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Determining Optimal Transit Charges: The Kiel Canal in Germany*

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The Kiel Canal in Germany connects ports on the Baltic Sea with the rest of the world and is the most-used artificial waterway in the world. Despite this fact, it generates a balance sheet loss. Revenues, which are mainly generated by the transit charge, do not cover its operating expenses. This situation raises the question: What reforms could be made to make the canal generate a balance sheet profit?

In this paper, we focus solely on the canal's revenue. Because the canal is a monopoly that allows, in principle, for perfect price discrimination, we contrast the current charging system with an optimal charging system based on the willingness-to-pay (WTP) approach. We devise a general approach to calculate optimal transit charges and apply it in a case study that includes four different ship types. We conclude that much higher revenues could be generated, on the order of between $5 and $45 million more per year and ship type if the transit charge were based not only on ship size but also on a ship's departure and destination ports.

Keywords: optimal transit charge, Kiel Canal, shipping cost, Germany, price discrimination

JEL classification: R48, L92

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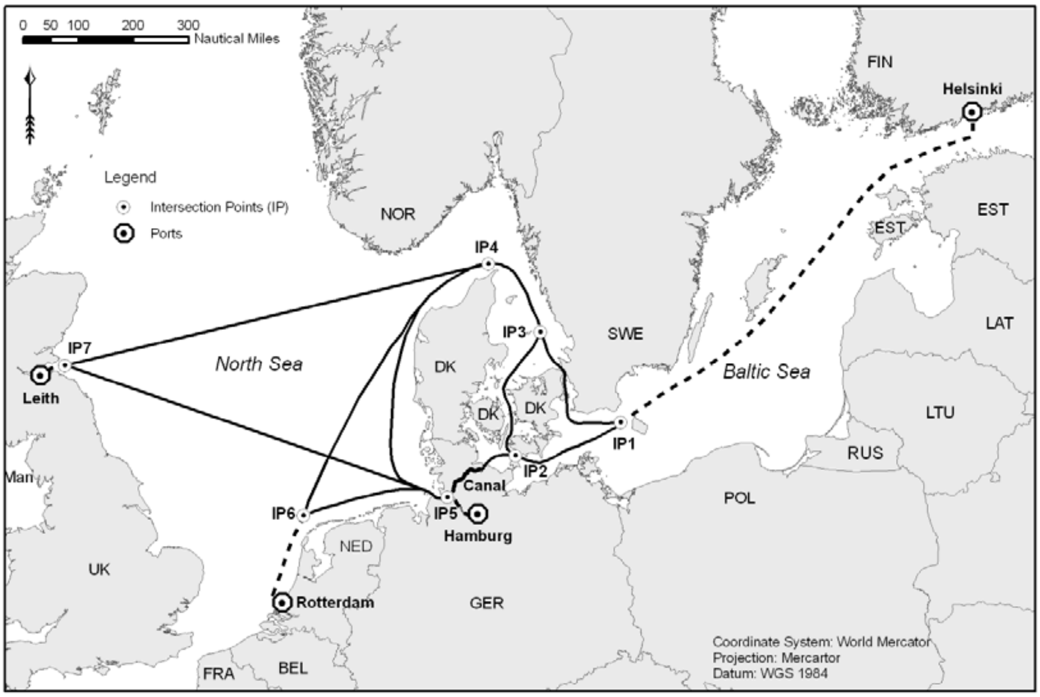
1 Introduction

Maritime transportation of goods is a costly business. One major determinant of the costs is the time it takes a ship to sail from one port to another. Ships operating between ports of the Baltic Sea and the rest of the world, for example, have the choice of alternative passageways to leave or enter the Baltic Sea. They can use the Kiel Canal passageway, the most-used artificial waterway in the world, or one of the two natural passageways around Denmark: through the Great Belt passageway or through the Oresund passageway. Sailing through the Kiel Canal saves, on average, 250 nautical miles[1] and, depending on the type of ship, up to several hours. Figure 1 shows the three alternative passageways for four ports in the region.[2]

Figure 1: Shipping routes and alternative passageways.



Source: own presentation based on ESRI Base Map; Shipping routes are based on Kerbaol and Hajduch (2009) and Helcom Map and Data Service.

The Kiel Canal is used by roughly the same number of ships as the Panama Canal and Suez Canal taken together, but handles significantly less cargo tonnage. 43,378 ships transporting 99.78 million tonnes of cargo passed the Kiel Canal in 2007, (WSD Nord, 2011b).[3] In comparison, during the same year, 14,721 ships transporting 208.2 million tonnes of cargo passed the Panama Canal (Panama Canal Authority, 2009), and 20,384 ships transporting 848.2 million tonnes of cargo passed the Suez Canal.[4]

[1] http://www.kiel-canal.org/english.htm.

[2] We define route as the connection between ports, and passageways as the alternative ways on that route.

[3] This includes cargo and non-cargo ships, but excludes all other categories such as small boats (sailing boats etc.).

[4] http://www.suezcanal.gov.eg/TRstat.aspx?reportId=3.

Despite the large amount of ship traffic the Kiel Canal handles, it nevertheless generates a balance sheet loss. Its revenues, which are mainly generated by the transit charge (charged by the Waterways and Shipping Authority North (WSD Nord)), do not cover its operating expenses. The transit charge is determined by the gross tonnage (gt) of a ship and includes up to four components, such as a transit toll, a pilotage due, a pilotage fee, and a helmsmen fee.[5] The last two components (pilotage fee and helmsmen fee) are passed on to the pilots and helmsmen for providing their services.[6] The pilotage due is used by the WSD Nord to maintain the pilotage facilities.[7] The WSD Nord relies mainly on the transit toll to cover expenses such as investments in extensions, operating and maintenance costs, and administrative costs.[8] Revenues in the period 2005-2010 covered only between 14% and 30% of expenses (WSD Nord, 2011a). The difference was covered by funds provided by the federal government.

This loss and the current discussion on further widening and deepening of the Kiel Canal raise the question whether the current transit charges collected by the WSD Nord are too low and could be raised. The Kiel Canal is a monopoly that allows, in principle, for perfect price discrimination. Under perfect price discrimination, a monopolist charges each customer her willingness-to-pay (WTP). WTP is the maximum price the customer is willing to pay for a good, i.e., she is just indifferent between buying the good at her WTP and not buying the good at all. We define the WTP as the optimal price. Applied to the Kiel Canal, optimal pricing under perfect price discrimination implies charges that amount to the total cost savings a ship operator realizes when choosing the route via the Kiel Canal instead of the one around Denmark. These cost savings result mainly from reduced sailing time and reduced consumption of bunker fuel.

The first analysis to apply the theory of price discrimination to the topic of this was by Hutchinson (1912), who applied the theory of price discrimination to the Panama Canal. He investigated the US government's action to exclude coastwise shipping from paying charges and offset the decrease in revenue by increasing the charges for international shipping. His results indicate that the resulting loss would not be offset by such a policy. Despite Hutchinson's early analysis, the literature related to this field of research remains limited. Most of the literature studies the competiveness of certain shipping routes from an operator's point of view. Liu and Kronbak (2010), for example, study the economic potential of the Northern Sea Route (NSR) as an alternative transit route to the Suez Canal route. Their results indicate that the ice-breaking fee is one of the main factors influencing the competiveness of the NSR. Somanathan et al. (2007, 2009) compare the Northwest Passage with the transit route via the Panama Canal.

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5 The German terms distinguish between fees that are regulated by public law and fees that are regulated by private law. The transit toll (Befahrensabgabe) and the pilotage due (Lotsenabgabe) are regulated by public law, whereas the pilotage fee (Lotsengeld) and the helmsmen fee (Kanalsteurergeld) are regulated by private law. We follow the official English translation of the WSD Nord to emphasize that differences in terms exist.

6 Pilots and helmsmen are not employed by the WSD Nord. Pilots work freelance (§21 Seelotsgesetz) and helmsmen are organized in a registered association (http://www.kanalsteurer.de/index.html).

7 In accordance with Seelotsgesetz § 6.

8 In accordance with Seeaufgabengesetz §13. Note that the WSD Nord collects additional revenues in the form of fines, grants, refundings, and other fees, but that these additional revenues are of minor importance.

They conclude that the most important factors determining the competiveness of the Northwest Passage are a ship's capital costs, fuel costs, and the number of potential round trips it can make per year.

