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PRIORITY 1.6.2
Sustainable Surface Transport

CATRIN
Cost Allocation of TRansport INfrastructure cost

D 10 – Allocation of infrastructure cost in the maritime sector

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0 Executive summary

This deliverable consists in principle of two parts; one part with a review of the literature around maritime infrastructure cost with a focus on fairways (section 3), pilotage (section 4) and ports (section 5) and another part with an in-depth study on the Baltic icebreaking fleet (section 6).

Our main conclusion from the first part is that all these parts of the infrastructure (fairways, pilotage and ports) show significant economies of scale. A long run marginal cost pricing strategy will never recover the cost and a short run pricing strategy (including user costs) will have problems with cost recovery if the capacity utilisation is low. The pricing strategies observed seem to use numerous forms of two part tariffs and “Ramsey” pricing solutions to solve the cost recovery issue of the sector. The consequence of all these (small) deviations from marginal cost pricing should probably be further analysed.

- The economic literature of maritime economics has one branch on shipping and one on port economics. Port economics is a rather new branch and constitutes maybe 20% of the literature in maritime economics. The literature seldom deals explicitly with the cost of fairways or pilotage.
- Our review suggests that the use of fairways in general has a very low marginal cost although the literature to support such a claim is almost non existent.
- Pilotage seems also to run under economies of scale and the cost is, to a large extent, independent of vessel type and size.
- The practice in charging for pilotage in some Member States is a two part tariff structure where one charge is related to the actual pilotage while the other is a form of tax levied on all ships to recover the cost of pilotage. In other Member States there is a hidden cross subsidy between fairway dues on all ships and the cost of pilotage.
- Comparing the expected marginal pilotage cost with the price structure suggests that the category of ships with lowest charges are charged something equal to marginal cost while the bigger ships pay a mark-up, basically to improve cost recovery. Consequently, in addition to the two part tariff system a type of “Ramsey” pricing could be observed.
- Port charges are a complex issue as it contains the infrastructure for ships as well as the infrastructure for cargo. In general the conclusion seems to be that ports are a multi-product industry where the production is taking place under economies of scale.
- While the cost of consumption of the port’s resources is of minor importance the vessel cost is dominant and is probably approximately 10-20 times higher than the infrastructure cost of a port call. Thus the most important element in infrastructure pricing is the cost imposed on other users. The optimal port charge would take the queuing cost into account which is the natural form of the short run marginal cost. This cost can be analysed both for the ship and for the cargo. The theoretical charge will thus comprise the two dominant element of charging port services today – charges related to vessels and charges related to cargo.
- The queuing model for pricing will nevertheless not ensure cost recovery. The literature has developed a number of models along the lines of “Ramsey” pricing where joint costs are allocated in a way that disturbs demand as little as possible. However, this solution calls for different mark-ups on different cargo and ship categories to reflect the differences in the elasticity of demand.
The second part deals with icebreaking and notes that icebreaking in open water is not charged for by any EU Member State. Still the case study reported in this paper shows that the operation is characterised by considerable marginal costs.

- Marginal cost for ice-breaking is represented by the variable costs in the case study modelling and the summed marginal cost is estimated at some € 30 million per year in the Baltic, given cooperation. Scarcity costs should be added to that and perhaps also the emission costs.
- Obviously, current charging regimes are theoretically inoptimal. The scheme is not sanctioned by efficiency, but by equity considerations.
- When it comes to icebreaking the most prominent efficiency gains may be to develop the forms for international co-operation, rather than aiming at efficient charging schemes – schemes possibly unlikely to be politically accepted.
- A crucial issue for the further development of icebreaking cooperation is that cost can be properly allocated between the contracting parties. That is true for developed cooperation but also for a piecemeal development from current practice. This study suggests that there are considerable economic gains to be collected.
- Traditionally, countries with ports where ice problems occur have been seen as the rightful owner of the problem. Each county has got and taken the responsibility to cater for the access to and from ports in their own territory.
- It is argued in the report that the European infrastructure budget, TEN-T, could or should contribute to fund icebreaking infrastructure. A common European icebreaker, and in the long run possibly even a common icebreaker fleet, could serve as a trigger for improved cooperation.

Finally, a relevant question to address is to what extent there are justifications for European or international legislation on maritime charging in the light of economic theory. Obviously, it is useful to address different parts of the maritime infrastructure separately.

- Analytically, (fairways in) open waters is probably best seen as a common good. When used by someone, it does not prevent someone else to use it and it does not add to costs for the “infrastructure manager”. The financial cost to provide the infrastructure is close to zero. Charges on (foreign) traffic could be tempting, but would hamper the global economy and would not be in line with international law. Thus, current international legislation appears to be appropriate.
- However, emission charges would be theoretically adequate to provide incentives for shipowners to reduce externalities in terms of air pollution. An international framework for emission charging would have potential. Emission trading could be an alternative. Such a scheme could reduce administrative costs compared to pure charging; reduce risks for market distortions as well as for discriminating charging schemes.
- Maritime accesses are used by the ports’ customers. Excessive charging would then first and foremost hamper the port business, but not the global economy. Local regional or national infrastructure managers may have incentives to recover their costs for providing the infrastructure, but to do it in a way that does not harm the port business. Apart from regular competition law that guarantees non-discrimination, there is no obvious need for international legislation to this end. Still arguments may be raised for environmental charges to make up for air pollution. On the other hand it can be argued that emissions are better handled within a general charging scheme (including open waters).

The main justifications for European policy related to Sea port infrastructure is to:
Prevent distortive state aid. It has been argued that aid to one port can harm the competitiveness of a neighbouring port active in the same market segment.

Trigger efficiency by eliminating monopoly and monopolistic charging for services like stevedoring.

There may be reasons to look upon inland waterways in close parallel to road and rail. The justifications for European charging policy may be similar. Rail charging as well as the charging of HGVs are regulated in European law, basically as a means to prevent overcharging of international transports. To this date the issue has been regulated by regional, international agreements.
1 Introduction

In the CATRIN project studies are carried out to examine the marginal infrastructure cost in all modes. For the maritime sector the focus is on icebreaking. However, to ensure a better coverage of the issues in the sector an additional task is devoted to a survey of cost allocation practices and research in the maritime sector. This report D10 of CATRIN is a summary of the general survey over the cost allocation issues in the maritime sector and an in-depth case study for ice breaking services in the Baltic Sea.

From previous EU funded project such as GRACE and UNITE considerable knowledge has been developed of the (other) external cost such as air pollution, noise, accidents and congestion etc. For the maritime sector the previous projects have mainly presented results for air pollution in the maritime sector. CATRIN is devoted to further develop the knowledge of infrastructure cost. The GRACE project concluded for example: “in the literature practically no useful data on marginal infrastructure cost in the maritime and port sector are found”\(^1\). The ATTENCO study made a deeper review of the port sector and concluded that the cost recovery objective was the main objective of port pricing in a number of European major ports.

This deliverable contributes the current literature and previous EU funded projects with a coverage of the infrastructure cost from the point where the ship enters into fairways (section 3), may need assistance by pilots (section 4) and finally when it is berthed and served in the port (section 5). And as a specific issue the report analyses the situation under winter navigation in a unique way for Baltic Icebreaking services (section 6). Conclusions are offered in section 7.

\(^1\) Bickel et.al. (2006) page 3.
2 Infrastructure and policy in the Maritime sector

This section sets the scene with a discussion on which maritime infrastructure elements that are covered in this report (section 2.1) as well as giving a brief overview over the European Union policy in the area (section 2.2).

2.1 Maritime services

As the Maritime sector usually is defined as including the multimodal interchange between sea transport and land-transport (ports) the number of services covered by the sector is rather diverse covering the service to ships and service to cargo handling. For most other modes the focus, when discussing infrastructure, is towards the service the infrastructure provides for the vehicles. However, in maritime transport the pure infrastructure costs before the cargo enters the terminals are a minor part, as the sea is free, compared with the cost of cargo handling within the ports. Consequently, studies of maritime infrastructure are often focused on the ports.

Table 1: Services in the maritime sector

<table>
<thead>
<tr>
<th>SERVICES TO THE SHIP</th>
<th>OTHER SERVICES TO USERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Safe Navigation</td>
<td>• Leasing land, other resources</td>
</tr>
<tr>
<td>• Aids to navigation</td>
<td>• Office space</td>
</tr>
<tr>
<td>• Dredging</td>
<td>• Warehouses</td>
</tr>
<tr>
<td>• Pilotage</td>
<td>• Equipment, long-term rental</td>
</tr>
<tr>
<td>• Towing</td>
<td>• Land for development</td>
</tr>
<tr>
<td>• Services at the Berth</td>
<td>• Land for operations</td>
</tr>
<tr>
<td>• Berthing</td>
<td>• Security</td>
</tr>
<tr>
<td>• Stevedoring, wharf handling</td>
<td>• Vessels</td>
</tr>
<tr>
<td>• Equipment, short-term rental</td>
<td>• Cargo</td>
</tr>
<tr>
<td>• Water, bunkers garbage removal</td>
<td></td>
</tr>
<tr>
<td>• Electricity and communications</td>
<td></td>
</tr>
<tr>
<td>• Stowage planning</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SERVICES TO THE CARGO</th>
<th>OTHER PORT ACTIVITIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Cargo Processing, Storage</td>
<td>• Marketing and Sales</td>
</tr>
<tr>
<td>• Storage, short-term</td>
<td>• Market analysis</td>
</tr>
<tr>
<td>• Storage, long-term</td>
<td>• Marketing activities</td>
</tr>
<tr>
<td>• Processing to different form</td>
<td>• Human Resource Development</td>
</tr>
<tr>
<td>• Consolidation: decoupling</td>
<td>• Training</td>
</tr>
<tr>
<td>• Equipment, short-term rental</td>
<td>• Recruitment</td>
</tr>
<tr>
<td>• Information Processing</td>
<td>• Reorganisation of work and</td>
</tr>
<tr>
<td>• Cargo inventory</td>
<td>gang</td>
</tr>
<tr>
<td>• Notification of vessel and cargo arrival</td>
<td></td>
</tr>
<tr>
<td>• Cargo clearance</td>
<td></td>
</tr>
</tbody>
</table>


In addition to ports the maritime infrastructure cost consists of i) fairways, ii) icebreaking and iii) pilotage. It can be argued also that hydrographic survey and search and rescue should be included in the infrastructure costs. In this report we will focus on fairways and pilotage in
addition to ports and icebreaking. Hydrographic survey is regulated both internationally and nationally where IMO and SOLAS convention regulates the right to issue official nautical charts.

### 2.2 European Union policy

The Green Paper of 10 December 1997 on seaports and maritime infrastructure\(^2\) set out principles for the European Common Transport Policy in the field of Port and maritime transport. The Green Paper, together with the regulation of port services, dedicated a section to the financing and charging for ports and maritime infrastructure. For a deeper discussion on the Green Paper see CATRIN D11.

In the port area, the Commission advocates a general framework requiring charges to be linked to costs. The most frequent port charges are: i) charges for the provision of services and facilities to enable a ship to enter safely and use the port; ii) charges for specific services or supplies rendered and iii) rents or charges for the use of land or equipment owned (or otherwise supplied) by the port. Depending on the individual port, these charges reflect, to varying degrees, the use of services and facilities, both of which should be addressed in a future charging framework.

Different approaches are possible with regard to infrastructure costs: i) average cost pricing; ii) charging for operating costs only or iii) marginal cost pricing. According to the Green Paper, the long-term objective of an infrastructure pricing policy should be to charge for marginal social costs (capital, operating, environmental and congestion costs) of infrastructure use. This would ensure that investments are demand-driven and would also ensure fair competition in the port sector, in the longer term.

Based on the approach of the Green Paper, an initial proposal for a directive on market access to port services was presented by the Commission in 2001 as part of the Communication entitled ‘Reinforcing quality service in sea ports: a key for European transport’ (known as the Ports’ Package). When this proposal failed a new proposal was made in 2004. The proposal aimed at establishing a Community legal framework for access to the provision of port services, considering their importance in the interest of consumers and of business alike. Principles for charging port services had a minor role compared to the first proposal. Also this proposal was rejected and the main obstacle was the opening up of ports to competition from providers of services like piloting, loading and unloading ships.

The charging of maritime transport, outside coastal areas and archipelagos, is not a community competence. The field is regulated by UNCLOS and its obligation for states to allow “innocent passage”.\(^3\) With reference to port state jurisdiction states (or EU) may apply charges for vessels that pass a fairway to call a port in the state or enter inland waters. However, charges must not be discriminatory.

\(2\) COM (97) 678

\(3\) United Nations Convention on Law of Sea. For vessels who claim the right to innocent passage the coastal state can only assume rules regarding construction, design, equipment or manning if these constitute an expression of an internationally accepted standard i.e. in principle the rules that are laid down in various international conventions.
The charging for direct infrastructure costs related to the maritime access has not directly been addressed by European policy. Policy issues related to emissions, including green house gases have been discussed but no formal proposal has been tabled. Non-economic instruments to reduce emission costs (sulphur and nitrogen) have been decided by the IMO (International Maritime Administration).
3 Fairways

Seen from an analytical perspective, it may be clarifying to make a distinction between fairways in the open sea and port related fairways – the port access. The latter may be fairly long when it follows a river or pass an archipelago.

The cost to provide fairways in the open water often is limited to hydrographic survey and the production of official navigational charts. The cost to perform hydrographic survey is a purely sunk cost for a common good. It needs to be done once only and all users can benefit from the investment at no additional cost. Moreover, seen from an infrastructure perspective the cost is most limited. According to international law National Maritime Administrations are liable to produce navigational charts. They are charged for, but full costs may not be recovered. Nautical charts have to be corrected over time. Ship owners often subscribe to electronic corrections of their electronic nautical charts (ENC). As explained above, the charging for the use of fairways in open waters is prohibited according to international law.

Fairways related to port accesses often require regular hydrographic survey. Ship movements and currents may cause sedimentation and reduced depth. The fairways also involve expenses related to aids to navigation (AtoN) and dredging operations. AtoN includes lights, buoys, beacons, etc to guide a vessel. When it comes to dredging the situation differs considerably. In some cases the natural geography offers proper conditions and no or very limited dredging is needed. More often dredging operations have to be undertaken, often regularly. For inland waterways, the need for dredging most often is considerable.

3.1 Literature review – Fairways

It is clear that infrastructure economics is only a minor subset of Maritime economics where the shipping part of the sector is dominant. Brooks et.al. (2002) identified the following six major fields; carrier management and operation, competition policy and pricing, vessel finance, fiscal treatment of shipping, law and policy, markets and market structures and, finally, ports. The latter field is the only one that deals with infrastructure. Of the total number of articles represented in Brooks et.al. four out of 33 consider ports of which one discusses optimum throughput and performance evaluation in marine terminals, the second hinterland transport, then third, the international seaport competition and the last article environmental management.

According to the literature reviewed the marginal costs for the use of fairways are negligible, the main marginal costs are associated with emissions (Ministry of Enterprise, 2003, SIKA, 2004). Neither are there many European countries which have extensive fairways and fairway dues. Hence, there is hardly any literature which describes the aspects of how to set the price for fairways based on marginal costs of wear and tear.

Atenco (2001 p111) presents an estimate of the cost of dredging in Antwerp, Rotterdam and Hamburg. Practitioners often refer to that ship movements, in certain fairways increase the movement of water and sediment and thus increase the sedimentation in fairway channels. The interval between dredging operations are reduced, translating into a marginal cost. However, the conditions are suggested to be most specific and vary between one part of a channel to another, from one vessel to another and also between one captain and another (speed and route in the channel). There are no known studies published to develop the issue
further. Haralambides and Veenstra (2002) conclude that cost recovery for navigation aids and dredging still is much influenced by political beliefs and still are a challenge to economics.

3.2 Fairway dues

Although the marginal cost is limited fairway dues exist however in the following north European countries: Sweden, Finland, Estonia, Latvia and Norway. The Swedish and Finnish fees are clearly higher that the charges in the other countries. In Lithuania, Russia and the UK, fairway charges are partly integrated in the harbour due system.

As mentioned above the marginal cost for one more ship to use the fairway normally is very small. The Finnish fairway dues have developed into a formal taxation scheme. The tax is still formed along the same lines as the prior charges. They are designed to cover the cost for construction and maintenance of public fairways. They include an incentive to promote vessels with good ice-going capacity (safety justification and cost savings in terms of less need for icebreaking assistance). The payment is also related to the ship’s net tonnage.

