CARGO}}(y)}{\partial y} \right) = \frac{\partial c(y)}{\partial y}.
\end{align*}
\]

At the level production level \( y^* \), the marginal cost of providing the amount of public good equals the sum of marginal willingness to pay, this is the efficient level of public good. Furthermore, from the graphical representation it is clear that agent CARGO is willing to pay more for the amount \( y^* \) than agent BULK. \(^{21}\) In other words, the former is willing to exchange more of its (monetary) input for the public output than the latter:

\[
\text{MRS}_{\text{CARGO}} > \text{MRS}_{\text{BULK}}.
\]

\(^{20}\) The marginal rate of substitution, reduces to marginal utility or marginal willingness-to-pay under quasilinear utility functions of the form \( u_i(y, x_i) = b_i(y) + x_i \), since \( \partial u_i(y, x_i)/\partial x_i \) will be equal to 1.

\(^{21}\) This depends on the assumptions we make on the different characteristics of the two shipowners.
3.2. The set of core allocations

Once the efficient level of public good is determined, the individual shares in the total cost of providing the infrastructure can be calculated. The following a priori restrictions on these shares are imposed: the shares must be positive (i.e. no agent receives money), their sum must equal the cost of providing the efficient level of public good (balanced budget condition), and they should not exceed the individual willingness to pay of the economic agents (voluntary participation condition).

The above conditions can be expressed formally by:

\[ x_i \geq 0, \quad \sum x_i = c(y), \quad x_i \leq b_i(y). \] (9)

The resulting set of cost allocation shares represents the “core”. It can be assumed that, under the existing assumptions on utilities and costs, this core will never be empty (Moulin, 1995, p. 281). Moreover it will typically include more than one solution. In other words, the core sets loose bounds on the division of costs. Fig. 1 shows the set of possible solutions (cost ratios) that are contained in the core. All cost allocations on the line \( X^*X^* \) ensure a balanced budget. Allocations that are situated below the horizontal dotted line, \( (b_{BULK}(y^*)) \), do not violate the voluntary participation condition for agent BULK: his willingness-to-pay is greater than his allocated share in the costs. A similar line of thought with respect to agent CARGO holds for the allocations on the left-hand side of the vertical dotted line \( (b_{CARGO}(y^*)) \). By exclusion, the core can be identified. This is represented by the bold segment in the figure. As it can be seen, this contains a number of possible solutions among which one should be picked.

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22 Allocations that are in the core guarantee automatically a balanced budget under the provision that each agent participates.
3.3. A deterministic selection from the core

In order to determine which, among the possible core solutions, should be picked it is necessarily to introduce the concept of "ratio equilibrium". The term ratio equilibrium was first introduced by Kaneko (1977) and can be compared to the competitive equilibrium of an exchange economy, in which each of the agents receives a price signal. These price signals consist in paying a share of total costs and are personalised in such a way that any one of the agents will demand the same amount of the public good. More formally, the definition of ratio equilibrium, can be expressed as Moulin (1995, p. 287): given a public good provision problem \((u_1, \ldots, u_n; c)\), a set of ratios is a vector \((r_1, \ldots, r_n)\) where \(r_i \geq 0\) for all \(i\) and \(\sum r_i = 1\). We say that the outcome \((y^*; x^*_1, \ldots, x^*_n)\) is a ratio equilibrium with ratios \((r_1, \ldots, r_n)\) if we have, for all \(i\):

\[
x^*_i = r_i c(y^*)
\]

and

\[
u_i(y^*, x^*_i) = \max_{y \geq 0} u_i(y, r_i c(y)).
\]

It depends on the (in)divisible character of the public good whether this solution concept picks out one single value from the core, or more than one. In fact, we have that, in the case of indivisible units of the public good provided – where utility is quasilinear, marginal costs are increasing and marginal utility decreases (the regular convexity assumptions) – there exists at least one ratio equilibrium. In the case of divisible units of the public good, and under the same assumptions, there exists exactly one ratio equilibrium.