Two studies exist that look at the Kiel Canal. Baird (2006) implicitly looks at the Kiel Canal by analyzing transport distances associated costs for established and potential alternative hub locations to find the optimal hub location for northern Europe. He finds that all established hub locations, including Rotterdam and Hamburg, are more expensive than the alternative hub location Orkney, located in the north of Scotland. Using Orkney significantly reduces costs for serving the Baltic Sea region via feeder shipping routed through the Kiel Canal. He does not look at the transit charge but takes it as given. Böhme and Sichelschmidt (1997) look at the Kiel Canal explicitly by analyzing the determining factors that cause the Kiel Canal's balance sheet loss. They find that the main way to leverage the loss is to reduce costs rather than to increase revenue. They suggest cutting operational costs mainly in order to increase profits. We build upon their results but also challenge them by analyzing the revenue part of the profit equation in more depth.

To our knowledge, no study exists that seeks to determine optimal transit charges by comparing the costs differences between alternative routes. As explained above, our main aim is to determine these optimal transit charges for a ship using the Kiel Canal compared to the same ship using either the Great Belt passageway or the Oresund Passageway. We contribute to the existing literature by taking the point of view of the canal authority to determine the optimal transit charges under perfect price discrimination. Charging the cost difference yields the maximum revenue for the canal authority. In principle, marginal costs must also be taken into account when determining optimal transit charges, i.e., optimal charges amount to the maximum of marginal costs and WTP. We assume for convenience that marginal costs amount to zero and, thus, neglect, for instance, marginal damages ships cause to the canal.

The paper is structured as follows. Section 2 presents information on the Kiel Canal, including its history, traffic data, and transit charge system. Section 3 introduces a general approach to calculate optimal transit charges. Section 4 presents a case study based on four ship types that typically use the Kiel Canal: a 550 TEU container ship, a 1400 TEU container ship, a handymax bulk carrier, and a container-oriented multipurpose ship. Section 5 discusses the results. The final section, Section 6, concludes.

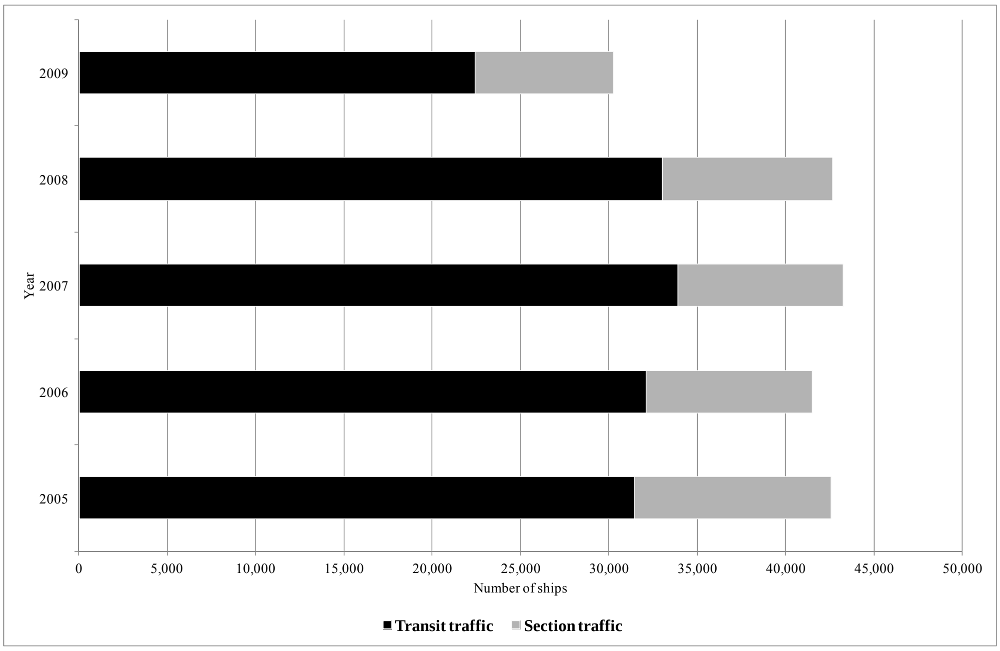
2 The Kiel Canal: History, Traffic Data, and Transit Charge System

In the past, the route around Denmark was considered to be a time-consuming and difficult shipping route. The main trade routes between Italian ports and the North Sea and Baltic Sea ports were land routes. But after the discovery of America and the route to East India, shipping to and from the North Sea ports gained momentum. Ships from America, East India, and Africa started to transport goods directly to ports of the North Sea, since it was more cost effective than shipping by land. Due to an increased interest in trading with the states in the Baltic Sea region, there was a need for a short and safe waterway connecting the North Sea with the Baltic Sea.

This need was originally fulfilled by the Eider Canal, which was opened in 1784. It went from the Kiel Bay to Rendsburg, where it merged with the Eider, which finally provided access to the North Sea. However, by the middle of the 19th century, the Eider Canal was no longer able to handle the growing number and size of naval and merchant ships. Thus, construction work on the Kaiser-Wilhelm Canal was begun in 1887 and it was opened in 1895. It was declared, by the Treaty of Versailles, to be an international waterway in 1919 and since then has been known internationally as the Kiel Canal (Wulle, 1927).[9]

In the following years, the number and size of naval and merchant ships continued to grow and the volume of traffic thus increased considerably, by 66%, or from 19,960 to 33,158 ships, in the period 1896–1906 (Wulle, 1927). Therefore, in recent decades the canal has been widened and deepened several times.[10] The most recent construction work to widen and deepen the canal and to build a new lock was begun in 2010.[11]

Figure 2: Traffic through the Kiel Canal (2005-2009)



Source: Own presentation based on data from WSD Nord, 2011b.

Today the Kiel Canal, which is approximately 99 km long, has a general width of 162 m (in places only 102.5 m) at the waterline, a general width of 90 m (in some places only 44 m) at the bottom, and a depth of 11 m. It is the most traveled artificial waterway in the world: 40,105 ships per year, on average, passed through it in the period 2005-2009 (WSD Nord, 2011b).[12]

[9] The Kaiser-Wilhelm Canal was renamed the Nord-Ostsee-Kanal in 1948 (http://www.kiel-canal.org/english.htm).
[10] The first time construction work took place from 1907 to 1914. The second time it took place from 1965 to 2000 (http://www.wsa-kiel.wsv.de/Kanal/index.html).
[11] http://www.wsa-kiel.wsv.de/ausbau_nok/
[12] Small boats are omitted, although their share in total traffic is not negligible. For example, in 2008, an average of 117 merchant and non-cargo ships and about 43 small boats used the canal per day (transit and section traffic).

Traffic on the canal is predominantly transit traffic, i.e., it consists of ships passing completely through the canal in transit. Transit traffic amounted to approximately 30,500 ships per year, on average, in the period 2005-2009. Section traffic, i.e., traffic consisting of ships that leave from or call at a port in the canal, or travel from one port to another in the Canal, amounted to approximately 9,500 ships per year, on average, in the same period (Figure 2). For comparison, total traffic around Denmark amounted to 54,492 ships per year, on average, for the same period (2005-2009), see Table 1.

Table 1: Total traffic around Denmark and total traffic through the Kiel Canal (2005-2009)

Year	Denmark	Kiel Canal	Total overall	% Kiel Canal
2005	39,521	42,552	82,073	52
2006	52,075	41,472	93,547	44
2007	59,721	43,378	103,099	42
2008	58,402	42,811	101,213	42
2009	62,743	30,314	93,057	33
Ø 2005-2009	54,492	40,105	94,598	42

Source: Own presentation based on data from WSD Nord, 2011b.

The reasons for traveling around Denmark are manifold. Ships may be simply too large to use the Kiel Canal.[13] The maximum allowed length and beam of ships using the canal is 235 m and 32 m, respectively. But more importantly, a significant number of ships make weekly round trips from and to ports on a fixed schedule and a fixed route and thus are not free to choose between different routes. Another reason is that the demand for maritime transportation decreased sharply during the recession in 2009 and led to overcapacities in the market. Ship operators reacted by laying-up ships, reducing services, or by slow steaming, which reduces fuel consumption and overcapacity (UNCTAD, 2011). As a consequence, maritime transportation became so cheap that the passageways around Denmark become more attractive economically. The volume of traffic (transit and section) through the canal decreased by 29% between 2008 and 2009 (see Table 1). This decrease was more pronounced in transit traffic than in section traffic (Bösl, 2010).