3.2.1 Environmental differentiated fairway dues - Sweden.

The fairway due is mandatory for marine vessels sailing to and from Swedish ports. The existence of and arguments for the fairway due is similar in Sweden as in Finland. This is justified by e.g. their large archipelagos and the need for icebreakers (Ministry of Enterprise, 2003). The fairway due consists of two parts, one based on the ships’ gross tonnage (GT\(^4\)) and one based on the amount of cargo (but not passengers) loaded and unloaded in the port. The number of times that the first part of the fairway due will be charged is limited to a maximum of five times per month for cruise vessels, passenger ships and rail ferries, while the limit for other ships is two times per month. The fairway dues are set to cover the costs and activity of the Swedish Maritime Administration (SMA). For the year 2008 the cost of maintaining the fairways for SMA was 300 million SEK, while the revenues from the fairway dues amounted to 1000 million SEK (SMA, Annual report 2008, 2009). Fairway dues thus finance other activities of SMA such as supporting pilotage and ice breaking.

The part of the fairway due which is based on the ships’ GT is designed as shown in Table 2 below.

<table>
<thead>
<tr>
<th>Category of ship</th>
<th>SEK/GT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Passenger ships and railway ferries</td>
<td>1.80</td>
</tr>
<tr>
<td>2. Cruisers</td>
<td>0.80</td>
</tr>
<tr>
<td>3. Oil tanker</td>
<td>2.05</td>
</tr>
<tr>
<td>4. Other ships</td>
<td>2.05</td>
</tr>
</tbody>
</table>

Source: (SMA, 2008)

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4 Gross tonnage – the total of all enclosed spaces within a ship expressed in tonnes, each of which is equivalent to 100 cubic feet (Port of Brisbane, http://www.portbris.com.au/schools/glossary, 2009-01-12).
The second part is based on the amount of goods loaded and unloaded in the port. This due is calculated to 3,05 SEK/tonne loaded or unloaded cargo, although low-value bulk cargo is charged 0,80 SEK/tonne (SMA, 2008).

The system contains several discounts for certain vessels and cargoes e.g. transit cargo and ferry traffic. Another aspect of the fairway dues, fundamental in the Swedish debate is that it is environmentally differentiated. The differentiation aims to create incentives for ships to reduce their emissions of nitrogen oxides (NO\(_x\)) and sulphur. However, it is only the part of the fairway due based on the ships' GT which is differentiated (SMA, 2008). The differentiation was introduced in the year 1998, but it has been revised over the years and the most recent change was made in April 2008. The main reason for the revision was that the incentives have not been strong enough, especially not with the increased price of bunker fuel\(^5\). Therefore an increased discount has been set (SMA, 2007). The differentiations for NO\(_x\) and sulphur emissions are designed in separate ways. Today, the most environmentally friendly vessels with respect to NO\(_x\) and sulphur emissions pay no vessel related fairway charge.

In order to receive the discount for reduced NO\(_x\) emissions the ship operator has to collect a certificate from the Swedish Maritime Administration, which verifies that measures have been taken and indicates what discount the ship is entitled to, see the table below. To reduce NO\(_x\) emissions new technology usually has to be installed which can be rather expensive (Friedrich et al., 2007).

**Table 3 NO\(_x\) differentiation, SEK per GT**

<table>
<thead>
<tr>
<th>Emission level (g NO(_x)/kWh)</th>
<th>1. Passenger ships and railway ferries</th>
<th>2. Cruisers</th>
<th>3.4 Oil tanker and Other ships</th>
</tr>
</thead>
<tbody>
<tr>
<td>0,00 – 0,49</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0,50 – 0,90</td>
<td>0,15</td>
<td>0,03</td>
<td>0,25</td>
</tr>
<tr>
<td>1,00 - 1,90</td>
<td>0,40</td>
<td>0,08</td>
<td>0,61</td>
</tr>
<tr>
<td>2,00 – 2,90</td>
<td>0,63</td>
<td>0,16</td>
<td>0,77</td>
</tr>
<tr>
<td>3,00 – 3,90</td>
<td>0,77</td>
<td>0,24</td>
<td>0,93</td>
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<td>4,00 – 4,90</td>
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<td>8,0 – 8,9</td>
<td>1,47</td>
<td>0,64</td>
<td>1,73</td>
</tr>
<tr>
<td>9,0 – 9,9</td>
<td>1,61</td>
<td>0,72</td>
<td>1,89</td>
</tr>
<tr>
<td>10,0-</td>
<td>1,80</td>
<td>0,80</td>
<td>2,05</td>
</tr>
</tbody>
</table>

Source: (SMA, 2008)

In addition, a charge of 0,70 SEK/GT is added to the fairway due if the ship operator does not have a certificate for sulphur oxide reductions. The certificate is provided by the SMA and the ship operator needs to prove that the ship uses bunker oil with a low sulphur level at all times.

\(^5\) During 2007 the number of ships qualifying for the discounted fairway due for using low-sulphur fuel was reduced. This due to the increased fuel prices which had reduced the incentives given by the Swedish Maritime Administration and the Swedish ports. SMA (2007) Förändringar i farledsavgiftssystemet från den 1 april 2008.
to receive a discounted sulphur charge (SMA, 2008). The differentiation for sulphur is shown in Table 4.

**Table 4 Sulphur differentiation**

<table>
<thead>
<tr>
<th>Sulphur content, percent</th>
<th>Passenger ships, SEK/GT</th>
<th>Other ships, SEK/GT</th>
</tr>
</thead>
<tbody>
<tr>
<td>0,00 - 0,20</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0,21 – 0,50</td>
<td>0,20</td>
<td>0,20</td>
</tr>
<tr>
<td>0,51 -</td>
<td>0,70</td>
<td>0,70</td>
</tr>
</tbody>
</table>

Source: (SMA, 2008)

### 3.3 Conclusion

Many studies have dealt with maritime emission costs, but pure infrastructure costs have been given most limited attention. We have in principle found no literature about the marginal (infrastructure) cost of fairways. There seems to be a wide-spread view that this marginal cost often is close to zero. In teaching economics a lighthouse has been the traditional example of a public good with zero marginal cost of provision. Dredging could be a cost that could give rise to a marginal effect when more vessels use the fairway. However, there are no studies known to us that have examined this effect in detail. The absence of literature could probably be explained by the fact that only a few countries have an extensive fairway system outside the ports.

We have also found that fairway dues are used to finance other services, such as ice breaking or pilotage. This form of cross subsidy can, for the case with pilotage, be explained as a sort of two part tariff pricing where the fairway due is paid by every vessel and the pilot charge only by vessels taking a pilot onboard. Fairway dues are also employed as a means to achieve environmental policy objectives.
4 Pilotage

References to pilots are made already in the Bible\(^6\) as well as by Homeros. Their task is still the same – to guide ships through dangerous or lately also congested waters. There is in principle a trade-off between investments in the quality of fairways and the need for pilots. We therefore examine pilotage as a part of the infrastructure cost.

Typically, larger vessels are obliged to engage a pilot when they use a fairway to or from a port. In some regions specific port pilots are engaged for maneuvering in the port area. Rules and restrictions differ from port to port. In many areas shipowners have the choice to hire and educate officers with the technical and nautical skills to qualify for pilot exemption. While the pilot guides and maneuvers the ship, legally the master remains in command of the ship and the pilot is an adviser only. Instead of being part of the ship's crew, pilots are employed locally and therefore act on behalf of the public rather than of the shipowners. Normally the pilot joins an incoming ship at sea via pilot boat or (more rarely) helicopter. When an outgoing vessel is about to leave coastal waters, a pilot boat returns the pilot to land or to an incoming ship, for his next mission.

4.1 Literature review

The literature review has resulted in a very limited amount of literature on the economics of pilotage. The only study with a mainly economic perspective we have found, Andersson (2007), is summarised in section 4.3 below. However, pilotage is covered by some of the port economic studies examined in chapter 5 below.

4.2 Pilotage in some Member States\(^7\)

Organisation of pilotage shows all different forms from a public authority responsible for both regulation and pilotage to a division between a public or private monopoly with a separate regulatory body. Charges are basically designed to recover the full cost of pilotage. In some Member States a general charge is levied on all ships travelling in waters where pilots may be needed and an additional charge is paid when a pilot is actually used. Other states only have a pilot charge which often is dependent on distance.

4.2.1 Denmark

In Denmark pilotage for entering and leaving Danish ports is open for competition since 2006 (1 December). For ships passing from the North Sea to the Baltic and back pilotage is voluntary but the business is still a regulated state monopoly. However, the Swedish pilot organisation (SMA) offers a parallel, competing service.

A first private pilot company was established in 2007. In addition, ports may qualify for their own pilot service. A regulatory body – Lodstilsynet – has been created since the opening up of the market. According to the law the Government may decide the maximum charges for

\(^6\) Hesekiel 27

\(^7\) Section based on information in SOU 2007:106
pilotage in Denmark. However, in practice the pilot company decides on the charges themselves and the public pilot organisation is instructed to set their charges to recover their costs only. Only ships taking onboard a pilot pays the charge. The public pilot organisation is fully financed by charges.

4.2.2 Finland

In Finland a public company – Finnpilot – is responsible for all pilotage in Finland while the Maritime Administration is the regulatory body. The charges shall be set to recover the full cost except for pilotage in some inland waters where the ships only pay 26%. The charge is paid only by ships taking pilot onboard. The charge is dependent on the distance (eight length categories) and the size (five size categories) of the ship. (Finnish State Pilotage Enterprise, 2007).

4.2.3 The Netherlands

In the Netherlands pilotage is carried out by a private monopoly since 1988 which is divided into four regional districts. The Ministry is the regulatory body. The charge consists of a sea and a river pilotage tariff that are based on the vessel’s maximum draught. The river tariff depends on the distance while the sea tariff is not affected by distance. Vessels whose draught is more than 17.4 meters must use two pilots and the charge is increased with 50 per cent.

4.2.4 Norway

In Norway a public body – Kystverket – is responsible for pilotage in the whole country. Pilotage shall be fully financed by charges but in Norway also ships that don’t take a pilot have to pay a partial charge. Ships that actually take a pilot on board pay an additional charge depending on the time the pilotage takes with a minimum time of three hours. The hourly charge is different for ten vessel size categories.

4.2.5 Germany

Also Germany has a charge for all ships to finance pilotage- a pilot tax. The actual pilotage charge is depending on time and finances the pilot’s salary. Pilotage in Germany is carried out by public cooperation’s – Lotsenbruderschaft. Each pilot district has its own table for both the pilotage tax and the pilotage usage fee. The fee depends on the vessel size (GT), distance, district and area as well as type of vessel.

4.2.6 Sweden

In Sweden the Maritime Administration is responsible for all pilotage services. The Swedish Transport Board is responsible for regulation. The pilotage charge is based on the vessel’s gross tonnage and pilotage time. The vessels tonnage is indicated by 14 size categories. The pilotage time is rated by a time scale with a minimum of one hour and a maximum of 30 hours divided into half-hour intervals. In 2006 the revenue from pilotage charges in Sweden
was 373 MSK while the cost was approximately 557 MSEK. The remaining cost (169 MSEK) was financed through the Fairway due.

4.2.7 Estonia

In Estonia the pilotage charge outside the port area depends on the vessel’s gross tonnage and the pilotage distance. The vessels’ size is indicated by 17 categories and the distance by six categories. A separate port pilotage tariff is applied in port areas independently of the distance in the port. The port pilotage tariff is applied to all movements in the port (Finnish State Pilotage Enterprise (2007)).

4.2.8 Summary

The Finnish State Pilotage Enterprise (2007) has made a comparison of pilotage tariffs in a number of Member States as illustrated in figure 4.1 below. Nine vessels were selected as examples in the comparison. The price for the pilotage was studied in terms of a pilotage distance of seven nautical miles from the sea to the port. In countries where the pilot tariff is based on time the comparison was made on the assumption that a seven miles journey takes one hour. In countries where the tariff is fixed a port was chosen with an approach distance with pilotage of approximately seven miles. A range of vessels where chosen as examples. The vessels are presented in table 5. Length and draught refers to maximum length and draught. The characteristics of the vessels are presented in the table below. Note that the two biggest ships can’t enter the port of Copenhagen or Rostock.

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>BT</th>
<th>NT</th>
<th>Length (m)</th>
<th>Beam (m)</th>
<th>Draught (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vessel 1</td>
<td>Dry-bulk</td>
<td>85616</td>
<td>54975</td>
<td>289</td>
<td>45</td>
<td>17.6</td>
</tr>
<tr>
<td>Vessel 2</td>
<td>Oil tanker</td>
<td>64259</td>
<td>30846</td>
<td>252</td>
<td>44</td>
<td>15.3</td>
</tr>
<tr>
<td>Vessel 3</td>
<td>Passenger vessel</td>
<td>50764</td>
<td>28641</td>
<td>230</td>
<td>32</td>
<td>7</td>
</tr>
<tr>
<td>Vessel 4</td>
<td>Passenger ferry</td>
<td>30285</td>
<td>10769</td>
<td>204</td>
<td>25</td>
<td>6.6</td>
</tr>
<tr>
<td>Vessel 5</td>
<td>Container vessel</td>
<td>9981</td>
<td>6006</td>
<td>134</td>
<td>22</td>
<td>8.7</td>
</tr>
<tr>
<td>Vessel 6</td>
<td>Ro-Ro</td>
<td>10488</td>
<td>3146</td>
<td>153</td>
<td>21</td>
<td>6.9</td>
</tr>
<tr>
<td>Vessel 7</td>
<td>Chemical tanker</td>
<td>4468</td>
<td>2142</td>
<td>107</td>
<td>17</td>
<td>7.3</td>
</tr>
<tr>
<td>Vessel 8</td>
<td>Dry carfo vessel</td>
<td>2329</td>
<td>1349</td>
<td>82</td>
<td>12</td>
<td>5.4</td>
</tr>
<tr>
<td>Vessel 9</td>
<td>Dry cargo vessel</td>
<td>1264</td>
<td>511</td>
<td>76</td>
<td>11</td>
<td>3.6</td>
</tr>
</tbody>
</table>

The difference between the Member States is significant with the lowest charges in Sweden and Finland while Norway and Rostock have the highest charges. All Member States differentiate the charge depending on vessel size. In the next section we review a study on the actual marginal cost of pilotage.
**4.3 Marginal Pilotage Cost - Swedish Case**

An investigation has taken place recently in Sweden to examine the organisation etc of pilotage. This investigation (SOU 2007:106) also carried out some pioneering empirical work on pilotage.

Sweden has 22 pilot stations making in total 41 788 pilotage and working in total 100 833 hours (in 2006). The average pilotage takes 2.41 hours. The smallest station has 3 pilots and the largest 28.

Normally half of the pilots at a station are working and half are at rest in periods of four to five days. A pilot may be doing pilotage for eight hours a day with a maximum working time of 13 hours. The working time always starts at the pilot’s home. The actual pilotage time and the travel time is thus the labour cost of a pilot. In addition to pilots a station also has a transport organization with boats and seamen that transports the pilot to and from the ship. Each station is linked to a planning organisation that handles the orders from the ships or their

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8 This text is based on Andersson, P. (2007)
agents. Most orders are placed by e-mail, but phone may still be used. This part of the organization has often a joint function together with the traffic supervision organisation.

The pilot capacity is dimensioned for a high degree of service for the ships with a minimum of waiting time for the ships. During off peak there is a high degree of over capacity. Many stations are also so small that one pilot (the smallest input unit) will not have enough pilotage to do. This is met by developing the pilot’s skills to cover more fairways in larger regions. The average capacity utilisation level is 0.55 varying between 0.25 and 0.75.

This variation in capacity utilisation means that the actual marginal cost will vary strongly between different fairways, times and to some extent due to weather conditions. A ship that needs a pilot off peak imposes a marginal cost limited to the supplementary reimbursement to pilots and the marginal costs for transportation. A ship at peak - when the capacity is fully utilised - has a high marginal cost, where a scarcity component may be considerable. This cost structure suggests that a very detailed price structure could be developed where the pilot organisation can offer different level of services to different ships where a low cost service means that ships have to wait until a pilot is free while high price services offer a pilot directly etc. Such a pricing would be optimal if it were possible to influence the time pattern of demand for pilotage.