Since, until now, we have assumed an ex-ante position, we can assume that the public good can be produced in any continuous amount, and is, therefore, divisible. Moreover, under the regular convexity assumptions, this unique ratio equilibrium has the feature that the relative share in total costs is proportional to the marginal rate of substitution. This follows directly from developing the first-order conditions for optimality from (10) and (11):

\[
\frac{\partial u_i(y, r_i c(y))}{\partial y} = 0 \iff \frac{\partial u_i(y, x_i)}{\partial y} + \frac{\partial u_i(y, x_i)}{\partial x_i} \frac{\partial x_i}{\partial y} = 0 \iff \frac{\partial u_i(y, x_i)}{\partial y} + r_i \frac{\partial u_i(y, x_i)}{\partial x_i} \frac{\partial c(y)}{\partial y} = 0.
\]

After rearranging we get

\[
\frac{\partial c(y)}{\partial y} r_i \frac{\partial u_i(y, x_i)}{\partial x_i} = \left| \frac{\partial u_i(y, x_i)}{\partial y} \right| = \text{MRS}_i.
\]

Since, at the optimal level of production, the marginal cost equals the sum of all individual marginal rates of substitution, we have the following straightforward result:

\[23\] However, it has a famous ancestor, the Lindahl equilibrium. These two concepts differ in that for the ratio equilibrium the price is non-linear in the quantity of public good, since it is a share of a cost (function). Of course the Lindahl equilibrium and the ratio equilibrium coincide if the cost function is linear. See Moulin (1995, p. 287 and p. 319) for a discussion.
The most relevant characteristics of the ratio equilibrium are that: it is in the “stand-alone core” \(^{24}\) and thus, as Moulin (1995) states: “...has a positive interpretation as the set of stable agreements if each agent has free access to the technology” and it is Pareto-optimal. \(^{25}\) In other words it guarantees efficiency and fairness in the sense that, if every (coalition of) economic agent(s) would have the possibility of constructing the infrastructure it needs for itself, with the existing technology, he would end up paying more than his assigned cost share, \(r_i\). Moreover, compared to cost allocations based on the Shapley or the Owen value, the ratio equilibrium is closer to reality since it does not consider uniquely costs, but includes the preference structure of the economic agents through a weight in their utility function.

In Section 4 we will present an empirical application of the theoretical framework outlined starting however, from a different assumption. The hypothesis is, in fact, that of being in an ex post situation: the infrastructure has been built and the cost has to be allocated.

4. An example that accounts for the specific characteristics of maritime infrastructure

In this section, in order to take account of the demand side, we assume that there are two agents, respectively a BULK and a CARGO shipowner, each with a different preference structure \((v_i)\). The different preferences are dictated by the fact that while shipowner CARGO operates general CARGO ships with shallow draught but that carry high value CARGO, shipowner BULK has a fleet of deep-draught BULK vessels, carrying CARGO of lower value. The maximum size of the biggest ships in the two fleets is respectively: 28 and 36 ft. Allowance must be made in both cases for “keel clearance”. \(^{26}\) We also consider that the production technology operates under decreasing returns to scale, i.e. increasing average costs. We assume that the preferences of the two shipowners can be represented by the following quasi-linear utility functions: \(^{27}\)

\[
u_{BULK}(y, x_{BULK}) = b_{BULK}(y) - x_{BULK} = 2v_{BULK} \sqrt{\min\left(y; 36 + \left(y - \frac{36}{10}\right); 38\right)} - x_{BULK},
\]

\[
u_{CARGO}(y, x_{CARGO}) = b_{CARGO}(y) - x_{CARGO} = 2v_{CARGO} \sqrt{\min\left(y; 28 + \left(y - \frac{28}{10}\right); 29\right)} - x_{CARGO}.
\]

The rationale behind these utility functions is the following: first, all other things being equal, shipowner CARGO will give to a specific draught a value greater than shipowner BULK, since he

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\(^{24}\) For a concise definition, see Moulin (1995, p. 281).

\(^{25}\) For a proof, see Moulin (1995, p. 287).

\(^{26}\) The distance between the keel of the ship and the bottom of the channel.