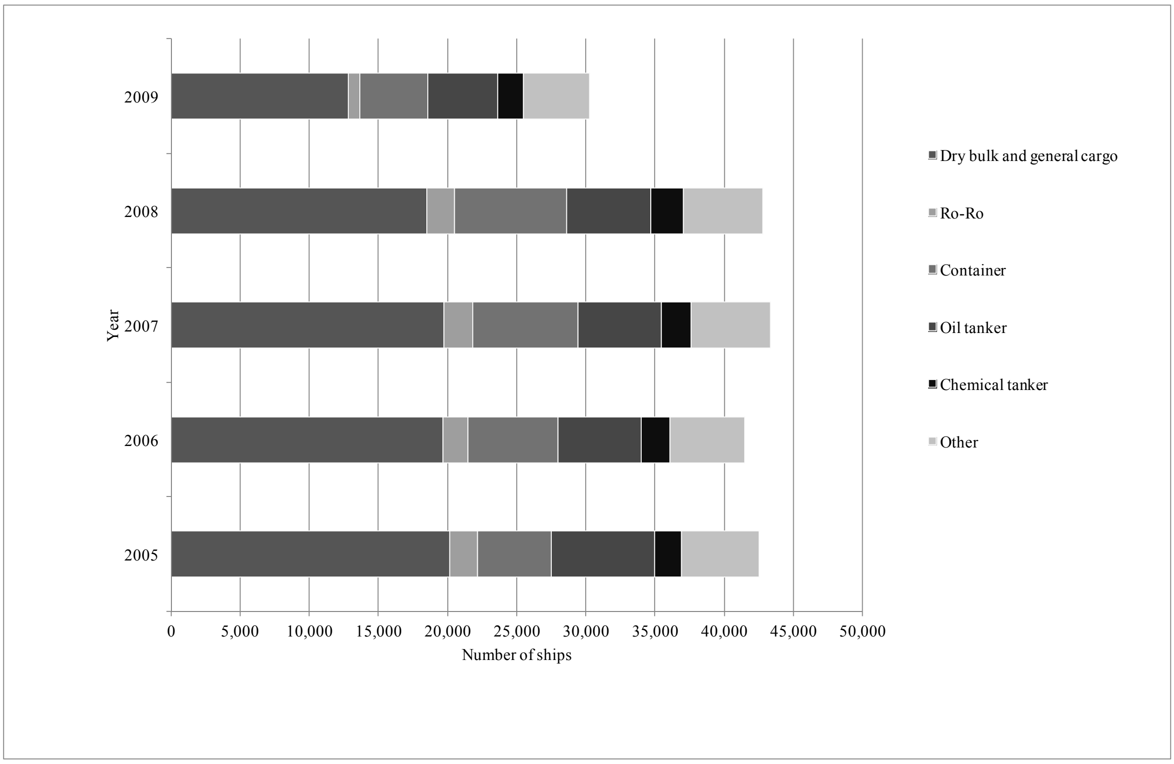
Analyzing traffic through the Kiel Canal by ship type reveals that the canal is mainly used by merchant ships.[14] Figure 3 shows that general cargo ships (including dry bulk carriers) clearly make up the largest portion of the merchant ships (45%) using the canal, followed by container ships (16%), and oil tankers (15%). Non-cargo ships, e.g., such as fishing, naval, or service ships, account only for approximately 10 percent of total ship traffic. Most of the ships using the canal have a tonnage of 2,501 to 6,000 gt. Ships smaller than 700 gt or larger than 10,000 gt are much less common on the canal (WSD Nord, 2011b).

[13] Note that ships traveling around Denmark can travel either through the Great Belt or through the Oresund. The former has no draft constraint, whereas the latter has a constraint of 8m maximum draft (Helcom, 2009).

[14] Here the term "merchant ships" includes general cargo ships (including dry bulk carrier), ro-ro ships, container ships, passenger ships, crude oil tankers, gas tankers, chemical tankers, and other tankers.

PLANCO (Meesenburg et al., 2010) estimates that about 50,000 merchant ships will transit the Kiel Canal per year by 2025, with an increase in general cargo ships (including dry bulk carrier) and container ships.

Figure 3: Ship types using the Kiel Canal (2005-2009)



Source: Own presentation based on data from WSD Nord, 2011b.

The transit charge to travel through the canal includes, as mentioned in the introduction, up to four components: a transit toll, a pilotage due, a pilotage fee, and a helmsmen fee.[15] These are charged according to a ship's characteristics, e.g., its length, width, and draft and the classification of its cargo (whether or not it is classified as dangerous or environmentally hazardous goods).[16] The amount that has to be paid for each component depends on a ship's gross tonnage. Sport boats, unmotorized boats, and ships with a gross tonnage of 300 or less pay the transit toll only. All other ships, excluding the service ships of the WSD Nord, are obliged to pay transit and pilotage due[17]. Pilotage and helmsmen fees are charged if a ship exceeds predefined dimensions.[18] There are, however, several exceptions, and discounts exist. For example, a feeder ship that travels the canal on a regular basis per year is eligible for a discount of up to 50% on the transit toll.[19]

[15] NOKBefAbgV (2003), LTV (2010), Kanalsteuertarifverordnung (2010).

[16] Ships are classified according to six different traffic groups (so-called Verkehrsgruppen 1-6). This classification helps the canal's traffic controllers plan traffic through the canal to avoid collisions and to determine the transit charges.

[17] Pilotage dues are charged to provide pilotage facilities in a pilotage district (Seelotsgesetz, 1984 and LTV, 2010).

[18] See §42 Abs.5 SeeSchStrO (SeeSchStrO, NOK-LV,2003, Bekanntmachung WSD Nord: Annahmepflicht Kanalsteuerer).

[19] NOKBefAbgV (2003).

Note also that in addition to the transit charge for the Kiel Canal, a pilotage due and a pilotage fee for the Kiel Bay (before entering/after leaving the canal) and the Elbe estuary (after entering/before leaving the canal) might be due (NOK-LV, 2003).

Pilotage dues and pilotage fees for the Kiel Canal are adjusted on a regular basis, e.g., the last two adjustments were in 2010 and 2011(LTV 2010 and 2011). In contrast, transit tolls and helmsmen fees are adjusted much less frequently, e.g., the last two transit toll adjustments were made in 1996 and 2003 (NOKBefAbgV 1996 and 2003) and the last two helmsmen fee adjustments were made in 2004 and 2010 (Kanalsteurertarifverordnung 2004 and 2010).

3 Method

Before we can talk about the method we use to calculate the optimal transit charge, we first have to define the terms, relating to shipping costs and contractual agreements in shipping. We follow the widely accepted approach used by Stopford (2009) in defining costs, since no generally accepted standard cost classification exists for the shipping industry. The overall costs of running a ship can be divided into five cost categories: capital costs, operating costs, voyage costs, periodic maintenance costs, and cargo-handling costs.

Capital costs include interest and capital payments when debt financed, or dividend payments when equity financed. *Operating costs* include factors necessary for the day-to-day running of a ship. It does not matter whether the ship is actually on a voyage. These factors include costs for manning, stores and consumables, maintenance and repairs, insurance, and general costs like registration fees. *Voyage costs* include the fuel consumption of a ship whether it is at sea, in estuary (with possible speed restriction), in canal or in port. In addition, they include transit charges as well. *Periodic maintenance costs* include interim dry-docking and major survey costs. *Cargo-handling costs* include loading and discharging costs, and any claims that may arise (Stopford, 2009).

The distribution of these costs between owner and charterer depends on the type of contractual agreement, called a charter, that they have. Common types of charters are bareboat charters, time charters, and voyage charters.[20] Under a *bare boat charter*, the owner assumes the role of a financial investor. He bears the capital costs and charges the charterer a charter rate payment for providing her the ship. The charterer is given full control over the ship's activities and thus bears all other costs. Contracts usually run for 10–20 years. Under a *time charter*, the owner not only owns but also manages the ship and therefore bears capital, periodic maintenance, and operating costs. In this case, the charterer only has operational control over the voyage and consequently bears only the voyage and cargo-handling costs. Two types of time charter exist: period charters and trip charters. Period charters are contracts based on specified periods. Trip charters are contracts based on voyages. Under a *voyage charter*, the owner offers transport for a specific amount and type of cargo for a negotiated price per unit of transported cargo (freight rate). The owner generally bears all costs. In some cases, the owner bears all costs except cargo-handling costs (Stopford, 2009).

[20] A variant of the voyage charter is called contract of affreightment (Stopford, 2009).

Now we proceed to present the method we used to calculate the difference in total costs for a ship traveling from a port on the Baltic Sea to a port on the North Sea, or vice versa, and going through the Kiel Canal or through either the Oresund or the Great Belt passageway. Differences in total costs occur because the costs incurred by using a particular passageway differ for several reasons, e.g., navigational conditions (such as length, possible speed, or canal transit) affecting the duration of a trip and a ship's fuel consumption. We define the difference in total costs ($\boldsymbol{C_{dif}}$) as the optimal transit charge ($\boldsymbol{k^*_{tr}}$):

$$\boldsymbol{k^*_{tr} = C_{dif}}. \tag{1}$$

This is the amount that would make a ship operator indifferent between using the Kiel Canal or one of the two passageways around Denmark. In order to calculate the optimal transit charge ($\boldsymbol{k^*_{tr}}$), we assume that the actual Kiel Canal transit charge does not exist; consequently, it is not part of the total costs per route when the Kiel Canal passageway is used.