In SOU 2007:106 it is suggested that demand for pilotage is basically inelastic with respect to pilot charges making this type of price signals without effect. Instead the report focuses on the expected short run marginal cost of production which is the average marginal cost at a specific fairway. Assuming that the price for pilotage is based on this average marginal cost the shipowner will, based on this price, know if he is willing to go to the port and if he will take on board a pilot or not ex ante.

In estimating the total cost for pilotage information on input variables - number of pilots, boatmen, transport- and traveltime as well as fleet - are collected for each pilot station. These physical information are multiplied with uniform unit prices for each input variable such as salary etc. This method presupposes a uniform input cost structure. In addition, the cost of pilotage is adjusted for the level of capacity utilisation, i.e. if the capacity utilisation is 0.55 it is assumed that 45% of the time the cost for pilotage is free. The capacity utilisation is estimated for each station. This adjustment is based on a rather strong assumption, i.e. that the alternative cost for a pilot is zero.
**Table 6: Basic pilotage data (2006)**

<table>
<thead>
<tr>
<th>Station</th>
<th>Number of pilotage</th>
<th>Pilotage time</th>
<th>Number of pilots</th>
<th>Capacity utilisation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Luleå</td>
<td>523</td>
<td>1215</td>
<td>4</td>
<td>41.6</td>
</tr>
<tr>
<td>Skellefteå</td>
<td>1124</td>
<td>1773</td>
<td>5</td>
<td>46.5</td>
</tr>
<tr>
<td>Umeå</td>
<td>505</td>
<td>580</td>
<td>3</td>
<td>23.9</td>
</tr>
<tr>
<td>Skag</td>
<td>1214</td>
<td>2174</td>
<td>5</td>
<td>59.3</td>
</tr>
<tr>
<td>Sundsvall</td>
<td>1138</td>
<td>2151</td>
<td>7</td>
<td>56.0</td>
</tr>
<tr>
<td>Söderhamn</td>
<td>769</td>
<td>983</td>
<td>3</td>
<td>47.0</td>
</tr>
<tr>
<td>Gävle</td>
<td>1608</td>
<td>1987</td>
<td>7</td>
<td>33.9</td>
</tr>
<tr>
<td>Stockholm</td>
<td>2306</td>
<td>9456</td>
<td>16</td>
<td>65.2</td>
</tr>
<tr>
<td>Målaren</td>
<td>5374</td>
<td>21774</td>
<td>28</td>
<td>75.2</td>
</tr>
<tr>
<td>Gotland</td>
<td>642</td>
<td>469</td>
<td>4</td>
<td>50.1</td>
</tr>
<tr>
<td>Oxelösund</td>
<td>2052</td>
<td>5754</td>
<td>10</td>
<td>62.0</td>
</tr>
<tr>
<td>Oskarshamn</td>
<td>847</td>
<td>1086</td>
<td>4</td>
<td>45.3</td>
</tr>
<tr>
<td>Kalmar</td>
<td>992</td>
<td>1058</td>
<td>4</td>
<td>36.1</td>
</tr>
<tr>
<td>Karlskrona/Åhus</td>
<td>2881</td>
<td>3269</td>
<td>8</td>
<td>62.7</td>
</tr>
<tr>
<td>Malmö</td>
<td>2090</td>
<td>2667</td>
<td>7</td>
<td>44.9</td>
</tr>
<tr>
<td>Helsingborg</td>
<td>2076</td>
<td>1658</td>
<td>7</td>
<td>38.4</td>
</tr>
<tr>
<td>Halland/Halmstad</td>
<td>1562</td>
<td>1456</td>
<td>6</td>
<td>35.0</td>
</tr>
<tr>
<td>Göteborg</td>
<td>5671</td>
<td>9348</td>
<td>23</td>
<td>45.6</td>
</tr>
<tr>
<td>Marstrand</td>
<td>1941</td>
<td>5112</td>
<td>10</td>
<td>48.5</td>
</tr>
<tr>
<td>Lysekil</td>
<td>2027</td>
<td>3710</td>
<td>8</td>
<td>47.4</td>
</tr>
<tr>
<td>Vänern kanalen</td>
<td>3519</td>
<td>16522</td>
<td>25</td>
<td>62.2</td>
</tr>
<tr>
<td>Vänern vänern</td>
<td>927</td>
<td>6681</td>
<td>8</td>
<td>71.1</td>
</tr>
<tr>
<td>Total</td>
<td>41788</td>
<td>100883</td>
<td>-</td>
<td>55.6</td>
</tr>
</tbody>
</table>


The expected total variable cost (TVC) is then estimated as a function of the number of pilotages (P). In equation 1 below pilotage has a fixed cost of 5.7 MSEK (1 SEK=0.10€) and a marginal cost of each pilotage of 3938 SEK. In an alternative model a Stockholm-dummy is included which results in a fixed cost of 5 MSEK and an additional fixed cost for the expensive Stockholm area of 15.8 MSEK. The expected marginal cost per pilotage is 3783 SEK. An additional model is estimated on pilot hours (H). In this latter case the fixed cost is much higher since the transport organisation mainly is independent on the pilotage time.

\[ \text{TVC} = 5735232 + 3938 \times P \]  
\((R^2 = 0.67)\)  
\((\text{Eq 1})\)

\[ \text{TVC} = 5310184 + 3783 \times P + 15810597 \times S \]  
\((R^2 = 0.94)\)  
\((\text{Eq 2})\)

\[ \text{TVC} = 9105632 + 762 \times H + 13533722 \]  
\((R^2 = 0.64)\)  
\((\text{Eq 3})\)

The average cost with this structure is falling which can be seen in the figure below for the case outside Stockholm (S=0). Consequently, all of the pilot stations exhibit increasing returns to scale and thus have a natural monopoly in its region.
In the long run the number of pilots, boats and seamen can be adjusted. The long run variable cost can be estimated (TLVC) as a function of the number of pilotage (P) and with a Stockholm dummy (S).

\[
\text{TLVC} = 6137536 + 5217P + 16536610S
\]  
(Eq 4.)  
(R²=0.97)

The long run marginal cost is higher than the short run marginal cost which is a result of the fact that the degree of capacity utilisation is low in the material. With a higher degree of capacity utilisation we would expect the short run marginal cost to start to increase and become higher than the long run marginal cost. We would also expect the short run total average cost curves to be tangent to the long run total average cost curve.

Figure: 1 Average variable pilotage cost and marginal cost (SEK) based on equation 2 above (outside Stockholm)

4.4 Conclusion

It seems to be of a minor interest for the academic literature to examine the marginal cost of pilotage or pilotage economics in general.

When examining the practice in Member States we find a huge variation in practice and in the level of charges. Some Member State has chosen a two part tariff construction. Norway have a “readiness fee” levied on all ships in Norwegian waters, German has a pilotage tax and Sweden makes a cross subsidy from the fairway due - which all ships have to pay – and the pilotage organization. Both the two-part tariff solution and the Ramsey price solution mirror
of the same phenomena – a decreasing cost activity that has to run under a cost recovery objective.

There are two aspects that may link vessel size to the costs to perform pilotage. First, a large vessel may require more than one pilot. Secondly, the number of pilots having certificate for large vessels are more limited; the pilot must be more qualified. After a basic education, pilots typically get a first certificate to assist smaller ships and over time, based on experience and proved skill, they gradually get certificate to handle larger vessels. Apart from that pilotage cost has little to do with vessel size. The wide spread habit of varying the charge depending on vessel size should first and foremost be seen as an attempt to employ some kind of Ramsey pricing.

The review of the actual marginal cost suggests that it may vary very much from one area to another. The method presented also assumes that the alternative cost of pilots when underutilized is zero which reduces the marginal cost if an assumption is made of a more efficient staffing. In the Swedish case the (short run) marginal cost is approximately 3800 SEK (approx € 380) related to number of pilotages. This is below the average (variable) cost. A cost elasticity expressed as MC/AVC is around 0.5 at the mean production of 2000 pilotages. The cost function is better explained by the number of pilotages than pilotage time since the former determines the capacity needed. It is also found that the short run marginal cost is below the long run marginal cost which is an effect of the low capacity utilisation. A pattern can be discerned where the actual marginal cost tends to equal the lowest charges for the smallest ship in the sample of practises in Member States. The “over charging” of the vessel size is an effect of a cost recovery criteria.
5 Ports

The two first examined cost categories – fairways and pilotage – are rather unknown species in the academic literature. That is partly because much of these costs are covered by ports and thus examined in port economics. For port economics we find a much larger body of literature although the number of examples of marginal cost estimates is limited.

5.1 Literature review

Heaver (2007) makes a comprehensive review of the evolution and challenges of port economics. The development of port economics in the maritime economic literature is rather late and started not to develop until the 1960’s. He concludes that less than 22% of articles on maritime economics during the period 1960 to 1987 were on port economics topics. Of the articles one part discusses the issue of port cost and pricing.

Ports are organized in a variety of forms, e.g. state owned, regional/local government owned, or private enterprise and they are subject to different degrees of regulation and supervision. The underlying principles can be classified into two doctrines - the (continental) European, and the Anglo-Saxon doctrines (Bennathan and Walters (1979)). The former views the port as part of the (social) infrastructure and highlights its value in terms of input to the development of the region and not necessarily in terms of profitability. The Anglo-Saxon doctrine suggests that the port should be self-sufficient and should make a profit.

It would be fair to say that earlier literature focuses on a marginal cost pricing policy developing congestion or queuing charges (section 5.1.1.) while the later literature have highlighted the problem of cost recovery from such a policy. A number of alternative full cost allocation methods have been developed (section 5.1.2). An additional argument for this development is the suggested lack of ability of ports to determine their marginal cost (Talley (1994)). A complimentary area of research examines the scale economies of ports (5.1.3).

5.1.1 Marginal cost

Walters (1975) argues that considerable benefits may accrue from port pricing on marginal cost principles. He further argued for introduction of two-part tariffs as many of the facilities exhibit economics of scale. The main examples are related to the channel due and the handling charge. Assuming that a channel is dredged from 30 feet to 40 feet he notes that the current practice is that vessels drawing 40 feet will have to pay the extra cost of this work as they “cause” the cost. With a marginal cost principle the drawing of the vessel is irrelevant – “once the channel is dredged […] then, unless there is congestion of vessels using that channel, the marginal cost of the passage of a vessel, of whatever draft, is virtually zero” (p. 101). He then argues for a change in the structure of the pricing schedule with less charge on the biggest vessels compared to the practice during this time. In addition, Walters argues for introduction of congestion charges of congested facilities. Marginal cost pricing in ports would thus encourage larger ships, which means that trade can benefit from the economies of scale in vessel size. The pricing principle would also encourage quicker handling of cargo.

Most of the services supplied by a port are provided to facilitate the movement of goods Gardner (1977) claims that it is not logical to base any part of the charges for these services
on the characteristics of the ships but that prices should only be based on the goods themselves.

Button (1979) is concerned with the problem of improving the methods used to price port facilities. He presents a simple economic model of how an optimal pricing policy may be arrived at, employing an adaptation of an interactive supply-demand framework initially developed in the context of allocating car-parking places in urban areas. The model demonstrates the basic economic tenet that charges should be set equal to the full marginal social opportunity cost of facilities used, with premiums added where capacity restrictions would otherwise lead to excessive queueing. As others he recognised that the application of short run marginal cost pricing in a decreasing cost industry, such as a port, would result in a financial deficit. Button summarise three ways to recoup the deficit, a) the government, or its administrations, may directly subsidize investment, b) the port authority adopt a system of discriminate charges or c) the port authority may employ a two-part tariff including a fixed periodic charge (p 205). The use of a probability demand curve shows that no excessive resource misallocation due to miscalculations of the marginal cost occurs. Button also argues that many of the arguments set out against marginal cost pricing of ports are “either ill-founded or unlikely to be of practical importance—ports are little different to other goods and services consumed in the economy and standard economic policies apply to them” (p 201).

Jansson and Rydén (1979) focus on the problem of the fixed cost of ports. Stevedoring charges, although more important for revenue, is seen as rather simple and could be levied as a charge per tonne. However, for port costs (cranes etc) they develop a model on queuing cost. Their final conclusion is a structure where the tariff should be divided into i) a charge per tonne of cargo that would be differentiated with respect to the elasticity of demand and, ii) a charge levied on the carrier to reflect the opportunity cost of using the facility (an occupancy charge).

Jansson and Shneerson (1982) develop a model based on queuing theory where the charge is divided into a port charge and a stevedoring charge. The port charge is in turn divided into two parts, one crane charge based on the queuing cost of waiting ships and one storage charge depending on the queuing cost of waiting cargo. The distinction between queuing cost and congestion cost is made. For queuing the service time of a ship is constant and the waiting time depends on the number of ships entering the port while in congestion the service time is not constant but affected by the occupancy rate. Their approach is presented in section 5.3.2 below. The same approach was taking in the UNITE project by Jansson and Eriksson (2002).

Congestion pricing was discussed both by Bennathan and Walters (1979), and Vanags (1977) with the former pointing out that congestion pricing poses practical problems, since prices will have to vary over the season.

Bickel et.al. (2006) develops a deterministic model of the cost of a port call where the different elements of a call is modelled in subsequent steps as a ship enter the port and requires pilot, locks, tugboats etc until they reach the berth. Vessel cost is also included in the model but no explicit queuing or congestion is considered. The model includes external cost in the form of environmental damage and accidents (see section 5.3.1 below).

Pettersen-Strandenes and Marlow (2000) noted that “ports are no different from any other multi-product industry offering a range of services and operating under different environments and organisational structures” (page 2). They suggest a two-part tariff to capture
the two-dimensional cost structure. The two parts reflect the demand elasticities of price and of time, respectively. The first replaces vessel and goods dues and is fixed irrespective of quality class. The second part should reflect quality class with higher prices for fast and punctual port services than for port services without any quality guarantee (p. 20).

Finally, Pettersen-Strandenes and Marlow concludes that “it appears unlikely that there could ever be one simple panacea. There is no single pricing principle that would be universally applicable to all ports but perhaps a more flexible approach might be useful”.

5.1.2 Cost allocation

Numerous alternatives to the marginal cost pricing principle have been developed more with the aim to be practically workable and less to find an optimal solution. Bergantino and Coppejans (2000) note that ease of computation comes at the expense of a certain amount of welfare.

UNCTAD (1995) discussed two basic approaches for a port pricing policy: one economic, the other financial. The former is grounded on marginal cost pricing, while the latter bases prices on accounting costs. The 'cost, performance, value' (or CPV) approach allows port managers through tariffs to accomplish different sets of objectives.; i) cost-based tariffs can maximise the use of port services; ii) performance-based tariffs can maximise throughput and reduce congestion, iii) value-based tariffs generate sufficient revenue to cover the port's cost.

The ATENCO project concluded that: “the main conclusion of a comprehensive academic literature review on port pricing was that pricing in ports can and should be based on costs (Haralambides et al., 2005, p 200). Haralambides et.al. also suggested that the most “appropriate basis for efficient prices” where the long run marginal cost (p 201). However, in addition the study concluded that any policy development should focus on the condition of high-quality cost information availability (p. 202) instead of prescribing any principle of pricing. The project also concluded that it is a general consensus on the importance of cost recovery (Atenco (2001) p 138).

A commonly used method is the fully distributed cost (FDC) method. This method allocates also shared cost to different forms of output without any economic meaning often based on the proportion of the output of 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” (Bergantio and Coppejans (2000) page 100).