\(^{27}\) The 10 at the denominator of the utility functions is included as a scaling factor.
carries CARGO of a higher value. This is taken account of by giving to \( v_{\text{CARGO}} \) a value greater than \( v_{\text{BULK}} \). These two parameters could be used also to take account of different characteristics, e.g. shipowner CARGO calls at the port more frequently than shipowner BULK, etc. Second, the square root assures utility to be concave in draught i.e. the shipowners extract additional utility from one extra feet of draught. This marginal utility is decreasing: all ships profit from, for instance, the first \( x \) feet, but only the biggest ship of the shipowners CARGO and BULK need, respectively, a draught greater than 28 and 36 ft. in order to be physically able to enter the channel. From 36 ft. onwards, marginal utility of shipowner BULK for additional draught is greatly reduced. The obvious reason is that all of his ships can access the port. Yet, this marginal utility is not zero, because he needs an additional 50% for the so called “keel clearance” to be able to proceed at full speed. 28 From a draught of 56 ft. onwards the marginal utility he gains from additional draught reduces to zero, 29 the same line of reasoning holds for Shipowner CARGO. Finally, the “\( \min \)” operators reflect the occurrence of satiation among the operators towards the “good” draught.

On the supply side, the cost function is a rough estimation of the dredging cost to maintain \( y \) feet of tide-independent draught (in mil USD). Without dredging (cost = 0) ships with a draught of approximately 23 ft. can enter the port 24 h a day. The cost of providing a tide-independent window for ships of deeper draught increases with a factor to the power of three. 30 It can be assumed that the following function, for which the coefficients have been determined empirically using data obtained from the Port Authority of Antwerp, yields a realistic representation of the cost schedule for the dredging programme: 31

\[
c(y) = -2 + 0.170 \left( \frac{y}{10} \right)^3 \quad (\text{for values of } y > 23, \text{ else } c(y) = 0).
\]  

(17)

4.1. The optimal level of draught

At the optimal level of draught, the difference between the total utility to the two shipowners and the cost of providing this level of infrastructure, reaches a maximum. From a “marginal” point of view, this means that, at this efficient level of provision, the sum of the individual willingness-to-pay for a marginal feet of draught equals, exactly, the marginal cost of providing this extra foot. In other words, willingness-to-pay for draught is, in this context, equivalent to the rate at which the shipowner is willing to substitute the public output good \( y \) for the private input good \( x \), money. Evidently marginal willingness-to-pay is then equivalent to the MRS. The well known condition for efficiency:

\[
MRS_{\text{BULK}} + MRS_{\text{CARGO}} \equiv MC
\]

is respected.

\[28\] This is due to a problem known as “squatting” of the ship.

\[29\] This, for shipowner BULK, is obtained from the following: 36 + (\( y \) – 36)/10 > 38 \( \iff \) \( y > 56 \) (where 38 ft. is used for calculation reasons). Again, the same reasoning holds for shipowner CARGO.

\[30\] Derived from Bergantino and Coppejans (1997).

\[31\] The coefficients of Eq. (17) have been obtained by fitting a function to a limited data set concerning dredging costs for the port of Antwerp taken from a publication of the Ministerie van de Vlaamse Gemeenschap (1994).
The built-in satiation levels lead to a structure of the MRS that is not continuous, but is different according to the three different draught-satiation levels. (Table 1).

Both shipowners enjoy an extra tidal window up to 28 ft., although CARGO will extract more marginal utility than BULK (since $v_{\text{CARGO}} > v_{\text{BULK}}$). From 28 ft. on, all the ships of shipowner CARGO can physically enter the port. Additional draught will be of minor value to him, but this extra draught will allow him to proceed at optimal operational speed. This shipowner has no interest in a round the clock tidal for ships with a draught deeper than 38 ft.: his marginal utility drops to zero. The same line of thought holds for shipowner BULK.

Marginal costs are straightforward from (17).

The resulting optimal level of production depends on the parameters that reflect the value of the CARGO, $v_{\text{CARGO}}$ and $v_{\text{BULK}}$. As an exercise, these are set to be equal to 10 and 0.25, respectively. In Fig. 2, the marginal utilities (MRS$_{\text{CARGO}}$ and MRS$_{\text{BULK}}$) are confronted with the marginal cost (MC); this illustrates the issue graphically. The optimal level of production is 35.2 ft., which, rounded off would be 35 ft. This implies that shipowner BULK will not be able to call at the port with his biggest ship.