Total costs per route ($\boldsymbol{C_{ij,z}}$) associated with one of the three passageways can be calculated using different approaches, depending on the type of charter responsibilities, and, therefore, costs are distributed differently between the owner and the charterer. If the ship is operated by the owner (voyage charter), then capital, operational, and voyage costs per trip would be the appropriate basis for calculation. If the ship is operated by a charterer, two cases apply. In the case of a time charter, the charter rate payment and the voyage costs per trip are the appropriate basis. In the case of a bare boat charter, the charter rate payment and operational and voyage costs per trip are more appropriate. Time charter rates are often based on a fixed per-day basis ($/day). According to Baird (2006), they are a representative measure for the cost of providing a ship.

We assume that ships are period-chartered, which implies that the following cost components need to be considered: the charter rate payment and the voyage costs. The total costs per route ($\boldsymbol{C_{ij,z}}$) for a ship on a voyage from port $\boldsymbol{i}$ on the Baltic Sea to a port $\boldsymbol{j}$ on the North Sea via passageway $\boldsymbol{z}$, with z=Kiel Canal, the Oresund or the Great Belt passageway, is determined by

$$\boldsymbol{C_{ij,z} = P_{char,ij,z} + VC_{ij,z}} \tag{2}$$

where $\boldsymbol{P_{char.ij,z}}$ denotes the charter rate payment per route and $\boldsymbol{VC_{ij,z}}$ denotes the voyage costs per route. The charter rate payment depends on the charter rate($\boldsymbol{char}$), which approximately represents capital and operational costs (plus a benefit for the owner for providing the ship), and on the duration ($\boldsymbol{D}$) of the voyage. The duration (in hours) of sailing a specific route ($\boldsymbol{D_{ij,z}}$) depends on the length (in nm) of the route and the speed (in kn) of a ship. In addition, if a ship uses the Kiel Canal, it also depends on the lock time ($\boldsymbol{d_{lock}}$) and the waiting time before entering the lock ($\boldsymbol{d_{waiting}}$):

$$\boldsymbol{D_{ij,z} = nm_{ij,z}/kn_{ij,z} + d_{lock} + d_{waiting}}. \tag{3}$$

The voyage costs include bunker fuel costs per route and, if applicable, charges for entering a pilotage district. We assume that costs associated with port stopovers are generally the same, no matter which passageway is actually chosen.

Thus, we exclude port costs including port charges, fuel consumption in port, and cargo-handling costs for simplicity from our analysis. The costs per route ($\boldsymbol{C_{ij,z}}$) can, therefore, be rewritten as

$$\boldsymbol{C_{ij,z} = (char/24) * D_{ij,z} + FuelC_{ij,z} + k} \quad (4)$$

where **(char/24)** denotes the charter rate per hour, if char is given on a per day basis, and $\mathbf{(char/24) * D_{ij,z}}$ denotes the charter rate payment per route. $\mathbf{FuelC_{ij,z}}$ denotes fuel cost per route. Depending on the passageway, charges (**k**) for pilotage services (pilotage dues and fees) in pilotage districts need to be paid. Bunker costs (**FuelC**) are a function of a ship's fuel consumption (**fc**) and the bunker price ($\mathbf{p_{bunker}}$):

$$\boldsymbol{FuelC_{ij,z} = fc_{ij,z} * p_{bunker}} \,. \quad (5)$$

Fuel consumption varies along a shipping route due to differences in navigational conditions. A shipping route can be divided into four different sections: at sea, in speed restricted estuary/pilotage district, in port and in canal. Depending on the section, traveling speeds differ and waiting times might occur.

The fuel consumption (ton/h) of a ship's main engine is determined by

$$\boldsymbol{fc = fc^{*}(s/s^{*})^{\beta}} \quad (6)$$

where $\boldsymbol{fc^{*}}$ is defined as design fuel consumption (in ton/h), $\boldsymbol{s}$ as speed (in kn), $\boldsymbol{s^{*}}$ as design speed (in kn) (Stopford, 2009). The exponent $\boldsymbol{\beta}$ indicates the type of engine. According to Stopford (2009) $\boldsymbol{\beta = 3}$ for diesel engines and $\boldsymbol{\beta = 2}$ for steam turbines.

In general, ships are designed to fulfill a predetermined transport performance/demand per period of time. To do so, they have to operate at a specific speed. Thus, ships are designed to operate at a specific speed, called the design speed ($\boldsymbol{s^{*}}$). After determining the design speed, the engine (and the hull) is designed to provide the required speed. The relationship between engine size ($\boldsymbol{E_{size}}$) and speed ($\boldsymbol{s}$) is approximately given by $\boldsymbol{E_{size} \approx s^{3}}$ (Holst, 2008; Corbett et al. 2009).

In general, the design fuel consumption per hour is determined by

$$\boldsymbol{fc^{*} = E_{size} * F^{*}_{load} * SFOC/10^{6}} \quad (7)$$

where $\boldsymbol{E_{size}}$ is the engine size (in kW), $\boldsymbol{F^{*}_{load}}$is the design engine load factor (in % Maximum Continuous Rating (MCR)), and $\boldsymbol{SFOC}$ is the related specific fuel oil consumption (in g/kwh) (Buhaug et al., 2009).

A ship generally has a main engine that provides motive power and more than one auxiliary engine that provide power for other necessary services on board.[21]

[21] Ships are equipped with several auxiliary engines, with generators (small diesel engines) for producing electricity as the most important auxiliary engine. Ships usually have at least three of these generators, which operate by turns, to guarantee failure-free operation (Buhaug et al., 2009).

Thus, the fuel consumption of the main engine ($\boldsymbol{fc_{ME}}$) and the fuel consumption of the auxiliary engines ($\boldsymbol{fc_{AE}}$) need to be differentiated. The fuel consumption per route ($\boldsymbol{fc_{ij,z}}$), taking the different route sections into account, is then given by

$$\boldsymbol{fc_{ij,z} = fc_{ME,ij,z} + fc_{AE,ij,z}}. \tag{8}$$

The fuel consumption of the main engine is given by

$$\boldsymbol{fc_{ME,ij,z} = d_s * fc^*_{ME} * (s_s/s^*)^\beta + d_e * fc^*_{ME} * (s_e/s^*)^\beta + d_c * fc^*_{ME}(s_c/s^*)^\beta} \tag{9}$$

where $\boldsymbol{fc^*_{ME}}$ is defined as design fuel consumption per hour and $\boldsymbol{d_s}$ as the time spent sailing at sea, $\boldsymbol{d_e}$ as the time spent sailing in estuary (pilotage district), and $\boldsymbol{d_c}$ as the time spent sailing on the canal.

The fuel consumption of the auxiliary engines is given by

$$\boldsymbol{\sum_{r=1}^{n} fc_{AE_r,ij,z} = \left(E_{size_r} * F_{load_r} * SFOC_r/10^6\right) * d_{AE_r}} \tag{10}$$

where $\boldsymbol{r = 1, \ldots, n}$ denotes the number of auxiliary engines and $\boldsymbol{d_{AE_r}}$ the duration of their operating time. The number of auxiliary engines in operation and the actual time they spend in operation depends on the type of ship.[22] If the main engine and the auxiliary engines would require a different type of bunker fuel, than the bunker costs are given by

$$\boldsymbol{FuelC_{ij,z} = fc_{ME,ij,z} * p_{bunker_v} + fc_{AE,ij,z} * p_{bunker_w}} \tag{11}$$

where $\boldsymbol{v}$ and $\boldsymbol{w}$ denote different types of bunker fuel.

Given the geographical scope of our analysis, certain ports and route sections can be clustered to simplify the calculations. For this reason, we define intersection points to calculate, for each route, the differences in costs associated with each of the three different passageways (Kiel Canal, the Great Belt, or the Oresund). The advantage of doing this is that instead of calculating the costs for the total length of the route three times for each of the different passageways and subtracting the three sets of costs from each other, only the costs for the diverging sections of the routes, i.e., the costs associated with each of the passageways, need to be calculated (see Figure 1, black lines).