A more advanced form is to use cooperative game theory (see CATRIN D3) to allocate the joint cost in such a way that there is no cross-subsidy between different users of the same shared components. Talley (1994) suggested a pricing mechanism – sometimes called the axiomatic approach - which determines the prices of the outputs of multi-product firms by allocating the full cost of production to all the outputs under some desirable characteristics (axioms). It is assumed that the demand for port services is relatively inelastic with respect to port prices, i.e. it does not consider the preferences of different shipowners. This methodology determines prices that allow for full port cost recovery, do not require the estimation of marginal costs.
Bergantion and Coppejans (2000) develops a two stage model where the optimal level of the public good port is determined while a second stage with given infrastructure allocates the (port) cost taking shipowners’ preferences into account. The model assumes that the technology operates under decreasing returns to scale which seems to be opposite to the empirical observation of the sector. The cost of dredging is considered and comparing the marginal utility of shipowners with the marginal cost of dredging the optimal level of infrastructure (draught) can be determined. In the second stage the cost to develop this optimal dredging is allocated to shipowners ensuring that no one has to pay a price above his willingness-to-pay. The chosen solution is based on the ratio equilibrium where the cost of dredging is allocated in proportion to the relative marginal utility of a certain shipowner (Price\(_i\)=Cost*\(\text{MRS}_{\text{shipowner}_i}\)/Sum\(\text{MRS}_{\text{shipowners}}\)). The solution would thus reduce the effect highlighted by Walters (1975) where a high share of cost allocation to the shipowner which demands the deepest draught would discourage the use of the facility. However, the application of the model requires both cost data and true information about shipowners’ preferences.

5.1.3 Economies of scale and long run marginal cost

Walters (1975) divides the question of economies of scale into two questions; i) the economies of optimal location of facilities and ii) the appropriate size of these facilities. When an optimally located port with optimal size has to increase capacity it is clear that this will be associated with rising unit costs. In principle ports would exhibit diseconomies of scale. However, as we move towards bigger ports more efficient technology can be used and they can deal with larger vessels with lower cost per cargo unit than the small ship configuration. This reduces the unit cost and over a range ports will exhibit economies of scale. However, finally internal land distribution cost will start to increase.

The relationship between the long run marginal cost (LRMC) and the economies of scale is straight-forward. Let the total cost C be a function of the vector of input quantities and prices (W) and the vector of output (Y). In the long run case all inputs are variable and the corresponding marginal cost for output type i can be written as \(\frac{\partial C(W,Y)}{\partial y_i}\). The scale economies S is evaluated with scaling up (or down) all inputs in the same proportion and evaluates the maximum proportionate growth rate of outputs. The denominator is equal to the total revenue under marginal cost based pricing and S thus also express the cost recovery where S>1 indicates that the cost is higher than the (marginal cost based) revenue.

\[ LRMC_i = \frac{\partial C(W,Y)}{\partial y_i} \]

\[ S = \frac{C(W,Y)}{\sum_i LRMC_i y_i} \]

Eq (5)

Jansson and Rydén (1979) examined the production cost function of Swedish ports in the 70-ies at a detailed level where man hours, number of cranes etc were examined. For quay cranes and crane operators the elasticity is related to the number of man-hours while for transit shed areas, open storage areas, fork-lift trucks and administrative personnel there were no data on service hours and the elasticity is therefore related to tonnage or ship calls. The
analysis gave strong evidence on the scale economies of ports although not for administrative staff or stevedoring labour (op cit ?page 150).

Jara-Diaz et.al (1997) examines the scale economies in Spanish ports. The service of Spanish ports is divided into two main groups; those related to infrastructure and navigation aids, and those related to cargo handling. The paper estimates a long run multiproduct cost function for the infrastructure service of Spanish ports on a database of 27 ports over the period 1985 to 1989. Three measures from the estimated cost functions (quadratic form) are derived for different cargo types; the long run marginal cost, the scale elasticity and the degree of scope.

The total cost (in pesetas) is related to five types of output measured in tonnes; containerized general cargo (CGC), non containerized general cargo (NCGC), dry bulk (DB) and liquid bulk (LB). In addition, space given for rent to private firms is included as an output (CANON) measured as total rent received. This study is further improved in Jara-Diaz et.al. (2007) where the dataset is prolonged until 1995. One important observation is the importance to deal with distinct outputs instead of aggregated measures where the latter could result in erroneous conclusions. The estimated marginal cost in relation to the five types of output is presented in the table below.

<table>
<thead>
<tr>
<th>Output</th>
<th>Marginal cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>CGC</td>
<td>427 pst/tonne</td>
</tr>
<tr>
<td>NCGC</td>
<td>500 pst/tonne</td>
</tr>
<tr>
<td>LB</td>
<td>125 pst/tonne</td>
</tr>
<tr>
<td>DB</td>
<td>183 pst/tonne</td>
</tr>
</tbody>
</table>

Source: Jara-Diaz et.al. (2007) table 1.

Based on the result Jara-Diaz et.al. (2007) conclude that the lowest marginal cost is related to liquid bulk and the highest to non containerized general cargo which seems reasonable. Containerization of cargo also significantly reduces the cost. The scale elasticity is estimated to 1.69 in the multioutput setting. They also concluded that there are economies of scope in port infrastructure; i.e. port specialisation is not supported.

The scale elasticity suggests that the rate of revenue over cost is 0.60 (=1/S). Other sources suggest that the fixed element of port costs could be as much as 80% of total costs. “For container operations as much as 80 per cent of the costs are independent of the number of vessels or volume of cargo handled. For break bulk operations the fixed element typically is smaller, but still 60 per cent of the costs are independent of the volume, see Bennathan and Walters (1979). Rudolf (1995) set the capital costs for container cranes at 70 per cent of total costs” (Pettersen-Strandenes and Marlow (2000) p. 7).

### 5.2 Practice in some Member States

Haralambides et al. (2001) indicate that there are substantial differences between funding and pricing practices applied in ports across Europe. This is also supported by Pettersen-Strandenes and Marlow (2000). The diversity is based on different legal and cultural traditions. It is also a consequence of differences in terms of port management style and the related issues of competencies and degree of autonomy.
Suykens (1996) made an overview over the relative importance of different charges in total payment by ships in ports and suggested that the port due consisted of 5-15%, pilotage, towage and berthing 2-5% and cargo handling the majority share 70-90% while agent fees where between 3-5%.

The pricing schemes in ports tend to reflect the fact that many ports of tradition see themselves as providers of public infrastructure open to any ship. In addition there is no tradition of managing the ships approaching the port and thus the principle of “first come first served” is widely applied (Pettersen-Strandenes and Marlow (2000)). Although most ports are publicly owned and administrated the authorities have incentives to reduce the subsidies paid which in many cases means a demand for cost recovery. There are two characteristics of port pricing that seems to return. One is the tradition of applying discriminatory charges where a difference can be found between import and export, between coastal and international transport etc. The second is the non transparency and rather complicated structure of port charges (ibid p. 13).

Charges are usually levied on the ship and on the cargo. Pettersen-Strandenes and Marlow present port pricing in Norway according to table 7 below and suggest that this is a typical structure of port charges in Norway.

**Table 8 Port charges in Norway**

<table>
<thead>
<tr>
<th>Tonnage Related Dues</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entry dues</td>
</tr>
<tr>
<td>Decreasing by vessel size</td>
</tr>
<tr>
<td>Berth dues</td>
</tr>
<tr>
<td>Decreasing by vessel size</td>
</tr>
<tr>
<td>Charged per day</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cargo Related Dues</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cargo and traffic dues</td>
</tr>
<tr>
<td>By tonne cargo or by TEU</td>
</tr>
<tr>
<td>Traffic dues for imports only</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Passenger Dues</th>
</tr>
</thead>
<tbody>
<tr>
<td>Service Related Dues - Renting Costs For</td>
</tr>
<tr>
<td>Ice-breaking</td>
</tr>
<tr>
<td>Storage</td>
</tr>
<tr>
<td>Cranes</td>
</tr>
</tbody>
</table>


Atenco (2001) presents a review of pricing practices in 13 large ports in Denmark, Belgium, Spain, UK, Ireland, Italy, Sweden, Germany, Portugal, Greece and The Netherlands. The review is also summarized in Haralambides et al., (2005, p. 208 ff.). One striking result from
the survey is the nearly uniform goal of cost recovery, at least at the overall port level. With one exception, all responding ports, regardless of ownership or management structure, stated that full cost recovery was a very important or critically important management goal. With respect to cost recovery at the level of individual activities (e.g., nautical services, cargo handling, land concessions, etc.), the evidence was mixed. Other pricing principles that were applied relatively frequently included the ‘user pays’ principle, pricing as a function of competition from rival ports, pricing ‘according to what the traffic can bear’ and two-part tariffs. Pricing principles that were used relatively infrequently by the ports in the survey included promotional pricing to attract specific cargo, promotional pricing to increase capacity utilisation, pricing according to time gains (faster services being charged more), pricing as a function of overall costs in the logistics chain, peak-load pricing, and marginal cost pricing (interpreted by respondents as short-run marginal cost pricing). The reasons stated for not using those pricing principles were their irrelevance, impracticability or their incompatibility with cost recovery goals. (Atenco (2001) p73).

**Figure: 2 Pricing practices in ports from the Atenco study**

![Pricing practices in ports from the Atenco study](source: Atenco (2001) page 74)

Most ports expected that an application of marginal cost pricing would result in a reduction of prices. The questionnaire used in the survey was, according to Atenco (2001) not sufficiently clear whether short-run or long-run marginal costs were meant but most respondents interpreted the question as referring to short-run marginal cost. Regarding the impact of marginal social cost pricing, the replies were mixed, with some ports expecting a decrease in prices, others expecting no changes and still others expecting an increase. The answers are determined by the port authorities’ view on which external costs are caused by port activities (e.g. should road congestion outside the port area be considered an external effect of the port?), and on their perception of the magnitude of external costs.

Most port authorities expected that the adoption of full cost recovery pricing would have little impact on pricing levels. The port users were generally aware of some impact or distortion
caused by public support schemes in European ports. However, the users considered the impact of subsidies to be of limited relevance in relation to the prices charged by the port operators to the users and only of some importance in relation to the overall port user costs.

### 5.3 Different approaches to estimate Marginal Cost

Walters (1975) notes that it is extraordinarily difficult to accumulate comparable data on port costs because there is a big difference between the characteristics of ports making cross section data very difficult to use. Following the latest research this still seems to be the case. In the subsequent section we present result from GRACE (5.3.1) where the limited amount of data resulted in a model being constructed and used to simulate the marginal cost and we also present result from Jansson et.al which base their study on time series data for one port - although rather old (5.3.2).

#### 5.3.1 The GRACE model

Bickel et.al. (2006) conclude that no data is available from the port sector and that the only way forward in estimating the marginal infrastructure cost of ports is to develop a simulation model. A number of marginal elements show up in infrastructure costs as a consequence of:

- using locks in the port,
- costs of crew onboard the vessel,
- operating and maintenance cost of the vessel,
- tugboats and
- pilotage boat (or helicopter).

In addition, accident costs (cargo damage as well as injuries of persons) and noise and air pollution costs were considered. The model divides the trajectory of a vessel in a number of stretches starting with i) maritime at sea, ii) use of a canal or river, and possibly also iii) a lock before it finally reaches v) the dock. Once berthed a number of terminal activities takes place including such as unloading/loading, storage and unloading/loading of hinterland connections before hinterland transport starts. The model considers the second to fifth stretch above (shadowed in the table below). The cost components for each of the stretches are summarised in the table below.
Table 9: Costs components for a port call trajectory

<table>
<thead>
<tr>
<th>Port call trajectory (arriving vessel)</th>
<th>Infrastructure costs</th>
<th>Supplier/operator costs</th>
<th>Transport user costs</th>
<th>External costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. At sea</td>
<td>None</td>
<td>Pilotage and towage (fuel, oil, spare parts)</td>
<td>Vessel operating costs (crew, fuel, stores, lubricants, spare parts, oil)</td>
<td>Accidents, air and water pollution</td>
</tr>
<tr>
<td>2. Waiting at buoy to enter port area</td>
<td>None</td>
<td>Limited vessel operating costs</td>
<td>Noise, air pollution, limited water pollution, accidents (limited)</td>
<td></td>
</tr>
<tr>
<td>3. From buoy to lock</td>
<td>None</td>
<td>Pilotage and towage (fuel, oil, spare parts)</td>
<td>Vessel operating costs (crew, fuel, stores, lubricants, spare parts, oil)</td>
<td>Limited noise, air and water pollution</td>
</tr>
<tr>
<td>4. Lock</td>
<td>Lock replacement costs, Maintenance costs</td>
<td>None</td>
<td>Limited vessel operating costs</td>
<td>Noise, air pollution, limited water pollution, accidents (limited)</td>
</tr>
<tr>
<td>5. From lock to berth</td>
<td>None</td>
<td>Pilotage and towage (fuel, oil, spare parts)</td>
<td>Vessel operating costs (crew, diesel oil used instead of heavy fuel, stores, lubricants, spare parts, oil)</td>
<td>Noise, air pollution, limited water pollution, accidents (limited)</td>
</tr>
<tr>
<td>6. Waiting at berth</td>
<td>None</td>
<td>None</td>
<td>Limited vessel operating costs</td>
<td>None</td>
</tr>
<tr>
<td>7. Loading and/or unloading at berth</td>
<td>None</td>
<td>Handling staff, storage staff, use-dependent replacement of superstructure and warehouses</td>
<td>Limited vessel operating costs</td>
<td>Accidents, noise and air pollution, limited water pollution</td>
</tr>
</tbody>
</table>

Source: Bickel et al. (2006)

The sample in GRACE consists of the ports of Antwerp, Felixstowe, Genova and Bordeaux. The theoretical results of the research show that different port settings do indeed lead to a different social marginal cost composition.

The simulation tool includes cost factors for each stretch depending on i) port call trajectory characteristics, ii) vessel type characteristics and iii) unit cost data. In the table below we present the marginal infrastructure cost for a number of ports and add information on the vessel cost of the call. Even with these average marginal costs the variation is huge between different ports. Variables with most impact turn out to be port location (river or coastal), port layout and traffic level.
Table 10: Marginal infrastructure, infrastructure service cost and vessel cost (€/per port call)

<table>
<thead>
<tr>
<th>Ship type</th>
<th>Ship size</th>
<th>Lock operation</th>
<th>Tugboat operation</th>
<th>Pilotage operation</th>
<th>Vessel cost</th>
<th>Tot Infra/ Tot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Container</td>
<td>200 TEU</td>
<td>0</td>
<td>455</td>
<td>103</td>
<td>5975</td>
<td>9%</td>
</tr>
<tr>
<td></td>
<td>600 TEU</td>
<td>0</td>
<td>272</td>
<td>103</td>
<td>6475</td>
<td>5%</td>
</tr>
<tr>
<td></td>
<td>3000 TEU</td>
<td>0</td>
<td>272</td>
<td>103</td>
<td>7257</td>
<td>5%</td>
</tr>
<tr>
<td>General Cargo</td>
<td>2500 dwt</td>
<td>177</td>
<td>474</td>
<td>103</td>
<td>4282</td>
<td>15%</td>
</tr>
<tr>
<td></td>
<td>8000 dwt</td>
<td>177</td>
<td>474</td>
<td>103</td>
<td>14527</td>
<td>5%</td>
</tr>
<tr>
<td></td>
<td>45000 dwt</td>
<td>236</td>
<td>607</td>
<td>103</td>
<td>13416</td>
<td>7%</td>
</tr>
<tr>
<td>Dry bulk</td>
<td>2500 dwt</td>
<td>236</td>
<td>607</td>
<td>103</td>
<td>4948</td>
<td>16%</td>
</tr>
<tr>
<td></td>
<td>8000 dwt</td>
<td>236</td>
<td>798</td>
<td>103</td>
<td>17586</td>
<td>6%</td>
</tr>
<tr>
<td></td>
<td>45000 dwt</td>
<td>236</td>
<td>607</td>
<td>103</td>
<td>25792</td>
<td>4%</td>
</tr>
<tr>
<td>Liquid bulk</td>
<td>2500 dwt</td>
<td>236</td>
<td>607</td>
<td>103</td>
<td>3818</td>
<td>16%</td>
</tr>
<tr>
<td></td>
<td>8000 dwt</td>
<td>236</td>
<td>798</td>
<td>103</td>
<td>7688</td>
<td>6%</td>
</tr>
<tr>
<td></td>
<td>45000 dwt</td>
<td>236</td>
<td>607</td>
<td>103</td>
<td>14941</td>
<td>4%</td>
</tr>
<tr>
<td>Passengers</td>
<td>200 pass.</td>
<td>0</td>
<td>360</td>
<td>103</td>
<td>10503</td>
<td>4%</td>
</tr>
<tr>
<td></td>
<td>700 pass</td>
<td>353</td>
<td>397</td>
<td>103</td>
<td>8798</td>
<td>9%</td>
</tr>
<tr>
<td></td>
<td>1500 pass</td>
<td>707</td>
<td>397</td>
<td>103</td>
<td>8703</td>
<td>12%</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>518</td>
<td>738</td>
<td>103</td>
<td>17743</td>
<td>7%</td>
</tr>
<tr>
<td>Antwerp</td>
<td></td>
<td>0</td>
<td>906</td>
<td>103</td>
<td>14335</td>
<td>7%</td>
</tr>
<tr>
<td>Bordeaux</td>
<td></td>
<td>200 pass.</td>
<td>906</td>
<td>103</td>
<td>1987</td>
<td>10%</td>
</tr>
<tr>
<td>Genoa</td>
<td></td>
<td>47</td>
<td>73</td>
<td>103</td>
<td>3652</td>
<td>5%</td>
</tr>
</tbody>
</table>

Source: Bickel et.al. (2006)

The cost of the vessel is the dominant cost of a port call. The sum of the infrastructure cost locks, tugboat and pilotage (=Tot Infra) is at its highest 20% of the total cost – including vessel cost – for a port call. A more common figure is between 5% and 7% of a port call.