As can be seen from Fig. 3, the marginal cost of providing 36 ft. exceeds the total marginal willingness to pay, therefore, from an economic point of view, it is not efficient to provide 36 ft. of draught.

In Table 2 some of the key figures related to the optimal level of the infrastructure are summarised; these are: the individual and the total willingness to pay of the shipowners for 35 ft., the cost to provide 35 ft. of tide independent draught and the net surplus that the two shipowners extract from this level of draught.

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Table 1
Marginal rates of substitution per interval of draught

<table>
<thead>
<tr>
<th>Shipowner BULK</th>
<th>MRS</th>
<th>Shipowner CARGO</th>
<th>MRS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interval of draught</td>
<td></td>
<td>Interval of draught</td>
<td></td>
</tr>
<tr>
<td>$y \leq 36$ ft.</td>
<td>$v_{\text{BULK}} / \sqrt{y}$</td>
<td>$y \leq 28$ ft.</td>
<td>$v_{\text{CARGO}} / \sqrt{y}$</td>
</tr>
<tr>
<td>$36 &lt; y \leq 56$ ft.</td>
<td>$v_{\text{BULK}} / 324 + y$</td>
<td>$28 &lt; y \leq 38$ ft.</td>
<td>$v_{\text{CARGO}} / 252 + y$</td>
</tr>
<tr>
<td>$y &gt; 56$ ft.</td>
<td>0</td>
<td>$y &gt; 38$ ft.</td>
<td>0</td>
</tr>
</tbody>
</table>

---

32 The numeric results presented in the remaining part of the paper depend strongly on the values assigned to the $v_i$ coefficient which the authors have assumed as being very different on the base of the consideration that the willingness to pay for the two types of shipowner varies significantly. The values have been chosen using information obtained through informal talks with representative shipowners chosen from both categories. In order to measure the variability of the results on percentage changes in the values assigned to the coefficients simulations have been made and these, carried out for percentage changes in the range of $\pm 25\%$ for each coefficient, show that the results do not change significantly. The authors, however, remain aware of the need to determine the values of $v_i$ more realistically; therefore the reader should take the following results mainly as a numeric exercise to show the possibility to implement the methodology described.
Having determined the net benefit and the total cost necessary to maximise the utility of the two shipowners, in the following sections the latter will be allocated to the two shipowners.
4.2. The set of core allocations

The issue now is how to share the cost of providing the optimal level of draught, under the restriction that no shipowner should receive money to use the infrastructure and that no individual cost share should be greater than the monetary value of the utility obtained. This translates in the following:

\[ 0 \leq x_{\text{CARGO}} \leq 107.1 \]  \hspace{1cm} (20)

\[ 0 \leq x_{\text{BULK}} \leq 3.0 \]  \hspace{1cm} (21)

with

\[ x_{\text{CARGO}} + x_{\text{BULK}} = 5.3. \]  \hspace{1cm} (22)

The upper bounds of the two inequalities guarantee “Voluntary Participation” – which implies that demand would not be deterred – and the lower bounds assure that no shipowner receives money to use the infrastructure. The equality stands for “efficiency”: the port is assured total cost recovery without extra profits (balanced budget). The set of allocations that respect this condition is rather large: it sets loose bounds on the allocation of the cost, and, therefore, of the surplus, among the two shipowners. Possible allocations vary between two extremes summarised in Table 3.

The deterministic selection from the core will be based on the ratio equilibrium according to Eq. (14) and will be situated between the two extremes in Table 3.

4.3. One unique selection from the core: the ratio equilibrium

In this section we apply the ratio-equilibrium solution to share the total cost of providing the optimal level of infrastructure.