The intersection point for all ships departing from or heading for one of the major ports in the eastern part of the Baltic Sea (west of Bornholm, Denmark) is IP1 (see Figure 1 above). The intersection point for all ships departing from or heading for a North Sea port between Rotterdam and LeHavre (west of Eierland, Netherlands) is IP6.[23] The intersection point for all ships departing from or heading for the North Sea port of Hamburg is IP5. Other intersection points are defined for other routes such that the points are as close as possible to the ports.

[22] Ships usually have one generator in operation, i.e., the others are put on hold, i.e., they are available for maintenance or are on standby (Buhaug et al., 2009). In some cases, ships are additionally equipped with a shaft generator for generating electricity, which reduces the need to operate generators at sea.

[23] The intersection point would be further northwest for all ships required to use the deepwater route.

4. Case Study

4.1 Data

In this section, we describe the data we use in our case study to calculate the actual and optimal transit charges for the four different ship types: a 550 TEU container ship, a 1,400 TEU container ship, a handymax bulk carrier, and a container-oriented multipurpose ship (MPP ship). Our reasons for selecting these types of ships are as follows. Container ships regularly use the canal. Typical container ships traveling through the Kiel Canal had a capacity of 508, 658, or 822 TEU in 2004 (Kågeson et al., 2009). Following the general trend to larger ships, ships (feeder ship segment) with a capacity of 1,200–1,700 TEU are common on the canal as well (Bösl, 2010). We selected the bulk carrier to include a ship that belongs to the group of large ships (20,000-30,000gt) that can use the canal but are nevertheless not frequent users (~1% of total ship traffic in the period 2005-2009; WSD Nord, 2011c). Further, we selected the MPP ship in order to account for possible differences in cost per ship types, since the MPP ship is comparable in size to the container ships.

Table 2: Ship type specifications

Characteristics	Ship category			
	Container vessel	Container vessel	Bulk carrier	General cargo
Type of ship	Handy	Feedermax	Handymax	Multipurpose (MPP)
Length (m)	160	135	182	130
Beam (m)	26	21	31	23
Design draft (m)	9.7	7.7	11.4	8.5
Allowed draft (m)	9.5	9.5	8.4	9.5
Actual draft (m)	$d_{min}<d_{ac}<d_{al}$	$d_{min}<d_{ac}<d_{al}$	$d_{min}<d_{ac}<d_{al}$	$d_{min}<d_{ac}<d_{al}$
Gross tonnage (gt)	16,438	6,967	27,596	10,468
Deadweight (dwt)			45,000	12,500
Container capacity (TEU)	1,400	550		600
Main engine (kW)	12,364	5,703	8209	5801
Engine type	2-stroke slow-speed	4-stroke medium/high-speed	2-stroke slow-speed	4-stroke medium/high-speed
Auxiliary engine (kW)	985	600	533	628
Engine type	4-stroke medium/high-speed	4-stroke medium/high-speed	4-stroke medium/high-speed	4-stroke medium/high-speed
Design speed (kn) at 90% MCR	19	16.8	14.4	15
Allowed max speed Kiel Canal (kn)	8.1	8.1	6.5	8.1
SFOC (g/kWh) main engine	165-175	180-195	170-180	175-185
SFOC (g/kWh) auxiliary engines	220	230	230	230
Type of bunker fuel ME/AE	HFO/MDO	HFO/MDO	HFO/MDO	HFO/MDO

Source: own presentation based on Buhaug et al. (2009), Stopford (2009).

The ship type specifications we used are presented in Table 2. The *allowed draft* (d_{al}) of a ship using the Kiel Canal is determined by its size dimensions: length and beam.[24]

Its *actual draft* (d_{ac}) depends on the load it is carrying and, thus, can range from the minimum draft (d_{min}), if not laden at all, to the design draft. We assume that ships are not fully laden and that they do not exceed the allowed draft. Specifications for *gt*, *dwt*, *TEU capacity*, *sizes, and SFOC of main and the auxiliary engines* are based on Buhaug et al. (2009).[25] Typical values of *SFOC* for 2-stroke low-speed engines built in 1984-2000 (170-180g/kWh) and 2001-2007 (165-175g/kWh), and for 4-stroke medium/high-speed engines built in 1984-2000 (180-195g/kWh) and 2001-2007 (175-185g/kWh), are also taken from Buhaug et al. (2009). Values for *beam*, *design draft*, and *speed* are taken from Stopford (2009).[26,27] Depending on a ship's classification into one of the six traffic groups (see Section 2), its *allowed speed* is 6.5 or 8.1 kn.[28]

Data on time charter (T/C) rates for the bulk carrier (45,000dwt) and the two container ships (550 TEU and 1,400 TEU) are taken from Fearnleys Monthly Report and cover the period January 2005 to December 2009. These T/C rates are charged in dollars per day for a period of 12 months T/C. Since rates vary between months, the WSD Nord would need to know the month the ship was chartered to calculate the optimal transit charge exactly. For simplification, we use the average over the last 12 months. For example, if a ship travels through the Kiel Canal in July 2008, we use the average T/C rate for the period August 2007 to July 2008. The T/C rates used for the 1,400 TEU container are calculated as the average of the rates for a 550 TEU and a 1,700 TEU container taken from the Fearnleys Monthly Report for the period January 2005 to December 2009. The T/C rates used for the MPP ship are taken from Gardiner (2010), but are available on an annual basis only.

Data on monthly bunker prices (heavy fuel oil and marine diesel oil) for the period 2005–2009 are taken from the Shipping Statistics Yearbook (ISL Bremen, 2008, 2009). Actual transit charges (in euros) for the Kiel Canal are those discussed above and are determined according to various regulations. The following regulations determine whether a ship is obliged or not to take helmsmen and pilots on board: Seeschifffahrtsstraßen-Ordnung (SeeSchStrO, 2006), NOK-Lotsverordnung (NOK-LV, 2003), and Elbe-Lotsverordnung (Elbe-LV, 2003). The Kanalsteurertarifverordnung (2004) is used to determine the helmsmen fee in the years 2005-2009.

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[24] § 42 Abs. 1 Nr. 1 und Abs. 6 SeeSchStrO: Zulassung zum Befahren des Nord-Ostsee-Kanals; Bekanntmachung der Waterways and Shipping Authority North.

[25] The respective ship categories in Buhaug et al. 2009 are Container 0-999TEU, Container 1,000-1,999TEU, Bulk 35,000-59,999dwt, General Cargo 5000-9999dwt, 100+, and General Cargo 10,000+ dwt, 100+ TEU. We use the average value for the MPP ship, which falls between two size classes of one category.

[26] The respective ship types in Stopford (2009) are Feedermax and Handy for container ships, Handymax for bulk carriers (including length), and Grand total for the MPP ship (including only speed).

[27] Stopford (2009) bases his values on the Containership Register 2006, Clarkson Research Services Ltd and Bulk Carrier Register 2006, Clarkson Research Services Ltd.

[28] In accordance with § 26 Abs. 3 SeeSchStrO: Höchstgeschwindigkeit; Bekanntmachung der WSD Nord.

The Lotstarifverordnung (LTO 2005, LTO 2006, LTO 2008, LTV 2009) is used to determine the pilotage fee in the years 2005-2009, whereas the Lotstarifverordnung (LTO 2001, LTO 2006, LTV 2009) is used to determine the pilotage due in the years 2005-2009. The Verordnung über die Befahrensabgaben auf dem Nord-Ostsee-Kanal (NOKBefAbgV, 2003) is used to determine the transit toll in the years 2005-2009. Data on monthly dollar-euro exchange rates for the period 2005 to 2009 are taken from the Deutsche Bundesbank.

Shipping route length is also important in determining the costs of shipping. We thus compare routes between Helsinki (Finland), a port on the Baltic Sea, and three alternative ports on the North Sea: Hamburg (Germany), Rotterdam (Netherlands), and Leith (UK). Table 3 presents an overview over the length of each these three possible routes when using each of the three passageways, i.e., the Kiel Canal, the Great Belt, and the Oresund. The Oresund passageway is restricted to ships with a draft of 8m or less (Helcom, 2009). If a ship's draft exceeds 8 m, it would have to travel through the Great Belt passageway, thus having to travel a greater distance. For our calculations, we assume that all ships operate without intermediate stops, i.e., ships that operate on a fixed route with multiple stops and fixed schedule around Denmark are excluded.

Total shipping route length is measured for each of the three routes when using each of the passageways (see Figure 1). We are, however, primarily interested in the length of those sections of the route that are coterminous with each of the passageways (black line), as, for example, the section of the Helsinki-Rotterdam route between Helsinki and IP1 and between Rotterdam and IP6 is a constant (dotted line) regardless of which passageway is used. We define the length of the sections that are coterminous with each of the passageways as relevant length (see Table 3). According to our calculations, by using the Kiel Canal on the Helsinki-Hamburg route, for example, more than 400nm could be saved compared to the Helsinki-Leith route, where less than 150nm would be saved.