Dividing the total infrastructure cost into its components we notice that tugboat operation seems to be the dominant part with almost 50% of the cost. The remaining 50% is equally divided into pilotage and infrastructure cost relating to locks.
Table 11: Relative importance of the “infrastructure cost components locks, tugboat and pilotage.”

<table>
<thead>
<tr>
<th>Ship type</th>
<th>Ship size</th>
<th>Locks/Tot Infra</th>
<th>Tugboat/Tot Infra</th>
<th>Pilotage/Tot Infra</th>
</tr>
</thead>
<tbody>
<tr>
<td>Container</td>
<td>200 TEU</td>
<td>0%</td>
<td>82%</td>
<td>18%</td>
</tr>
<tr>
<td></td>
<td>600 TEU</td>
<td>0%</td>
<td>73%</td>
<td>27%</td>
</tr>
<tr>
<td></td>
<td>3000 TEU</td>
<td>0%</td>
<td>73%</td>
<td>27%</td>
</tr>
<tr>
<td>General Cargo</td>
<td>2500 dwt</td>
<td>23%</td>
<td>63%</td>
<td>14%</td>
</tr>
<tr>
<td></td>
<td>8000 dwt</td>
<td>23%</td>
<td>63%</td>
<td>14%</td>
</tr>
<tr>
<td></td>
<td>45000 dwt</td>
<td>25%</td>
<td>64%</td>
<td>11%</td>
</tr>
<tr>
<td>Dry bulk</td>
<td>2500 dwt</td>
<td>25%</td>
<td>64%</td>
<td>11%</td>
</tr>
<tr>
<td></td>
<td>8000 dwt</td>
<td>21%</td>
<td>70%</td>
<td>9%</td>
</tr>
<tr>
<td></td>
<td>45000 dwt</td>
<td>25%</td>
<td>64%</td>
<td>11%</td>
</tr>
<tr>
<td>Liquid bulk</td>
<td>2500 dwt</td>
<td>25%</td>
<td>64%</td>
<td>11%</td>
</tr>
<tr>
<td></td>
<td>8000 dwt</td>
<td>25%</td>
<td>64%</td>
<td>11%</td>
</tr>
<tr>
<td></td>
<td>45000 dwt</td>
<td>23%</td>
<td>63%</td>
<td>14%</td>
</tr>
<tr>
<td>Passengers</td>
<td>200 pass.</td>
<td>0%</td>
<td>78%</td>
<td>22%</td>
</tr>
<tr>
<td></td>
<td>700 pass.</td>
<td>41%</td>
<td>47%</td>
<td>12%</td>
</tr>
<tr>
<td></td>
<td>1500 pass.</td>
<td>59%</td>
<td>33%</td>
<td>9%</td>
</tr>
<tr>
<td>Average</td>
<td>Antwerp</td>
<td>38%</td>
<td>54%</td>
<td>8%</td>
</tr>
<tr>
<td></td>
<td>Bordeaux</td>
<td>0%</td>
<td>90%</td>
<td>10%</td>
</tr>
<tr>
<td></td>
<td>Genoa</td>
<td>21%</td>
<td>33%</td>
<td>46%</td>
</tr>
<tr>
<td></td>
<td>Felixstone</td>
<td>0%</td>
<td>42%</td>
<td>58%</td>
</tr>
</tbody>
</table>

The huge amount of vessel cost compared with infrastructure cost is of particular interest in a context where congestion and scarcity costs occur. The section below therefore examines a series of research projects with the aim to include queuing in the pricing structure. As a start we present the classical functional form used by Jan Owen Jansson in numerous research projects (Jansson (1984)). The price relevant cost ($P^*$) is a sum of the producer marginal cost ($MC_{prod}$) and the congestion cost term which is a function of the changed average user cost ($dAC_{user}$) as the traffic increased ($dQ$) which will affect all users ($Q$). In addition external cost ($MC_{external}$) in form of environmental damages etc. should be included.

$$P^* = MC_{prod} + Q \frac{dAC_{user}}{dQ} + MC_{external} \quad \text{Eq (6)}$$

### 5.3.2 Queuing and congestion cost

Jansson and Shneerson (1982) presented in their book “Port Economics” an overview of the historical development of port organization and technology, production measures, short- and long-term cost functions as well as pricing, and investment. The starting point of Jansson’s and Shneerson’s analysis is that they consider both port costs and user cost as in eq 6 above. Based on this they end up in a model including queuing cost in addition to berth cost and stevedoring cost. Their basic long run cost function (LRTC) is written as:

$$LRTC = A + cn + n\lambda[g(n, \lambda) + s] + \sum f_i(Q) \quad \text{Eq (7)}$$
where the infrastructure long run fixed costs is included (A), number of berths (n), capital cost per berth (c). In addition user costs in the form of number of ship arrivals (λ), cost of ship’s time (v), expected queuing time per ship (q) and expected service time per ship (s). Finally the cost of transferring goods (Q) from sea to land transport is included as the function f. The expected service time is assumed to be independent of the occupancy rate of the port’s facilities. If the service time increases with occupancy rate a congestion cost occurs. They develop a queuing model and try to calibrate it on some observations and concluded that the actual queuing time is longer for low occupancy rates (a first assumption was that this is due to congestion in stevedoring but this is not empirically verified) and shorter at high occupancy rates (possible explained by the fact that ship chooses new ports if the waiting time is too long).

Jansson and Shneerson divides the charges into one port charge and one stevedoring charge. The optimal port charge per call consists of the expected delay cost due to increased queuing of one additional call. The delay occurs in their approach on two stages in the port, quay crane and storage where the former depends on the arrival of ships (λ₁) and the later on the arrival of cargo for storage (λ₂) (from/to the ships). The total queuing time Z is a function of the total service time in the first stage (X=s₁λ₁) and the total service time in the second stage (Y=s₂λ₂) and the number of service stations n₁ and n₂. The optimal price thus consists of one crane charge (1) and one storage charge (2)

\[
P_C = vλ_1 \frac{\partial q}{\partial λ_1} = v_s \left( \frac{\partial Z}{\partial X} - \frac{Z}{X} \right) \]

\[
P_C = vλ_2 \frac{\partial q}{\partial λ_2} = v_s \left( \frac{\partial Z}{\partial Y} \right) \]

The crane charge takes a form familiar from congestion charging theory where the price relevant cost is the difference between the short run marginal cost and the average cost (already internalised). For the cargo charge this structure is not the case as there is no value on waiting cargo in the model. The service time s is related to the occupancy rate (Φ). The optimal charge will then increase as the occupancy rate increases for a given number of service stations. When adding a new station the charge will drop dramatically and then start to increase as occupancy rate increases. This “saw shaped” figure is a result of the lumpiness of the investment. Jansson and Shneerson (1982) concluded that the rate of cost recovery (PC/cn) will be significantly below one for a small number of berth (n) but closer to one when the number increase to 9 – 15. Small ports applying optimal pricing would thus face a substantial financial deficit (p.101)

Jansson and Ericsson (2002) presented a case study on the queuing costs and congestion at the port of Uddevalla (Sweden) using 42 monthly observations on ship arrivals, ship laytimes, throughput and stevedoring costs from 1973 to 1976. The data and result seem to be similar to the analysis in Jansson and Shnersson. For the empirical analysis of queuing costs a regression of the total queuing costs Z with respect to the port occupancy rate Φ was carried

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out based on 41 (or 42 alternatively) monthly observations. The following exponential relationship was chosen on the basis of the observation data:

\[ \ln(Z) = c + d \cdot \ln(\Phi) \quad \text{Eq (9)} \]

The best fit turns out to be the explanation of \( Z \) by \( \Phi \), which is in round numbers \( Z=43\Phi^3 \).

Congestion costs at the port of Uddevalla were determined by a regression analysis of the berth occupancy rate \( \Phi \) as a proxy for total service time \( s \) with respect to port throughput \( Q \). Two functional forms (the linear relationship \( \Phi=a+bQ \) and the exponential form \( \ln(\Phi)=\alpha+\beta \ln(Q) \)) and two sets of observations were tested. The exponential form of the regression equation shows an elasticity very close to unity. This implies that a given increase in throughput will cause a proportional increase in the berth occupancy rate. Hence, there is no evidence of congestion costs in terms of longer service times. Also Bickel et.al. (2006) tried to find evidence on congestion cost in ports. They used a simpler aggregate model and could not find any evidence of congestion in the ports of Antwerp, Bordeaux, Genova, Felixstone or Gdynia (p 25).

Jansson and Eriksson (2002) also estimated the elasticity of stevedoring costs as a function of port throughput. Both, the linear and the exponential form indicate that the elasticity of total stevedoring costs with respect to throughput ranges around unity. Regressions made on the sum of service time costs and stevedoring costs indicate an elasticity around 1.04 depending on the sample. These results do not lend support to the hypothesis that the service costs of ships will increase with increases in the capacity utilisation. In other words, congestion externalities were not very pronounced or did even not exist at all at the port of the study.

\[ \text{5.4 Conclusions} \]

Port charges are a complex issue as it contains the infrastructure for ships as well as the infrastructure for cargo. While the port in the real world is a multimodal switch between sea and land-transport it seems predominantly to be examined as a part of the maritime infrastructure system. Nevertheless, the question of port charges can be analysed with traditional economic approaches.

In general the conclusion seems to be that ports are a multi-product industry where the production is taking place under economies of scale. Consequently, charges based only on the marginal infrastructure cost will not recover the full cost of production. This is true under the assumption that long run marginal cost pricing is applied. The review shows that the goal of cost recovery is an important aim for the port sector.

While the consumption of the port’s resources is of minor importance the vessel cost is dominant. In Bickel et.al. (2006) the vessel cost is approximately 10-20 times higher than the infrastructure cost of a port call which were analysed as the cost of locks, pilotage and tugboats. This takes us back to the principle of infrastructure pricing where the whole system has to be included into the problem. Thus one important element in infrastructure pricing is the cost imposed on other users. This is true in congested road networks as well as in ports. In ports the problem is analysed in two parts, the queuing cost during constant service time and the additional congestion cost due to increased service times. The optimal port charge would take the queuing cost into account which is the natural form of the short run marginal cost.
This cost can be analysed both for the ship and for the cargo. The charge will thus comprise the two dominant element of charging port services today – charges related to vessels and charges related to cargo.

The queuing model based pricing will nevertheless not ensure cost recovery. The literature has developed a number of models along the lines of “Ramsey” pricing where joint costs are allocated in a way that disturbs demand as little as possible. However, this solution calls for different mark-ups on different cargo and ship categories to reflect the differences in the elasticity of demand.
6 Infrastructure for winter navigation

Within the CATRIN project a specific task has been to study costs for icebreaking and potentials in cooperation. The nature of icebreaking provides scope for a joint Baltic approach and international cooperation. The rationales for cooperation have bases in elements of a common good, indivisibilities and systematic variations of demand:

- When weather conditions are favorable vessels are managed to form convoys with ships along a route, independently of their exact port of origin or destination. The convoy may be assisted by one icebreaker only and another vessel may be added to the convoy generally at no additional cost.
- Often one icebreaker has the capacity to cover a strait or an area where ice has piled up. If all countries with traffic passing the location have to send their own icebreaker to the area this would engage a number of icebreakers, all facing low utilization. By cooperation resources can be better optimized.
- Winds decide where ice will gather and cause problems for navigation. Thus, such problems will not affect all Baltic coasts at a time. Western winds, for instance, will cause problems at the eastern coasts of the Baltic, while the western side may remain open. Pooling resources, between east and west, south and north, reduces the total capacity needed.

Historically such collaboration has been established thru bilateral and multilateral agreements. A first fundamental agreement, still in force, was settled by Denmark, Finland, Norway and Sweden in 1961.\(^\text{10}\) In 2004 the icebreaking authorities around the Baltic Sea decided that the cooperation in the field should continue within the framework of BIM (Baltic Sea Icebreaking Management).\(^\text{11}\) The establishment of BIM is a manifestation of the Baltic States’ (Denmark, Estonia, Finland, Latvia, Lithuania, Poland, Germany, Sweden but also Norway) interest in exploring benefits of further developed cooperation. In principle, possibilities may range from developed bilateral agreements to joint icebreaking management, possibly including common management or even common ownership of some icebreakers.

The purpose of this task within the CATRIN-project is to analyze potentials in co-operation. The analysis should cover economics and include discussions on financial issues. Two basic scenarios will be addressed:

1. Base-scenario, where the states have individual arrangements to safeguard capacity but have some mechanisms to share excess capacity and co-operate when it comes to strategies and individual operations.

2. A full-fledged joint ice-breaking management, where all icebreakers are managed by a single organization. Questions related to priorities among imminent needs during capacity shortage and cost allocation are discussed.

\(^\text{10}\) Överenskommelse mellan Sverige, Danmark, Finland och Norge om samverkan vid isbrytning (Agreement by Sweden, Denmark, Finland and Norway on icebreaking cooperation), Helsinki, December 20, 1961. Signed by Germany on a later date.

\(^\text{11}\) www.baltice.org.
For the different scenarios it is discussed how possible alternative forms of cost allocation differ. For instance, costs can be allocated between states according to territory (where the assistance takes place), in relation to vessels origin/destination or in relation to assisted ships’ flag state.

6.1 Analytical framework

The demand for icebreaking services is a function of ice and weather conditions, traffic pattern (routing and frequency), applied restriction policy, vessels’ capability in terms of winter navigation and service targets. The latter typically implies delays due to ice condition accepted. The need for icebreaking resources (icebreakers, crew and fuel) also is a function of how services are organized.

For the purpose of modeling demand for icebreaking services in the Baltic, a traffic scenario is developed. The scenario is based on current traffic (winter 2007/08) and described in a form relevant to the study. In parallel to the traffic scenario, ice scenarios are developed. They are aimed to define plausible developments for a severe winter and a normal winter, respectively. How does the ice extension and its characteristics evolve during the winter season? By including ice restrictions in the ice scenarios the analytical framework also takes account of vessels’ ice capabilities.

Based on the traffic scenario and the two ice scenarios the need for icebreaking services is estimated. To accomplish this, a real world situation for the icebreaking management was recreated as realistically as possible. The Swedish icebreaking management has been engaged and faced with the traffic scenario (that actually describes a traffic situation familiar to the management) as well as ice scenarios described by the managements every day tool – ice charts.

The icebreaking management has had the task to apply “best professional judgment” along the lines they work in their regular capacity, to allocate sufficient icebreaking capacity to the different regions in the Baltic, given the different ice charts representing various time periods of the season. The capacity need is assessed given a situation with international cooperation as well as given a purely national approach, where all states have to rely on their own recourses to make the way for all traffic to and from their own national ports.

6.1.1 Traffic scenario

Three different data sources are used to develop the traffic scenario:

- Data from the automatic identification system (AIS). All vessels with a size of 300 GT or more have to be equipped with AIS according to international law. The system sends information over radio to vessels in the area. The information contains the vessel’s identity, speed, course, destination, vessel type, etc. The information also is recorded by national maritime administrations, such as SMA. The recordings offer the administrations excellent,

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12 The ice restrictions or traffic restrictions defines the ice coat capacity a vessel needs to fulfill to qualify for ice breaking assistance in a given area.
13 An international standardized formula to describe vessel’s size, to a large extent based on the vessel’s volume.
detailed statistics on ships movements. With the current instrument for statistical analysis (RAIS) the data is best suited to count traffic passing defined passage lines or to follow individual vessels. The research team has had full access to Baltic AIS data.