<table>
<thead>
<tr>
<th>Table 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net benefit and cost shares at the two extremes of the core</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Shipowner BULK</td>
</tr>
<tr>
<td>---------------</td>
</tr>
<tr>
<td>(1) A free ride for shipowner BULK, who pays nothing and cashes in 100% of his willingness to pay, while shipowner CARGO bears the full cost</td>
</tr>
<tr>
<td>Willingness-to-pay extracted utility, ( b_i(y) )</td>
</tr>
<tr>
<td>Cost share in absolute terms, ( x_i )</td>
</tr>
<tr>
<td>Net benefit, ( u_i(y) )</td>
</tr>
<tr>
<td>(2) A zero net benefit to shipowner BULK, with shipowner CARGO paying the remainder</td>
</tr>
<tr>
<td>Willingness-to-pay extracted utility, ( b_i(y) )</td>
</tr>
<tr>
<td>Cost share in absolute terms, ( x_i )</td>
</tr>
<tr>
<td>Net benefit, ( u_i(y) )</td>
</tr>
</tbody>
</table>
Because utilities are linear in the monetary input good, the MRS in (14), coincides with marginal utility, $b'(y)$. The marginal utilities of the shipowners CARGO and BULK at 35 ft. of draught are 0.59 and 0.04, respectively.

The resulting relative shares in total costs are:

$$r_{\text{BULK}} = \frac{\text{MRS}_{\text{BULK}}}{\text{MRS}_{\text{BULK}} + \text{MRS}_{\text{CARGO}}} = 6.3\%,$$

$$r_{\text{CARGO}} = \frac{\text{MRS}_{\text{CARGO}}}{\text{MRS}_{\text{BULK}} + \text{MRS}_{\text{CARGO}}} = 93.7\%.$$

The payable fees, in absolute terms are:

$$x_{\text{BULK}} = r_{\text{BULK}} c(y) = 0.063 \cdot 5.3 = 0.33,$$

$$x_{\text{CARGO}} = r_{\text{CARGO}} c(y) = 0.937 \cdot 5.3 = 4.97.$$

From which net utilities for the shipowners are:

$$u_{\text{BULK}}(y, x) = b_{\text{BULK}}(y) - x_{\text{BULK}} = 3.0 - 0.33 = 2.67,$$

$$u_{\text{CARGO}}(y, x) = b_{\text{CARGO}}(y) - x_{\text{CARGO}} = 107.1 - 4.97 = 102.13.$$

The imputed costs that induce an optimal demand for the public good are 0.33 and 4.97 for the shipowners BULK and CARGO, respectively. The ratio equilibrium solution clearly incorporates elements of competition: the prices that are presented to the single economic agents are such that those who attribute a low value to the marginal unit of infrastructure, i.e. those who are sensitive to higher prices, will be allocated a small share of the total cost. Fig. 3 shows this solution graphically.

In Fig. 3, point $A$ and point $B$ are, for shipowner BULK and shipowner CARGO respectively, the combination of output (draught) and charges that maximise their utility allowing total cost recovery for the port access provider.

4.4. Comparison of the outcomes of different cost allocation rules and topics for further research

Finally, it seems appropriate to conclude this work by comparing the results obtained applying the ratio equilibrium approach with those that would have been obtained had the Shapley value (Bergantino and Coppejans, 1997) or the Moriarity rule (Talley, 1994) been used. The results highlight the main drawback of the latter methods, in particular the fact that they do not take account of the preference structure of the relevant economic agents. The comparison is shown in Table 4. With the Shapley value, while the cost of the infrastructure used by both BULK and CARGO shipowners (draught below 28 ft.) would be shared, shipowner BULK would have to cover the full cost of the remaining infrastructure for a draught greater than 28 ft. (see also Bergantino and Coppejans, 1997). This allocation of costs is clearly not strategy-proof: the share of total costs allocated to the BULK operator would exceed his willingness to pay and he would

33 Since $\left| \frac{\partial b(y, x)}{\partial x_i} \right| = \left| \frac{\partial b(y) - x_i}{\partial x_i} \right| = 1$. 
not have an incentive to call at the port. From the results presented in the table, it can be seen that a similar line of reasoning holds for the application of Moriarty’s rule. In contrast, this problem does not arise for the solution obtained using the marginal benefit approach (ratio equilibrium).

Table 5 contains the calculated net benefit values for the three solutions.

In Table 5, the cost shares resulting from the application of the ratio equilibrium approach are stable from a strategic point of view, in the sense that net benefit is guaranteed to be positive for each agent and that, for this specific example, based on the artificially introduced coefficients relating to the value of CARGO, this net benefit represents more than 90% of the total potential benefit for both shipowners.