Table 3. Relevant length (in nm) between Helsinki and the three alternative ports at the North Sea

Route	Passageway	Route length	Relevant length	Nm saved by using Kiel Canal
Helsinki-Rotterdam	Kiel Canal	941.1	398.9	n.a.
	Oresund	1103.2	561.1	162.1
	Great Belt	1211.0	668.8	269.9
Helsinki-Hamburg	Kiel Canal	703.3	225.8	n.a.
	Oresund	1038.4	560.9	335.0
	Great Belt	1146.2	668.6	442.8
Helsinki-Leith	Kiel Canal	1161.4	689.1	n.a.
	Oresund	1198.3	726.1	37.0
	Great Belt	1306.1	833.9	144.8

Source: Own calculations based on ESRI Base Map.

While most of our model parameters, such as bunker price and route lengths, are observable and discrete, other parameters, such as travel time, may vary from voyage to voyage, and are thus unobservable. In order to take this into account, we make assumptions about the distribution of these unobservable parameters, namely the actual speed of the ship at sea, the canal waiting time, and the SFOC.

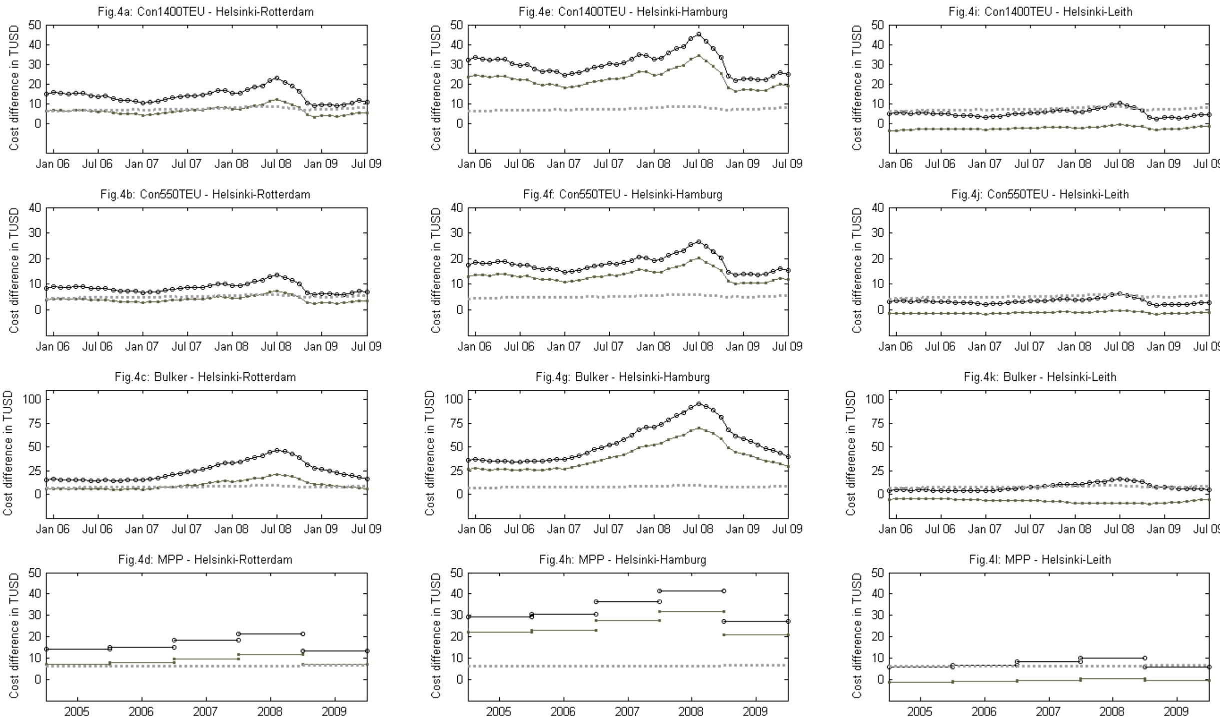
Based on the model devised by Somanathan et al. (2009), we use a triangular distribution with parameters a=0.85 and b=c=1 for speed at sea. This is to account for varying navigational conditions at sea, such as wind and the resulting waves. For the canal waiting time (in minutes) at the two locks of the Kiel Canal, which is included in the variable duration ($\boldsymbol{D}$) (see Section 3, Equation 3), we assume waiting times to be exponentially distributed with parameters λ = 18, 12, 15 and 12, for the four different ships entering the canal at the Kiel-Holtenau lock, and λ= 6, 6, 9 and 6, for the four ships exiting the canal at the Brunsbüttel lock. The variation in the parameters is due to the different ship sizes. The exponential distribution is chosen to reproduce potentially long delays in times of heavy traffic and moderate average latencies. To account for differences in types of main engine, we assume a uniform distribution of SFOC over the interval given in Buhaug et al. (2009) (see table 2).[29]

4.2 Results

Figures 4a to 4l show the results of our case study based on the mean values of our simulation runs for the different ship types.[30] These figures show the difference in total costs for the two passageways around Denmark (black dotted line for Great Belt and grey crossed line for Oresund) compared to the total costs of the the Kiel Canal passageway (without transit charge). The Kiel Canal functions as the benchmark (normalized to 0).[31] A positive cost difference shows that it is more costly for a particular ship type to travel around Denmark than to travel via the Kiel Canal, whereas a negative cost difference shows that it is less costly. This cost difference is, according to our definition, the optimal transit charge. Calculating the actual Kiel Canal transit charge (light dashed line) for each particular ship type makes it possible to compare it to the optimal transit charge (cost differences in total costs excluding actual Kiel Canal transit charge) at a glance.

[29] Since the transformation of this variable is linear throughout the model, the point estimate is the same as it would be for a deterministic value equaling the mean of this random variable. However, for interval estimations (see Appendix, Figures A1a – A1l), this assumption is useful.
[30] Information on confidence intervals is provided in the Appendix.
[31] Note that for the ship types 1,400 TEU container, 550 TEU container, and bulk carrier the results are based on monthly data (December 2005-July 2009). For the MPP ship, the results are based on yearly data (2005-2009) due to limited data availability.

Figures 4a-4l: Cost differences per ship type, passageway, and route (in thousand dollars)



Figures 4a to 4d (first column) show the cost difference for the ship types 1,400 TEU container (Con1400TEU), 550 TEU container (Con550TEU), bulk carrier (Bulker), and multipurpose ship (MPP) for the passageways Oresund (crossed line) and Great Belt (dotted line) on a voyage from Helsinki to Rotterdam and the actual Kiel Canal transit charge (light dashed line). Figure 4e to 4h (second column) show the cost difference on a voyage from Helsinki to Hamburg and figure 4i to 4l (third column) on a voyage from Helsinki to Leith.
Source: Own calculation.

In general, traveling through the Great Belt is the most expensive. The cost difference for this passageway is considerably larger than for the Oresund passageway (costs of the Kiel Canal serve as the benchmark). Comparing the cost difference to the actual Kiel Canal transit charge shows that in most cases the actual transit charge is lower than the optimal one. Most notably so for the Helsinki-Hamburg route, where the cost difference peaks in the middle of 2008 at approximately $95,000. One exception is the Helsinki-Leith route, for which the optimal transit charge is lower or close to the actual transit charge in some months.

The results for the Oresund passageway are different. Here, for all ship types on the Helsinki-Rotterdam route the optimal transit charges is close to the actual transit charge. For the Helsinki-Leith route, the optimal transit charge is lower than the actual transit charge. In almost all cases, it is even below zero. This is particularly pronounced in the case of the bulk carrier, where it is approximately $11,000 below the benchmark. The only exception where the actual Kiel Canal transit charge is considerably lower than the optimal charge is on the Helsinki-Hamburg route.

However, looking at the different ship types shows the following. The differences in costs between the bulk carrier and the 1,400 TEU container, and the MPP ship were nearly the same in the beginning of the time period analyzed (e.g., approximately 15,000 euros for ships on the Helsinki-Rotterdam route using the Great Belt passageway, and, approximately 6,000 euros for ships using the Oresund passageway). Cost differences for the bulk carrier started to increase faster than the cost differences for the other two ship types in 2007. This is particularly the case for the Helsinki-Hamburg route. The 550 TEU container had the lowest level of cost differences for both passageways.