- Baltic Port List. CMS compiles, on a yearly basis, port statistics and publishes the Baltic Port List.14 The publication covers all Baltic ports of importance for this study and reports port calls as well as cargo volumes. Obviously, these statistics are well suited to allocate traffic between ports. The research team has had full access to the basic statistical sources the Port List is compiled from.

- IBNet. The Finnish and Swedish icebreaking services have developed a common database on vessel movements and icebreaking assistances. The database answers to the needs of icebreaking management. Generally speaking this implies that the data is most reliable for times and places where winter navigation services are up and running, but less or even non-reliable, during times and in places with no winter conditions. The research team has had full access to IBNet data.

The traffic scenario focuses on dedicated freight vessels. Typically, ferry lines in the Baltic Sea employ modern ships with an ice coat capacity good enough for the ships to make their way through the ice, even during severe winters. The ferry line between Finland and Sweden, in the Quark, (Umeå to Waasa) is an exemption.15

To provide a good basis for the determination of need for icebreaking capacity, given different ice conditions, traffic in open sea as well as traffic in port regions must be plotted. The former is described by AIS-data and the latter first and foremost by data from the Baltic Port List, completed with IBNet-information. In some specific cases detailed AIS-data has been analysed to refine or double-check port data concerning seasonal variation, etc.

AIS-data has been retrieved for a period that answers to the ice scenario for a severe winter. It suggests that the weeks 50 until week 22 are of importance. The most recent data is used, namely late autumn 2007 to spring 2008. The traffic patterns at the Baltic Sea typically are stable from one year to another. Transport volumes tend to vary more than the number of vessel movements. Increasing transport volumes are balanced by increased average vessel size. All in all, last year’s data is seen as a reasonable proxy for the estimation of the need for icebreaking assistance during the next few years to come.

In order to paint the broad picture of Baltic maritime transport, ten passage lines have been defined. They are put in strategic straits and passages and, when possible put to avoid ferry traffic. In cases where this has been impossible specific data analysis has been conducted in order to separate ferry traffic, an option that AIS data and RAIS offers.

Passage lines defined are plotted and named in Figure: 3.

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15 However, in archipelagos, where the ice remains stable and does not drift, ferry traffic will reduce the need for icebreaking assistance for other ships by keeping an ice channel open. The ferries do not only serve as “their own icebreakers” – they add a positive external effect by “paving the way” for other vessels.
The AIS statistics in questions have been broken down on a weekly basis. Figure: 4 illustrates one passage line in some detail. The Quark, the narrow passage between the Bay of Bothnia and the Sea of Bothnia, serves as the example. The passage line is located to detect all traffic through the strait, but still to avoid the ferry line between Umeå (Sweden) and Vaasa (Finland). The figure also displays the traffic statistics.

**Figure: 3 Defined passage lines.**

**Figure: 4 Passage line “The Quark” and related traffic statistics displayed at an electronic nautical chart.**
As expected, there is a balance between southbound and northbound traffic. From one week to another there are some variations, but over the season there is a perfect match. This indicates that the statistics are reliable, rather than anything else. The statistics for The Quark as for other passage lines indicate that the traffic flow is stable over the season. A slight decline can be noticed during Christmas and Easter. The same pattern occurs for all passage lines. Thus, AIS-data confirm the notion that the basic transport demand is fairly constant during the winter season.

While ice conditions differ, the basic transport demand is similar for all winter weeks. Experiences suggest that traffic to ports where ice is more or less permanence during winter seasons generally involves ships with a proper ice coat capacity, independently of ice conditions. To ports in question, the logistics are developed to function all year around. The ships fulfil the ice restrictions to be expected, but still need assistance when ice builds up.

On the other hand, traffic to and from ports where ice is rarer, may need to adjust to icy conditions. Shippers may employ other vessels to perform the transportation than they usually do. Even alternative ports may be used, then with the “land-leg” accordingly adjusted. In other words – the basic transport demand remains, but the way to perform the logistic chain may be adjusted in the more southern parts of the Baltic.

Port statistics have rather been used to allocate the traffic volumes retrieved from AIS-data, than to defined absolute traffic levels. Ports in the different regions have been grouped at a level that answers to the need for this study. The regions represent areas where ice conditions typically are reasonably similar.

The traffic scenario is broken down into separate sub scenarios for port regions which are described below.
The Bay of Bothnia

Ports around the Bay of Bothnia have been divided into three groups: Karlsborg to Skelleftehamn (Sweden), Tornio to Raade (Finland) and Kokkola and Pietarsaari (Finland). Of the typically 120 ships weekly passing to and from the Bay of Bothnia, 20 percent, or twelve calls (24 ship movements) per week, of those go to the Swedish ports, 60 percent, 36 calls go to the most northern Finnish ports and remaining 20 percent calls the more southern Finnish ports (see Figure: 5.) The demand for icebreaking capacity is heavily influenced by an ore shuttle between Luleå and Raade. The ore shuttle operates regularly on a daily basis and is represented in the figure by a dotted line.

Figure: 5 Traffic scenario for the Bay of Bothnia. Ships passing to and from the Bay of Bothnia and their distribution between ports and port regions in the area.

The Sea of Bothnia

The passage line in the northern part of the Sea of Aaland is passed by about 330 vessels a week, a few more southbound than northbound. The reason for this unbalance is that some vessels choose to go east of Aaland, in the Archipelago Sea, when they have a light load and a lower draft. When heavily loaded, and a deeper draft, they need to use the main fairway through the Sea of Aaland. Of the 330 passages, 120 go straight to or from the Bay of Bothnia and remaining 210 ship movements are related to calls at ports around the Sea of Bothnia.
More than half the traffic goes to the most southern ones of the defined port regions. Some 20 percent, or 21 calls a week (42 ship movements) go to the five ports in the region Hudiksvall to Hallstavik (Sweden) and 35 percent, or 37 calls, go to the Mäntyluoto to Uusikaupunki-region (Finland). Somewhat less than ten percent, 8.5 calls per week go to or from Vaasa and Kaskinen (Finland) and about the same amount of traffic call Holmsund (Sweden). The port regions Rundvik to Örnsköldsvik (Sweden) and Ångermanälven to Sundsvall (Sweden) both attract about 15 percent of the traffic, implying 16 calls a week, respectively.

**Gulf of Finland**

Almost 200 ships pass the “Russian ports-passage line” for calls at ports in the Russian port region, Vyborg to Ust-Luga. The traffic to and from Russia does almost count for half the traffic passing the entrance of the Gulf of Finland. About 70 percent of the non-Russian traffic to and from the Gulf of Finland call Finnish ports; 35 percent to the outer port region, Koverhar to Sköldvik and 36 percent to the inner region, Loviisa to Hamina, ferries excluded. For both the regions the traffic equals somewhat less than 40 calls a week. To and from the outer Estonian port region, Paldiski and Tallin, goes 23 percent of the non-Russian traffic, or 24 calls. The inner Estonian port region counts for six percent of the traffic, corresponding to six calls a week.
The Baltic Proper

Somewhat less than 1500 ships pass Bornholm on their way to or from the Baltic Proper. About twenty percent of this traffic passes the passage line in the Sea of Aaland on the way north or vice versa, and almost thirty percent pass the “Gulf of Finland-passage line”. A huge part of the traffic has its origin or destination in the port region Liepaja to Gdansk (Lithuania, Russia, and Poland). This is a huge port region in terms of traffic as well as in term of geography. When it comes to winter navigation however, the ports in the region are much alike. They are all particularly affected during severe winters in periods with North West winds.

About two percent of the traffic passing Bornholm, or 15 calls a week, relates to ports in the Bay of Riga (Estonia, Latvia). The port region Stockholm to Oskarshamn (Sweden) accounts for 7.5 percent of the traffic passing Bornholm. It equals 55 calls a week. In the Baltic Proper there is also “internal” freight traffic – not leaving the Baltic Proper, and passing no passage line. This traffic is illustrated by dotted lines in Figure: 8. This “internal traffic” typically depends on icebreaking services during a severe winter.
Figure: 8 Traffic scenario for the Baltic Proper.

The Baltic Entrance

The traffic patterns are most complex in the Baltic Entrance. The major route to and from the Baltic, The Skaw, is passed by 1140 ships a week. Almost a fourth of this traffic goes to and from Gothenburg (Sweden), but does not pass on further into the Baltic. The remaining 77 percent continues towards the Baltic. Two thirds of the traffic chooses the closest route through Öresund and one third the Great Belt, the route that allows biggest draft. A considerable share of the traffic to and from the Baltic passes the Kiel Canal. It is the closest route to the North Sea, but a passage is charged and the biggest vessels cannot pass the canal. Some vessels can pass when they have a light load (often northbound) but not when they are fully loaded (southbound). Most of the Kiel Canal traffic goes in the direction to or from The Baltic Proper.
There are numerous ports in the Baltic Entrance. Based on how they tend to be influenced by icy conditions (severe winter) they are divided into five port regions. Each of them account for about one fifth of the traffic:

- A southern port region, Kiel to Swinoujscie (Germany, Poland), 18 percent
- Copenhagen (Denmark), 22 percent
- Helsingborg and Malmö (Sweden), 16 percent
- Aalborg and Aarhus (Denmark), 21 percent
- Gothenburg and Halmstad (Sweden), 23 percent
Table 12: Port calls per port region in the Baltic Entrance.

6.1.2 Ice scenarios

While one single traffic scenario is developed for the purpose of this study the analysis benefits from an examination of different ice scenarios. Thus, two ice scenarios are defined:

- A severe winter and
- A normal winter

The ice scenarios must describe the ice extension, ice thickness as well as existence and location of ice-walls, ice ridges and open water. The scenarios are described by the standard kind of ice-maps, produced as information to mariners\(^{16}\) and as background information to the icebreaking management.

After consultations with the Ice Services at SMHI, the institute was engaged to produce ice information for the project. The winter 1986/87 was choosen to represent a severe winter\(^{17}\).

An element of the ice scenarios also is to define relevant traffic restrictions. Such restrictions clarify what ice-coat capacity a ship should have to enter a specific area or to call a specific port. The ice-coat classification is based on vessel characteristics such as engine power and

\(^{16}\) Published at Internet pages such as: www.smhi.se/oceanografi/istjanst/produkter/sstcolor.pdf.

\(^{17}\) The Swedish Meteorological and Hydrological Institute (SMHI), Ice Conditions & Sea Surface temperatures, Ice Charts No. 94 – 100 1986 and No. 1 – 40 1987, mimeo.
the strength of the hull.\textsuperscript{18} The bases for setting ice restrictions, including the categorisation of vessels in ice-classes are, broadly speaking the same today as in the winter 1986/87. Thus, the 1986/87 ice restrictions are directly transferred to the ice scenarios.

**Severe winter**

In the severe winter-scenario, the ice starts to build up in the north (Bothnian Bay) and in the eastern part of the Gulf of Finland, in the beginning of December. The ice has its maximum extension in the middle of March. With an exception for an area in the Baltic Proper there was ice all over the Baltic Sea including the Baltic Entrance. In large areas of the Baltic Proper and the Baltic Entrance however, the ice was limited and hardly caused any problems for navigation. The ice chart representing the maximum extension (March 16) is shown in Figure: 10.\textsuperscript{19}

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\textsuperscript{18} A vessel that does not fulfill the requirements according to the ice restriction may still enter the area, but they do it on their own risk and cannot count on icebreaker assistance if stuck in the ice unless an emergency situation occurs. In such situation an icebreaker will rescue the ship, but may park it safely, somewhere where the ice does not move or return it to the ice edge.

\textsuperscript{19} The ice charts also report where different icebreakers operated during the winter of 1986/87. This provides poor guidance on where to allocate icebreakers today. The traffic has increased considerably during the last 20 years and the icebreaker fleet has been developed.
In the Gulf of Bothnia there is thick, solid ice along the coast in the north and consolidated and packed ice with a thickness of up to 70 cm further out. Ice ridges and hummocked ice add to problems for winter navigation. The ice conditions in the Sea of Bothnia is much alike the situation in the Bay of Bothnia, although the thickness of the ice is somewhat less. Winds
from south have formed a lead in the south of the area. In the Gulf of Finland there is, similarly, solid, thick ice along the coasts, with consolidated, packed ice, including walls and ridges in the middle. However, winds from the south has pushed the ice towards the Finnish coast and left an area along the south coast of the gulf with limited ice, 5 to 15 cm thick. It leaves a useful passage to and from a point east of Helsinki and Tallinn. The winds have left the southern and eastern coasts of the Baltic Proper more or less open. Consolidated ice, with ridges and ice walls have been formed in the middle of the Baltic Proper and along the eastern coast. Consolidated ice in Öresund and the Great Belt will influence passing traffic. Many ports and port regions in the area face ice in their vicinity.

After the maximum extension, ice conditions gradually improved. In the eastern part of the Gulf of Finland, ice remained until May.

**Normal winter**

The winter 1986/87 has been used also to develop a scenario for a normal winter. The ice extension in the high season, from mid January to mid April has been reduced. Thus, while the severe winter season is 25 to 30 weeks, the normal winter season is 18 to 22 weeks.

In the normal winter-scenario the ice formation is assumed to have reached its maximum extension in mid March as shown in figure 11 (Ice chart 1987-04-13). At that point in time the situation in the Bay of Bothnia is very much the same as during the peak of the severe scenario. In the Sea of Bothnia and in the Gulf of Finland there are areas with open water, but also regions with considerable consolidated ice with hummocked ice and ridges. In the Baltic Proper icy conditions show up in the port regions Gulf of Riga, Stockholm to Oskarshamn and Karlshamn. During the normal winter no ice occurs in the Baltic Entrance.
Figure: 11 Maximum ice extension in the scenario “Normal winter”.
6.1.3 Icebreakers and costs

Categorization of icebreakers

The Baltic’s and even the world’s icebreaker fleet consists of a limited number of vessels. Some of them are sister vessels e.g. the Atle-class (Atle, Frej, Sisu, Uhro and Ymer) and the Viking ice-breakers. The vessels’ capacity as icebreakers depends on construction. Design of hull, engine size, existence of stern propellers, etc are factors of importance. An icebreaker’s relative capacity also is influenced by ice characteristics.

For the purpose of this study, there has been a need to classify icebreakers according to their potential as icebreakers. The analysis has led to a classification into four groups:

Category A: Large icebreakers suited for off-coast operations. Their engine size and construction allow them to force the most demanding ice formations in the Baltic and their size (beam) offers ice channels wide enough for most vessels.

Category B: Relatively powerful, somewhat smaller icebreakers. Well suited for operations near the coast, in relatively demanding ice conditions. Limited beam makes them less suitable for assisting large vessels.

Category C: Less powerful icebreakers, with a medium icebreaker capacity, typically, well suited for operations in the Baltic Proper during severe winters, or similar.

Category D: Smaller vessels with icebreaking capacities are typically, mainly engaged in other activities such as tug boat operations. The category is fairly diverse.

The table below summarizes some characteristics of the categories, according to the CATRIN survey. It also reports the number of icebreakers in respective category. A complete list of all vessels and characteristics are found as an enclosure to this report.

Table 13 Icebreaker categories and their characteristics.

<table>
<thead>
<tr>
<th>Category</th>
<th>Engine power, kW</th>
<th>Length, m</th>
<th>Beam, m</th>
<th>Number in category</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>&gt;15 000</td>
<td>&gt; 100</td>
<td>&gt;= 24</td>
<td>12 -14</td>
</tr>
<tr>
<td>B</td>
<td>13 000</td>
<td>83</td>
<td>18</td>
<td>3</td>
</tr>
<tr>
<td>C</td>
<td>6 500 – 10 000</td>
<td>76 – 100</td>
<td>15 - 24</td>
<td>10</td>
</tr>
<tr>
<td>D</td>
<td>&lt; 5 500</td>
<td>&lt; 75</td>
<td>&lt; 18</td>
<td>13</td>
</tr>
</tbody>
</table>

An exchange rate of SEK 10 = € 1.
Costs for icebreakers

To a large extent icebreakers are individuals. They are built as unique vessels or in short series. Even sister-ships may be equipped with different machineries, manned differently, etc. Private shipowners, as well as the Finnish, state owned Finstaship are hesitant to open their books and reveal their costs. Thus, to a large extent, the costs estimates applied in this study have their origin in SMA. First and foremost SMA has cost information in the capacity as shipowner, with full access to own accountings. Secondly, the organisation purchases considerable additional capacity, on long term contract (notably the Viking icebreakers) as well as on short term contracts (basically category D icebreakers). Purchases of services and international cooperation also give considerable insights in other operators activities.