From this study, new ideas for further research arise. It is obvious that, when asked, the shipowners would have no interest in revealing their true preferences for maritime infrastructure, since this would only increase their cost share. While using the Shapley value or Moriarty’s rule this problem does not occur (since these allocation rules consider solely costs, not preferences). In this paper we solved this revelation problem by assuming that certain characteristics, such as the value of the CARGO and the number and size of ships of a certain shipowner that call at the port, can be used as proxy for shipowners’ preferences. It is a subject of future research to check if and when this assumption holds and to identify an appropriate methodology to calculate more reliable coefficients.

A second suggestion for future research is to investigate the applicability of so called Egalitarian-Equivalent solution concepts for the allocation of joint port infrastructure which can serve the purpose of solving the main defect of the ratio equilibrium, that of not being either population

<table>
<thead>
<tr>
<th>Table 4</th>
<th>Comparison of the cost shares using the different methods</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( x_{\text{BULK}} )</td>
</tr>
<tr>
<td>Paying the average marginal infrastructure cost (Shapley-value)</td>
<td>4.44</td>
</tr>
<tr>
<td>Paying according to Moriarty’s rule</td>
<td>4.00</td>
</tr>
<tr>
<td>Paying according to marginal benefit (ratio-equilibrium)</td>
<td>0.33</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 5</th>
<th>Comparison of the net benefit using the different methods</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Willingness to pay extracted utility</td>
</tr>
<tr>
<td><strong>Shapley value</strong></td>
<td></td>
</tr>
<tr>
<td>BULK</td>
<td>3.0</td>
</tr>
<tr>
<td>CARGO</td>
<td>107.1</td>
</tr>
<tr>
<td>Total</td>
<td>110.1</td>
</tr>
<tr>
<td><strong>Moriarty rule</strong></td>
<td></td>
</tr>
<tr>
<td>BULK</td>
<td>3.0</td>
</tr>
<tr>
<td>CARGO</td>
<td>107.1</td>
</tr>
<tr>
<td>Total</td>
<td>110.1</td>
</tr>
<tr>
<td><strong>Ratio-equilibrium</strong></td>
<td></td>
</tr>
<tr>
<td>BULK</td>
<td>3.0</td>
</tr>
<tr>
<td>CARGO</td>
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</tr>
<tr>
<td>Total</td>
<td>110.1</td>
</tr>
</tbody>
</table>
nor cost monotonic. Finally, in the course of further studies the problem of “satiation” cannot be disregarded. With the ratio equilibrium solution, an agent who is satiated before the efficient level of production has been reached will pay nothing even if his absolute benefit is large. In other words, a solution to the possibility of this unfair free riding behaviour should be found.

5. Some concluding remarks

Given the intensifying and world-wide trend towards port privatisation, determining the cost-shares for users of common facilities in a port is becoming of pivotal importance. The main aim of this paper is to determine a pricing mechanism for allocating maritime infrastructure cost which would allow not only a fair and efficient allocation of common infrastructure costs, but also a solution which would be strategy-proof. This is an improvement over previous work of the authors (1997) as it includes demand characteristics within the calculations.

The issue has been tackled in two stages. In the first, after a review of the various methods available and their main characteristics and drawbacks, classical theory has been used to illustrate how to determine the efficient provision of public goods and the ratio equilibrium model has been proposed as a possible method to allocate its costs. This method, by taking into account the preference structure of shipowners, assures a more realistic interpretation of the market.

In a second stage, the infrastructure has been taken as given and the allocation of the costs associated with it among the port users has been calculated for a specific example. The final part of the paper contains the results of the calculations and provides a comparison of the outcome of the ratio equilibrium solution with that of other allocation rules available. The results highlight the advantage that such a method has over the others: its capacity of considering both sides of a market, demand and supply. But it is urgent to undertake further research in the direction of identifying a methodology capable of yielding coefficients more accurately and reliably reflecting shipowners’ preferences, i.e., to overcome the reluctance of participants to reveal their value of the port facilities.

References


34 For an explanation of the terminology the reader is referred back to footnote 13.