For comparison, tables 4a to 4c show the cost differences in total costs, *including the actual Kiel Canal transit charge*, for all ship types on all three routes and all three passageways. It presents the highest cost difference (highest Δ), the lowest cost difference (smallest Δ), and the median cost difference (median Δ) in the time period December 2005-July 2005 and 2005 to 2009 for the MPP ship. In addition, the numbers in brackets show how many times (months or years for the MPP) a positive cost difference occurs during the time period analyzed. Moreover, the total cost differences of the highest and the lowest values are divided into charter costs, fuel cost, and charge costs. This sheds light on the cost level of the individual cost components and how they vary within the time period analyzed. As mentioned above, a positive cost difference shows that it is more costly for a particular ship type to travel around Denmark than to travel via the Kiel Canal, whereas a negative cost difference shows that it is less costly.

Table 4a. Difference in costs for the Helsinki-Rotterdam route (in $)

Passageways compared	Type of ship	Difference in total costs (Δ)		Difference composed of		
		median Δ (≥0)	highest Δ lowest Δ	charter costs Δ	fuel costs Δ	charge costs Δ
Oresund-Kiel Canal	Container 550TEU	-976 (4/44)	-2,752 -22	1,671 1,800	2,472 5,008	-6,895 -6,830
	Container 1400TEU	-696 (15/44)	-3,928 13	1,939 3,478	4,391 5,193	-10,258 -8,658
	Bulker	313 (23/44)	11,423 308	14,309 8,500	11,896 4,747	-14,782 -12,939
	MPP	1,282 (4/5)	3,469 -98	3,100 2,000	12,159 8,029	-11,790 -10,127
Great Belt-Kiel Canal	Container 550TEU	3,569 (44/44)	7,758 739	4,309 3,843	11,534 3,791	-8,085 -6,895
	Container 1400TEU	6,967 (44/44)	14,607 1,681	6,296 5,253	20,339 6,686	-12,028 -10,258
	Bulker	13,424 (44/44)	37,175 6,700	33,777 10,001	18,180 8,358	-14,782 -11,659
	MPP	8,588 (44/5)	13,149 6,241	6,521 4,207	18,418 12,161	-11,790 -10,127

Source: Own calculation.

The numbers presented in Table 4a show a heterogeneous picture, i.e., it is more economical for some ships to travel around Denmark in some months, whereas it is not in others. During the time period studied, it is more often economical for the two container ships to travel the Oresund passageway than to use the Kiel Canal, although the passageway around Denmark incurs higher charter and fuel costs. The reason for this is that the sum of the charges (Kiel Bay, Kiel Canal, and Elbe) outweighs the sum of the higher charter and fuel costs. This is particularly pronounced in times of low charter rates and low bunker prices. It is more often economical for the bulk carrier and the MPP ship to travel through the Kiel Canal than to travel around Denmark via the Oresund passageway.

The opposite is true for the Great Belt passageway. The cost difference with this passageway is always positive, i.e., it is more economic to travel through the Kiel Canal. Using the Great Belt passageway incurs higher charter and fuel costs that are not offset by the sum of charge costs.

Table 4b. Difference in costs for the Helsinki-Hamburg route (in $)

Passageways compared	Type of ship	Difference in total costs (Δ)		Difference composed of		
		median Δ (≥0)	highest Δ lowest Δ	charter costs Δ	fuel costs Δ	charge costs Δ
Oresund-Kiel Canal	Container 550TEU	8 (44/44)	14,237 5,046	5,789 5,162	13,969 4,592	-5,521 -4,708
	Container 1400TEU	15.446 (44/44)	25,943 9,091	8,699 7,257	24,563 8,076	-7,319 -6,242
	Bulker	27.748 (44/44)	60,364 17,915	45,582 13,498	21,992 10,110	-7,210 -5,693
	MPP	16.693 (5/5)	23,615 14,038	8,588 5,541	22,201 14,659	-7,174 -6,162
Great Belt-Kiel Canal	Container 550TEU	12,874 (44/44)	20,687 8,538	8,226 7,335	17,982 5,911	-5,521 -4,708
	Container 1400TEU	23,059 (44/44)	36,900 14,700	12,671 10,571	31,548 10,371	-7,319 -6,242
	Bulker	40,769 (44/44)	86,150 26,580	65,075 19,270	28,285 13,003	-7,210 -5,693
	MPP	23,999 (5/5)	33,295 20,378	12,009 7,748	28,460 18,792	-7,174 -6,162

Source: Own calculation.

The numbers presented in Table 4b reveal that it is more economical to travel through the Kiel Canal than through the Oresund or the Great Belt passageway. Using the Oresund or the Great Belt passageway saves charge costs but incurs considerably higher charter and fuel costs. Therefore, the fuel and charter costs savings achieved by using the Kiel Canal offset the charge costs.

Table 4c. Difference in costs for the Helsinki-Leith route (in $)

Passageways compared	Type of ship	Difference in total costs (Δ)		Difference composed of		
		median Δ (≥0)	highest Δ lowest Δ	charter costs Δ	fuel costs Δ	charge costs Δ
Oresund-Kiel Canal	Container 550TEU	-6,271 (0/44)	-6,889 -5,851	-938 -923	2,010 1,902	-7,961 -6,830
	Container 1400TEU	-9,702 (0/44)	-10,448 -8,804	-1,911 -2,128	1,721 3,485	-10,258 -10,161
	Bulker	-14,641 (0/44)	-18,909 -11,607	-7,648 -2,574	3,504 2,247	-14,765 -11,280
	MPP	-7,616 (0/5)	-7,774 -7,204	-873 -852	4,889 3,096	-11,790 -9,448
Great Belt-Kiel Canal	Container 550TEU	-1,695 (1/44)	-3,314 -70	1,321 1,474	2,260 6,134	-6,895 -7,678
	Container 1400TEU	-1,952 (4/44)	-4,838 313	1,402 1,620	4,018 9,653	-10,258 -10,960
	Bulker	-1,833 (15/44)	7,252 239	11,157 6,693	10,878 6,357	-14,783 -12,811
	MPP	101 (3/5)	1,906 101	2,548 2,489	11,148 7,060	-11,790 -9,448

Source: Own calculation.

The numbers presented in Table 4c imply that it is more economical to travel around Denmark than to use the Kiel Canal. The only exception is the MPP ship using the Great Belt passageway, where in three out of five years it is more economical to use the Kiel Canal. Using the Oresund passageway incurs higher fuel costs but saves charter and charge costs. Using the Great Belt passageway incurs higher fuel and charter costs but saves charge costs. Therefore, the fuel and charter costs savings achieved by using the Kiel Canal are usually not high enough to offset the higher charge costs associated with this passageway. In only 15 out of 44 months are they high enough.

The results of our simulation indicate that the actual Kiel Canal transit charge is not optimal. However, it is not possible to state that it is in general too low or too high. This depends on the route and the ship type. Results vary significantly for all three of the routes and all three of the passageways and all ship types. In some cases, it is close to the optimal transit charge, whereas in other cases it is considerably far away from it.

In the case of the Helsinki-Rotterdam route, the optimal transit charge should be higher than the actual transit charge for ships using the Great Belt passageway, whereas it should be lower for ships using the Oresund passageway. The only exception is in times with high bunker prices and high charter rates, where costs for the Oresund passageway increase more than the costs for the Kiel Canal.

In the case of the Helsinki-Hamburg route, the optimal transit charge should be considerably higher than the actual transit charge for ships using the Great Belt or the Oresund passageway.

In case of the Helsinki-Leith route, the optimal transit charge for the Oresund passageway is negative because it is more costly to travel through the Kiel Canal than to travel via the Oresund. In comparison, the optimal transit charge for ships using the Great Belt passageway is positive but most often less than the actual transit charge. The only exception is with the MPP ship. Here, the optimal transit charge is higher than the actual one. Consequently, if bunker prices and charter rates are not high, it is not economical for ships to travel via the Kiel Canal.

The actual Kiel Canal charge should be increased for ships traveling to ports near Rotterdam if they use the Great Belt passageway, whereas it should be decreased if they use the Oresund passageway. The actual Kiel Canal charge should be increased considerably for ships traveling to ports near Hamburg regardless of whether they use the Great Belt or the Oresund passageway. The actual Kiel Canal charge should be decreased for ships traveling to ports near Leith if they use the Great Belt passageway, whereas, theoretical, there should be no charge at all if they use the Oresund route.

5 Discussion

As mentioned above, the Kiel Canal produces a balance sheet loss. To get an idea about *if* and *by how much* this loss could be reduced by perfect price discrimination, we calculate the difference in revenues of two transit charge approaches (optimal and actual). To do so, we first evaluate the importance of individual elements (port, passageway, and ship type) that determine the costs.