Investment costs and alternative value

Investments in existing icebreakers are seen as sunk cost. It is not a realistic scenario to employ the vessels in question in other operations. They are built as icebreakers, and their alternative value, in other capacity is most limited. Thus, the concept investment costs are relevant for potential new buildings only. Icebreakers are fairly rarely built; there are no list-prices for the vessels. Prices depend on the ships’ specific design and technologies, steel prices, etc. Here, the investment costs for the different categories are estimated based on recent concept and pre-studies. The estimated investment costs are reported in the table below.

Table 14: Estimated investment costs for the different categories of icebreakers, million €.

<table>
<thead>
<tr>
<th></th>
<th>Cat A</th>
<th>Cat B</th>
<th>Cat C</th>
<th>Cat D</th>
</tr>
</thead>
<tbody>
<tr>
<td>M€</td>
<td>140</td>
<td>80</td>
<td>60</td>
<td>50</td>
</tr>
</tbody>
</table>

In line with the SMAs accounting manual, investment costs in new icebreakers are assumed to be written off over 30 years. This will affect the capital cost for possible new buildings.

However, there are some multipurpose icebreakers (basically some Finnish vessels and the contracted Swedish Viking-icebreakers and Oden). They have an alternative value. Their alternative value depends on the markets at the other markets – the market for off shore vessels and research vessels, respectively.

For the SMA the Viking icebreakers have no alternative value in the short and medium term. The costs for the Swedish Maritime Administration are defined in a contract with the shipowner:

- When the vessels were built, the SMA paid for additional costs related to the vessels’ ice-breaking capacity. It amounted to some € 6 500 000 per ship, a cost that is written off over 15 years.
- An annual fee of € 750 000 per ship for having the vessel at disposal for icebreaking from January to March. The fee is independent of whether the vessels actually are called in by the SMA or not.
In the perspective of governmental icebreaking activities and the CATRIN-analysis, these two costs components are to be seen as a sunk. From a social economic perspective however, it may be argued that an alternative value, according to the principles laid out in the discussion, should be applied for the Finnish multipurpose icebreakers and for Oden.

Running costs

Running costs are divided into fixed and variable running costs. The fixed part represents cost needed to have the vessel fit and stand-by for icebreaking. This is first and foremost costs for a crew and secondly cost for maintenance not related to hours of operation. The research team has first hand information on the costs of the Swedish icebreakers. For the Swedish category A icebreakers the annual fixed cost amounts to € 2 400 000, of which 1 800 000 makes up of cost related to crew and a fixed maintenance cost of € 600 000.

The fixed running costs for the Swedish category B icebreakers are as mentioned, according to the contract, with the shipowner € 750 000 per vessel and year.

The variable running costs are made up of fuel costs and costs for maintenance related to the icebreaking operation. The dominating part is fuel. A category A icebreaker has a fuel consumption of up to 80 ton per day. With a price of crude oil of about € 420 per ton, the maximum daily fuel cost for a Swedish category A icebreaker is about € 34 000 a day. However, the average consumption is considerably lower, for the Swedish icebreakers, during a severe winter; it amounts to 30 to 35 percent of the maximum level. For operations in the Baltic the variable maintenance cost are comparatively lower. The Baltic climate is favourable: There is only the less solid first year ice, the salinity is low and winds and waves are less demanding, etc. To summarize, the variable running costs are judged to be between zero, when the vessel is not used, and € 34 000 a day, when it’s full engine power is used the 24 hours of a day. The category A vessel Atle is equipped with catalytic converter. Therefore, the operation of the vessel (or rather its emissions control equipment) demands use of urea, a chemical that adds to the operation costs. The additional cost for the vessel is estimated to be a maximum of € 3 000 a day.

The variable cost for the Swedish category A icebreakers is up to a maximum of € 39 000 a day. It includes the costs to run the vessels’ catalytic converters.

In the absence of other more detailed information on the Russian category A icebreakers, they are estimated to have the same running costs as the corresponding Swedish icebreakers.

The fixed maintenance costs for the dedicated Finnish icebreakers are assumed to be equal to corresponding Swedish vessels costs, but the costs related to crew are estimated to be some 30 percent higher, due to a larger crew. The annual fixed running costs for the Finnish icebreakers are estimated at € 3 000 000. For the Finnish multipurpose icebreakers one fourth of that cost is allocated to icebreaking and the rest to off shore activities. This allocation can certainly be questioned, but it follows the expectation that the icebreakers in questions typically are used for icebreaking during 3 month a year.

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21 The average fuel use per hour differs due to the winter’s severity. The average fuel use for a Swedish category A icebreaker is 2.57 ton per hour during a severe winter, 2.42 ton per hour during a normal winter and 2.27 ton during a mild winter.
While the Swedish and Russian category A icebreakers use crude oil as fuel, some Finnish vessels use diesel oil, a fuel that in the autumn 2008 is about 60 percent more expensive than crude oil. This implies that the variable costs for the Finnish icebreakers are considerably higher. Their estimated maximum daily cost is €49 000.

The cost category C and D icebreakers are more diverse than the other categories. They are more diverse in technical as well as in operational terms. Still, our cost estimates to this end are more simplified. Even though this degree of averaging will imply elements of error in the individual cases it will be balanced by variations that go in the opposite direction. Estimates may not be correct for individual countries, but most certainly for the fleet in general.

Six out of four of the C icebreakers are old; 40 years or older. For those vessels the fixed annual maintenance costs are considerably higher compared to modern vessels. The maintenance cost is assumed to be of the same magnitude as the corresponding cost for category A icebreakers, namely a bit more than €600 000 a year. Two of the ten icebreakers in the group are of medium age, 24 and 26 years old. For these two vessels the maintenance cost is assumed to be 80 percent of an A icebreaker (€500 000 a year). For the two modern C icebreakers, both ten years old, the maintenance cost similarly is estimated at 60 percent of an A vessel (€400 000 a year).

For the category D icebreakers maintenance costs are similarly estimated. For vessels older than 40 years maintenance cost are assumed to be 80 percent (€500 000 per year) of a category A icebreaker, for vessels between ten and forty years 60 percent (€400 000 per year) and for the individuals younger than 10 years 40 percent (€250 per year).

For category C and D icebreakers the cost for crew, given that the vessel actually shall be ready for operation, are estimated to be about half of the cost compared to a category A icebreaker (€900 000). It should be stressed that this, in some cases, mirror reality poorly. For example, the Danish icebreakers currently have no dedicated crew.

A number of category D and C icebreakers are used for other purposes as well. Viscaria and the German icebreakers are all mainly employed as tugboats and Baltica’s and Scandica’s main employment is fairway maintenance. Thus, parts of the annual costs should be allocated to other activities, rather than to icebreaking.

Variable running costs for the category C and D vessels are estimated in relation to the different vessels’ engine power and age. The Swedish A-category icebreaker Frej, built in 1975 is used as a reference vessel. The variable costs are assumed to be linear to engine power, kW, at a cost level represented by Frej and her sister vessel Ymer.

The efficiency of icebreakers is, on average, judged to be improved by 0.75 percent per year. Basically, this refers to energy efficiency, but theoretically the same assumption applies for variable maintenance. The calculation implies that an icebreaker thirty years younger than Frej is 15 percent more efficient per kW. Correspondingly, an older vessel has a lower efficiency.

According to this formula the maximum variable daily costs for category C icebreakers varies in the range of €24 500 a day to €13 900 a day. The former represents the 54 years old, 10 200 kW Voima and the latter represents a 9 000 kW newbuilding. For the category D
icebreakers the upper end of the interval, € 12,900 represents the 50 years old, 5,500 kW icebreaker Karu, and the low end € 5,100, by the 25 year old, 2,600 kW Scandica. Cost data are reported in some detail in enclosure 1. Estimated costs for the individual icebreakers are disclosed.

6.2 Analysis

The described scenarios provide basis for a theoretical allocation of icebreaking resources (in term of category A-D) to meet the assistance needs. The allocation aims to mirror a real allocation as close as possible. Thus, the real world allocation method “best professional judgement” is applied. The Swedish icebreaking management has been given the traffic scenario and ice conditions (ice charts) with the task to allocate icebreaking resources along the methods regularly applied. They have not only done the allocation for Swedish waters, but also for other Baltic waters.

The allocation of icebreaking resources are modeled according to two parallel rationales:
- A national approach and
- An international cooperation approach.

The former implies that each single state ensures that traffic to and from national ports are assisted when ice conditions demands. Today, Russia has a pure national approach to icebreaking and this regime currently governs the activities in the Gulf of Finland. Estonian, Finnish and Russian icebreakers escort vessels in parallel in the area. Historically, that national approach was applied all over the Baltic.

The international cooperation approach implies for instance that two states agree that one of them allocate an icebreaker to an area where there are needs from both countries, while the other state keep an icebreaker in a similar area somewhere else. Finland may for instance cater for assistance in the Sea of Aaland, while Sweden provides services in the Quark. Instead of parallel assistance of ships, common convoys are formed and assisted by one icebreaker. States may also exchange resources; when winds and currents cause ice pressure and severe conditions along one side of the sea, leaving the other side open, icebreakers of different nationalities can operate at the coast in need. Today, cooperation is well developed, particularly between Finland and Sweden.

Based on the resource allocation economies of cooperation has been analyzed.

6.2.1 Allocation of icebreakers

When it comes to resource utilization the potential of cooperation is two-dimensional:

- First, cooperation limits the total capacity demand, the number of icebreakers needed.
- Secondly, cooperation improves the efficiency of operation, the output in terms of icebreaking services in relation to number of icebreaker hours in operation.

The former is directly linked to the capacity need during the period of maximum ice extension. The latter relates to icebreaker utilization during the entire season.
Based on the traffic and ice scenarios, the icebreaking management has concluded that four category A icebreakers and one B icebreaker is needed in the Bay of Bothnia during the week of maximum ice extension, given current well developed Finnish/Swedish icebreaking cooperation. The cooperation materializes in joint convoys for ships to and from the Quark in the south, full coordination of the assistance for the Luleå to Raahé ore shuttle and the employment of one single icebreaker in the south of the Gulf of Bothnia, assisting on both the Finnish and the Swedish side. With a purely national approach the need for icebreakers in the region would increase by two category A icebreakers and one category B icebreaker. The allocation is illustrated in the figure below.
Up in the Gulf of Bothnia ice conditions are relatively stable for a fairly long period. This maximum icebreaker allocation is identical for 13 consecutive weeks. All in all icebreaking services are conducted during 25 weeks.

During a severe winter cooperation is estimated to save 34 weeks of operation of A icebreakers, 15 weeks for B and three weeks for C icebreakers. During a normal winter seven weeks of operations of A icebreakers, two weeks for B icebreakers and three weeks for C icebreakers would be saved.

The ice conditions and traffic at the Sea of Bothnia would demand three category A icebreakers, one B and one category C icebreaker, given cooperation. Two A icebreakers would operate more along the Finnish coast, one in each port region, Vaasa to Kaskinen and Mäntyluoto to Uusikaupunki. The first mentioned will also assist the ferry line between Umeå and Vaasa. The third category A icebreaker will primarily stick to the vicinity of the port region Hudiksvall to Hallstavik. The category B icebreaker will operate further along the Swedish coast. All these vessels will have shared responsibilities in escorting convoys in south – northbound direction. The one allocated category C icebreaker will operate in the Sea of Aaland. In a situation where the current bilateral cooperation did not exists, two additional icebreakers would be needed; one category A icebreaker and one category B icebreaker. The icebreaker allocation is shown in Figure: 13.

Figure: 12 Icebreaker allocation in the Gulf of Bothnia, during the scenario “Severe winter” the week of maximum ice extension.

Figure: 13 Icebreaker allocation in the Sea of Bothnia, during the scenario “Severe winter” the week of maximum ice extension.
The ice conditions are less stable compared to the Gulf of Bothnia. This “maximum icebreaker allocation” is valid for three weeks only. The icebreaking season in the Sea of Bothnia is 19 weeks, given a severe winter.

Over a severe winter season cooperation is judged to save 16 weeks of operation of A icebreakers and 14 weeks for B icebreakers. During a normal winter, the savings, all icebreaker categories’ included, would be limited to 4 weeks of operation.

**Figure: 14 Icebreaker allocation in the Gulf of Finland, during the scenario “Severe winter” the week of maximum ice extension.**

During the maximum extension week in the *Gulf of Finland*, all in all, seven A-icebreakers, four C and seven D icebreakers are needed, given current regime, with no international cooperation. Three A and two C icebreakers are allocated to the two EU countries and the remaining to Russia. With cooperation one A icebreaker could be saved.
The benefits of cooperation would, for a severe winter in the Gulf of Finland, add up to 12 weeks of operation for A icebreakers and two weeks for category C. During a normal winter, the benefits would be minor.

Given cooperation, winter navigation in the Baltic Proper demands one icebreaker of each category during the maximum extension week. With no cooperation another A and another C icebreaker would be needed. Given the south eastern winds in the scenario the need for assistance is along the Swedish coast. With winds from the north, everything else being equal, the needs would rather show up in the southern parts of the Baltic. Traffic to and from the Bay of Riga would need assistance.

**Figure: 15 Icebreaker allocation in the Baltic Proper, during the scenario “Severe winter” the week of maximum ice extension.**

All in all, cooperation during a severe winter would save 13 icebreaker operation weeks, involving all the four icebreaker categories.

For the maximum ice extension week, four C icebreakers and five D icebreakers are allocated to the Baltic entrance, given international cooperation. With no cooperation two additional C and D icebreakers are needed.
In operational terms, cooperation during a severe winter would save 18 weeks of icebreaker operation. The savings are mainly related to category C and D icebreakers.

### 6.2.2 Summary of icebreaker needs

When the needs for icebreakers for the different parts of the Baltic Sea are summarized (Table 15) it is concluded that the existing fleet is more or less sufficient to keep up with the traffic even during a severe winter. Russia is assumed to have moved another two category A icebreakers to the Baltic to keep up with the situation in the Gulf of Finland and in the port region. In the non-cooperation alternative, on the other hand, there is a considerable lack of capacity. All in all, twelve additional icebreakers are needed. The additional need is fairly evenly distributed among the different icebreaker categories.

### Table 15 Summary of needs for icebreaker capacity a severe winter, given cooperation and non-cooperation.

<table>
<thead>
<tr>
<th>Area</th>
<th>Cooperation</th>
<th>No cooperation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cat A</td>
<td>Cat B</td>
</tr>
<tr>
<td>Bay of Bothnia</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Sea of Bothnia</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Gulf of Finland</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>Baltic Sea</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Baltic entrance</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Sum</td>
<td>14</td>
<td>3</td>
</tr>
<tr>
<td>Available</td>
<td>12 (14)</td>
<td>3</td>
</tr>
</tbody>
</table>
6.2.3 Investment needs and optimal utilization of icebreakers

The required additional icebreaker capacity to provide sufficient resources for a severe winter represents considerable investment costs. All in all the investment needs equals € 1 140 million. In Table 16 the costs are specified at a national level. The largest share relates to the two nations where cooperation currently is well developed, Sweden and Finland. Estonia, Denmark and Germany do also face investment needs to handle the winter navigation if no cooperation is applied.

Table 16 Investment needs for different nations, to handle the severe winter scenario given the no cooperation approach.

<table>
<thead>
<tr>
<th></th>
<th>Cat A</th>
<th>Cat B</th>
<th>Cat C</th>
<th>Cat D</th>
<th>Cat A-D</th>
<th>M€</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sweden</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>5</td>
<td>500</td>
<td></td>
</tr>
<tr>
<td>Finland</td>
<td>2</td>
<td>1</td>
<td></td>
<td>3</td>
<td>340</td>
<td></td>
</tr>
<tr>
<td>Estonia</td>
<td>1</td>
<td></td>
<td></td>
<td>1</td>
<td>140</td>
<td></td>
</tr>
<tr>
<td>Russia</td>
<td></td>
<td></td>
<td></td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Denmark</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>110</td>
<td></td>
</tr>
<tr>
<td>Germany</td>
<td>1</td>
<td></td>
<td></td>
<td>1</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>5</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>12</td>
<td>1 140</td>
</tr>
</tbody>
</table>

To model the optimal utilization of the icebreakers an optimization model has been developed. Based on the estimated costs for all the individual icebreakers, the least costly set of icebreakers are engaged. Generally, the most expensive option is to engage a new-building. The model is run both for the cooperation alternative and the non-cooperation alternative. The former implies that that all icebreakers are viewed as a common fleet, independently of the vessel’s flag and where the need for assistance occurs. In the latter alternative, icebreaking needs are seen in purely national perspectives, but the model still allows that icebreaking capacity is traded between nations. In other words, an important element of cooperation is included also in this calculation of “non-cooperation”. Thus, the calculated difference between the two alternatives understates the difference between full-fledged cooperation and a purely national approach. Still, the savings are considerable and amounts to € 67 million during a severe winter.

Table 17 Annual costs for Baltic icebreaking assistance a severe winter, € million.

<table>
<thead>
<tr>
<th></th>
<th>Non-cooperation</th>
<th>Cooperation</th>
<th>Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investment cost</td>
<td>37</td>
<td>0</td>
<td>37</td>
</tr>
<tr>
<td>Fixed operational cost</td>
<td>91</td>
<td>66</td>
<td>25</td>
</tr>
<tr>
<td>Variable cost</td>
<td>37</td>
<td>32</td>
<td>5</td>
</tr>
<tr>
<td>Total</td>
<td>165</td>
<td>98</td>
<td>67</td>
</tr>
</tbody>
</table>
6.3 Financial and organizational schemes to support cooperation

Obviously, considerably efficiency can be gained through cooperation. However, the costs for the cooperation and the distribution of benefits will vary due to organizational forms and financial schemes. To develop common understanding on organizational issues is fundamental for progress.

The Nordic Icebreaking agreement from 1961 basically presumes that the states cater for having icebreaker capacity enough to assist ships to and from ports on their own territory. Along the same lines, it is stated that the countries should strive for icebreaker utilization in relation to each nation’s needs. Economic transfers should be avoided. Still, the agreement allows for formal chartering of icebreakers involving economic compensation. This option also has been used, particularly during the last few years. Finland has leased Swedish icebreakers at a daily rate and Sweden has similarly hired a Danish icebreaker.

Seen from an efficiency perspective the Nordic agreement appears defective. Given differences in operation costs a lot more can be gained if the least costly unit, at a Baltic level, systematically is utilized rather than the most appropriate unit in each single nations’ vessel fleet. Moreover, joint investments in icebreakers also have potentials, particularly for countries with limited capacity need. Shared investments can reduce problems related to indivisibilities.

The SMA has presented a vision of future Baltic Icebreaking cooperation. The vision builds on three pillars:

- **A common icebreaking fleet** where all the larger icebreakers are operated by the same organization. The vessels may still have national flags and national ownership. The joint organization should also, to an appropriate extent, sign contracts with relevant shipowners to safeguard necessary capacity of smaller icebreakers, basically larger tug-boats or category D icebreakers according to the classification in this study. The most appropriate (least costly) icebreaker should be employed in every single moment, independently of ownership of the icebreaker.

- **A joint shipowning function** where maintenance, manning, etc. are coordinated. Economies of scale can then be better exploited. It would add flexibility when resources, to some extent can be swapped between units and a larger fleet allows more of flexibility for major maintenance work, when a ship needs to dock.

- **A joint icebreaking management** where one management unit, rather than a multitude of national offices, takes the comprehensive operational decisions. The administrative costs would be reduced.
7 Conclusion

We have reviewed the literature on maritime infrastructure cost with a focus on fairways, pilotage and ports. The economic literature of maritime economics has one branch on shipping and one on port economics. Port economics deals seldom explicitly with the cost of fairways or pilotage.

7.1 Efficient maritime charging

Our review suggests that the use of fairways in general has a very low marginal cost although the literature to support such a claim is almost non existent.

Pilotage seems also to run under economies of scale. The cost is, to a large extent, independent of vessel type and size. The practice in charging for pilotage in some Member States is a two part tariff structure where one charge is related to the actual pilotage while the other is a form of tax levied on all ships to recover the cost of pilotage. In other Member States there is a hidden cross subsidy between fairway charges on all ships and the cost of pilotage. In practice pilotage charges actually applied increase strongly with vessel size. Comparing the expected marginal cost with the price structure suggests that the category of ships with lowest charges are charged something equal to marginal cost while the bigger ships pay a mark-up, basically to improve cost recovery.

Current pilot charging schemes divert from the theoretical optimum. In most cases, for most vessels, charges seem to be well above marginal cost. Given a cost recovery constraint, schemes where large vessels pay more might be a reasonable way to address the issue. However, this project has not looked into the issue in all detail. It may be an area of interest for further research.

Port charges are a complex issue as they have to consider both the port infrastructure for ships as well as the infrastructure for cargo and moreover also the ship costs. While the port in the real world is a multimodal switch between sea and land-transport it seems generally to be examined as a part of the maritime infrastructure system. Nevertheless, the question of port charges can be analysed with traditional economic approaches.

In general the conclusion seems to be that ports should be regarded as a multi-product industry where production is taking place under economies of scale and scope. Consequently, charges based only on the marginal infrastructure cost will not recover the full cost of production. This is true under the assumption that a long run marginal cost pricing is applied. The review has shown that the goal of cost recovery is an important aim for most of the port sector.

While the consumption of the ports’ resources is of minor importance the vessel cost is dominant. In Bickel et.al. (2006) the vessel cost is approximately 10-20 times higher than the infrastructure cost of a port call which were analysed as the cost of locks, pilotage and tugboats. This takes us back to the principle of infrastructure pricing where the whole system has to be included into the problem. Thus one important element of infrastructure pricing is the (external) cost imposed on other users. This is true for congested road and rail networks as well as for ports. In ports the problem is analysed in two parts, the queuing cost during
constant service time and the additional congestion cost due to increased service times caused by congestion. The optimal port charge would take the queuing cost into account which is the natural form of the short run marginal cost. This cost can be analysed both for the ship and for the cargo. The charge will thus comprise the two dominant element of charging port services today – charges related to vessels and charges related to cargo.

The queuing model based pricing approach will take into consideration costs incurred for other ships but the approach will nevertheless not ensure cost recovery. The literature has developed a number of models along the lines of “Ramsey” pricing where joint costs are allocated in a way that disturbs demand as little as possible. However, this solution calls for different mark-ups on different cargo and ship categories to reflect the differences in the elasticity of demand.

Icebreaking in open water is not charged for by any EU Member State. Still the case study reported in this paper shows that the operation is characterised by considerable marginal costs. Marginal cost for ice-breaking is represented by the variable costs in the cost model used in the case study and is estimated at some € 30 million per year in the Baltic, given cooperation. Scarcity costs should be added to that and perhaps also the emission costs. To specify the marginal costs for different users, often would be complicated, however: Should the bulk of the variable costs be allocated to the first vessel in a convoy? How should costs for moving an icebreaker from one mission to another be split? What vessel causes delay for the others?

Obviously, current charging regimes are theoretically inoptimal. The scheme is not sanctioned by efficiency, but by regional equity considerations. In line with the arguments of the CATRIN deliverable D3 it could be argued that a club approach could be worth considering for the case of ice-breaking.

When it comes to icebreaking the most prominent efficiency gains may be to develop the forms for international co-operation, rather than aiming at efficient charging schemes – schemes possibly unlikely to be politically accepted.

7.2 Justifications for international law on maritime charging

A relevant question to address is to what extent there are justifications for European or international legislation on maritime charging in the light of economic theory. Obviously, it is useful to address different parts of the maritime infrastructure separately. Analytically, the passage of sea traffic in open waters is probably best seen as a common good. When used by someone, it does not prevent anybody else to use it and it does not add to costs for the “infrastructure manager”. The financial cost to provide the infrastructure is close to zero. Charges on (foreign) traffic could be tempting, but would hamper the global economy and would not be in line with international law. Thus, current international legislation appears to be appropriate.

However, emission charges would be theoretically adequate to provide incentives for shipowners to reduce externalities in terms of air pollution. An international framework for emission charging would have potential. Emission trading could be an alternative.22 Such a

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scheme could reduce administrative costs compared to pure charging; reduce risks for market distortions as well as for discriminating charging schemes.

Maritime accesses are used by the ports customers. Excessive charging would then first and foremost hamper the port business, but not the global economy. Local regional or national infrastructure managers may have incentives to recover their costs for providing the infrastructure, but to do it in a way that does not harm the port business. Apart from regular competition law that guarantees non-discrimination, there is no obvious need for international legislation to this end. Still arguments may be raised for environmental charges to make up for air pollution. On the other hand it can be argued that emissions are better handled within a general charging scheme (including open waters).

The main justifications for European policy related to Sea port infrastructure is to:
- Prevent distortive state (public sector) aid. As mentioned it has been argued that aid to one port can harm to competitiveness of a neighbouring port active in the same market segment.
- Trigger efficiency by eliminating monopoly and monopolistic charging for services like stevedoring.

There may be reasons to look upon inland waterways in close parallel to road and rail. The justifications for European charging policy may be similar. Rail charging as well as the charging of HGVs are regulated in European law, basically as a mean to prevent overcharging of international transports. To this date the issue has been regulated by regional, international agreements.

7.3 Cooperation on icebreaking

A crucial issue for the further development of icebreaking cooperation is that cost can be properly allocated between the contracting parties. That is true for developed cooperation, for instance along the SMA vision, but also for a piecemeal development from current practice. This study suggests that there are considerable economic gains to be collected. Thus, there is room for a solution that makes all participants winners. Conducted study suggests that it would be interesting to study this issue in more detail.

Traditionally, countries with ports where ice problems occur have been seen as the rightful owner of the problem. Each country has got and taken the responsibility to cater for the access to and from ports in their own territory.

The benefits of icebreaking assistance are not only to be identified in the states around the Baltic, but also at the common market in general. The common European interest in winter navigation has been acknowledged by the fact that icebreaking has been included in the TEN-T guidelines and Member States have received EU TEN-T funds for icebreaking purposes. It is obviously important that icebreaking continues to be regarded as a part of the TEN-T (i.e. important infrastructure) also under the new forthcoming guidelines. Along with the European discussion on TEN-T guidelines, and the policy implementation of the concept Motorways of the Sea and, specifically, Motorways of the Baltic Sea has been introduced. Maritime transport at the Baltic Sea has been specifically addressed. Seen from that perspective it is argued that the European infrastructure budget, TEN-T, could or should contribute to fund future icebreaking infrastructure. A common European icebreaker, and in the long run possibly even a common icebreaker fleet, could serve as a trigger for improved cooperation.
Discussions with infrastructure managers emphasises some practical an institutional perspectives on icebreaking. It is important that all nations follow the Helsinki Commission’s recommendation 25/7 on “Safety of winter navigation in the Baltic Sea Area” when traffic restrictions are applied. Different levels would leads to imbalance in icebreaker assistance. Furthermore, nations should take benefit of the joint information system IBNet. Real time data on icebreakers, ships in need for assistance and icebreaking operation are then made available for all parties. It is also worth stressing that the efficiency of the icebreaking services is depending on the skill of commanding officers on the bridge of the icebreaker. With skilful staff assisting times of the icebreakers are reduced and fuel consumption is decreased at the same time waiting times for merchant vessels are cut.
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CATRIN D10 – Allocation of infrastructure cost in the maritime sector


CATRIN D10 – Allocation of infrastructure cost in the maritime sector

9 Enclosure 1. Baltic icebreakers and icebreaker costs

The following table reports the relevant icebreakers in the Baltic. The categorization developed for the purpose of this study and estimated costs.

<table>
<thead>
<tr>
<th>Name</th>
<th>Engine power, kW</th>
<th>Length, m</th>
<th>Beam, m</th>
<th>Draught, m</th>
<th>Year of manufacture</th>
<th>Owner</th>
<th>&quot;Investment cost&quot;, €</th>
<th>Alternative value</th>
<th>Running costs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Fixed k€/day</td>
<td>Variable k€/day</td>
<td></td>
</tr>
<tr>
<td>Category A</td>
<td></td>
<td></td>
<td></td>
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10 Enclosure 2. Optimization model

The following optimization model has been developed and applied:

The problem to determine an optimal mix of icebreakers, and thereby, to calculate the total annual cost of the icebreaker fleet, can be formulated and solved as an optimization problem. We introduce the following notation:

The icebreakers listed in Enclosure 1 are indexed by $i = \text{Oden, Atle, \ldots, Newb-ing-D}$ and the categories by $k = A, B, C, D$. Then, the following sets are introduced:

$I^E$ = the set of existing icebreakers, $I^n$ = the set of new icebreakers,
$I_k^E$ = the set of existing icebreakers of category $k$,
$I_A^R$ = \{Russia_1 and Russia_2\}.

The new icebreaker of category $k$ is denoted by $i_k$.

The cost parameters listed in Enclosure 1 are $c_{i_{\text{inv}}}^i =$ investment cost of new icebreaker $i$, $c_{i_{\text{fix}}}^i =$ fix running cost of using icebreaker $i$, $c_{i_{\text{var}}}^i =$ variable cost for icebreaker $i$. The need for icebreakers of category $k$ in week $t$ is denoted by $d_{k_t}$, where $t$ takes the values of the set $T = \{50, 51, 52, 1, 2, \ldots, 22\}$. Observe that $d_{k_t}$ takes different values for the two cases “Cooperation” and “No Cooperation”.

For the existing and new icebreakers, the following variables are introduced:

$y_{i_t} = 1$ if existing icebreaker $i$ is used in week $t$, 0 otherwise,
$z_{i_t} = 1$ if existing icebreaker $i$ is used in any week, 0 otherwise,
$x_{i_t} =$ number of new icebreakers of category $k$ that are used in week $t$,
$w_{i_t} =$ maximum number of new icebreakers of category $k$ that are used over all weeks.

Finally, the following parameters are defined: $n =$ no. of working days in a week (here 7), $l =$ work level (here 0.35) and $a =$ depreciation time (here 30 years).

By these notations the optimization model can be defined as (P1)

\[
\begin{align*}
\text{min} & \quad \sum_{i \in I^n} \left( \sum_{t \in T} n_l c_{i_{\text{var}}}^i y_{i_t} + c_{i_{\text{fix}}}^i z_{i_t} \right) + \sum_{i \in I^E} \left( \sum_{t \in T} n_l c_{i_{\text{var}}}^i x_{i_t} + \left( c_{i_{\text{inv}}}^i / a + c_{i_{\text{fix}}}^i \right) w_{i_t} \right) \\
\text{st} & \quad \sum_{i \in I^n} y_{i_t} + x_{i_t} = d_{k_t}, \quad k \in K, t \in T \quad (1) \\
& \quad |T| z_{i_t} \geq \sum_{i \in I^E} y_{i_t}, \quad i \in I^E \quad (2) \\
& \quad w_{i_t} \geq x_{i_t}, \quad i \in I^n, t \in T \quad (3) \\
& \quad y_{i_t} \leq y_{j_t}, \quad i \in I_A^R, j \in I_A^E \setminus I_A^R, t \in T \quad (4) \\
& \quad w_{i_t}, x_{i_t} \text{ integer, } y_{i_t}, z_{i_t} \text{ binary} \quad \forall i, t
\end{align*}
\]

The two terms in the objective function express the costs of using existing and new icebreakers, respectively. Constraints (1) ensure that the need for icebreakers is satisfied. The subsequent constraints, (2) and (3), are coupling constraints, assessing that the values of the
variables $z_i$ and $w_i$ are correct, according to the values of $y_{it}$ and $x_{it}$, respectively. Finally, constraints (4) allow the Russian icebreakers in the set $I'_a$ to be used only if all other icebreakers of category $A$ are used in that week.

Model (P1) has been formulated in the modelling language AMPL [1] and solved by the optimization software Cplex [2]. The model separates over the categories $k = A, B, C$ and $D$, and can therefore be solved as four separate optimization problems. However, if it becomes necessary to solve this model with additional environmental requirements, e.g. on total CO2 emissions, the complete model should be used.