A comparison of the three ports on the North Sea in the light of cargo flows with the Baltic Sea region shows that Hamburg is the most important port, at least in container/feeder shipping (Lorenz, 2006). According to Kågeson et al. (2008), the majority of container/feeder shipping that travels through the Kiel Canal goes to Hamburg and Bremen and a minority goes to UK ports, Rotterdam, and Antwerp.

Comparing the two passageways around Denmark, the Oresund passageway is shorter and is used more frequently than the Great Belt passageway, but it has a draft constraint of 8m maximum. For this reason, it is used particularly by ships with a draft of less than 7m (Helcom, 2009). The Kiel Canal has a similar draft constraint of 7.0 to 9.5 m, depending on the beam and the length of a ship. This implies that larger ships that cannot use the Oresund passageway might also be too large to use the Kiel Canal. For example, if the bulk carrier referred to above were fully laden, its actual draft would exceed the allowed draft of both the Oresund (8m) and the Kiel Canal (8.4m) (see Section 4.1). Thus, as long as the Kiel Canal is not deepened, such ships can only use the Great Belt passageway. For other ships, including the 1,400 TEU container in our case study, which might be too large for the Oresund passageway but not for the Kiel Canal, the Great Belt passageway would serve as the substitute to the Kiel Canal.

Statistics provided by the WSD Nord about ship transits per year differentiate either between ship types or size classes (in gt). There are no statistics available about how many ships of a specific ship type in a specific size class pass the Kiel Canal per year. Statistics are only available for size classes. Thus, we take the number of ships in a particular size class to which our ships in the case study belong and multiply this number by the optimal and the actual Kiel Canal transit charge to determine the difference in revenues. For example, the 550 TEU container ship belongs to the size class 6,000-8,000gt. 3,633 ships of this size class passed the Kiel Canal, on average, counting both directions, in the time period (2005-2009).

As discussed above, the three ports, Hamburg, Rotterdam, and Leith are not equally important for maritime transportation in the Baltic Sea (northern Europe) region. Thus, we assume that most of the ships in a particular size class generally have Hamburg as their destination or departure port, e.g., 70% go to or depart from Hamburg and 30% go to or depart from Rotterdam. We assume that 100% of ships similar to the 550 TEU container go to or depart from Hamburg because within the time period analyzed, the Oresund passageway was often the more economical choice for ships going to Rotterdam (see Section 4). Thus, we assume that these types of ships only used the Kiel Canal if their destination or departure port was Hamburg. For simplicity, we do not consider Leith, since, for the majority of the ship types studied, it is not economical to travel through the Kiel Canal (see Section 4). Furthermore, we assume that ships in the size class (in gt) similar to the 550 TEU container have an actual draft of less than 8m, i.e., they are allowed to travel through both the Oresund and the Kiel Canal. We assume an actual draft of more than 8m for the majority of ships in the size classes similar to the 1,400 TEU container, the MPP ship, and the bulk carrier; i.e., these ships are not allowed to use the Oresund but to use the Kiel Canal or the Great Belt instead. We assume an actual draft of less than 8m only for a minority of these ships, e.g., when a bulk carrier is in ballast.

The results of our calculation are shown in table 5. Evidently, under the assumptions made, the optimal transit charge approach yields higher revenues than the actual transit charge approach. Differences in revenues are in a range of up to several million dollars.

Table 5. Difference in revenues between the optimal and actual transit charge approach (in million dollars)

Year	Con550TEU	Con1400TEU	Bulker	MPP
2005	26.4	8.4	5.0	10.3
2006	29.3	9.2	6.5	11.6
2007	34.6	12.2	14.8	9.4
2008	44.7	17.7	22.3	24.5
2009	15.5	8.2	6.8	11.7

Source: Own calculation.

However, differences are smaller if fewer ships with an actual draft of more than 8m are assumed to travel to Hamburg. For example, if we assume that only 50% of the ships travel to Hamburg and 50% to Rotterdam (instead of 70% and 30%), the differences in revenues would range from $0.4 to $21.4 million compared to $5 to $24.5 million (Table 5, columns 3-5).

6 Conclusion

In this paper, we assume that the Kiel Canal Authority has full information about ships and can employ perfect price discrimination to determine optimal transit charges. In this case, optimal transit charges should amount to the cost savings that ship operators could achieve by choosing the route via the Kiel Canal instead of the ones around Denmark. The comparison of the actual Kiel Canal transit charge with the results of the simulation shows that the current, i.e., actual, charge is not optimal compared to a perfect price discrimination rule. Depending on the route and the ship type, the optimal transit charge is higher or lower than the actual Kiel Canal transit charge.

The optimal price discrimination would theoretically require complete knowledge about a ship's departure and destination, cost structure, and operating conditions. Such knowledge is generally not available to the Kiel Canal Authority. Therefore, they would have to rely on a type of price discrimination that depends on the information they can actually obtain about a particular ship using the Kiel Canal.

Whereas the current charge system essentially takes only the size (based on gross tonnes) of the ship into account, the simulation results show that a higher revenue could be generated by the canal if the transit charge were based not only on ship size but also on a ship's departure and destination ports. The cost advantage of using the Kiel Canal for a particular type of ship is driven mostly by the distance saved, often resulting in lower fuel costs and charter costs, compared to the other two passageways. Hence, information about the actual departure and destination ports of a ship would provide the Kiel Canal Authority with the opportunity to raise additional income.

This price discrimination would have two dimensions for the canal authority. It could set higher charges for ships going to or coming from Hamburg. But it could also attract additional traffic to the Kiel Canal by lowering charges for ships that are currently not using the Canal because it would not be profitable to do so. However, setting higher charges might prove difficult, since political acceptance might be low. Lowering charges to attract more traffic might be easier to implement and would also provide additional income; how much the charge could be lowered depends on how much traffic could be attracted to the Kiel Canal. Given that less than half of the merchant ships actually use the Kiel Canal, it may be possible to increase traffic through the Kiel Canal by lowering charges for specific user groups. Unfortunately, we do not have information about the type or the departure and destination ports of those ships that have decided not to use the Kiel Canal. Therefore, the potential additional market that could be accessed cannot be determined.

As long as the departure and destination ports of the ships are not known to the Kiel Canal Authority, it is essentially impossible to determine what the optimal charge would be. Raising the charge would raise more revenue from those ships traveling to or from Hamburg, but it would also lower income from ships going someplace else when they choose alternative passageways to the Kiel Canal.

If there were information on the composition of ship types and their departure and destination ports, it would be possible to compute the optimal price even when the canal authority cannot discriminate according to the individual departure and destination ports of the ships.

It is important to point out that a number of limitations apply. The case study is based on specific ship types and routes and the results might change by employing other ship types or routes. Moreover, some ships are excluded due to the size restrictions of the Kiel Canal or due to the nonavailability of time charter rates. Time charter rates are often only available for ships of a certain size, particularly for large ships, but the Kiel Canal is mostly used by lower-middle-sized ships. Further, some of the ships might operate on a fixed route and a fixed schedule, so that they cannot choose between alternative passageways.

It would be interesting to know whether considering external costs would change the results. For example, additional costs caused by CO_2 emission regulation in the shipping sector could change the results because ship operators might decide to travel the less CO_2-intensive passageway. This is a topic for future research.

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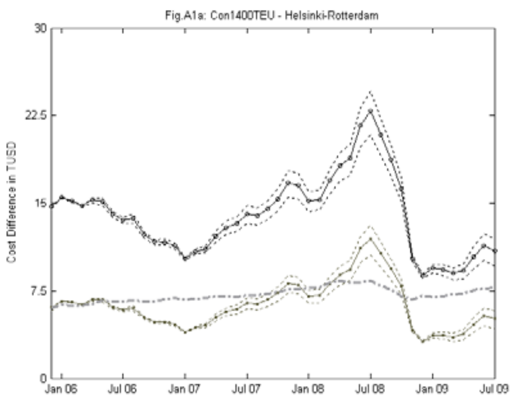
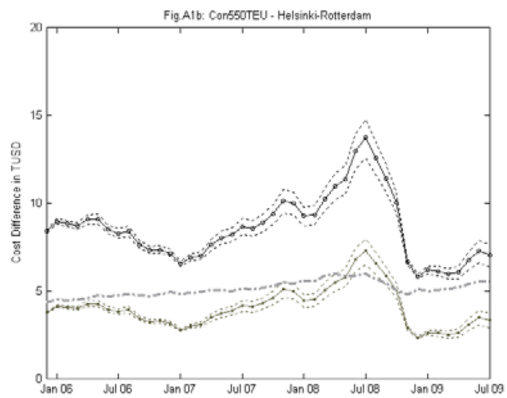
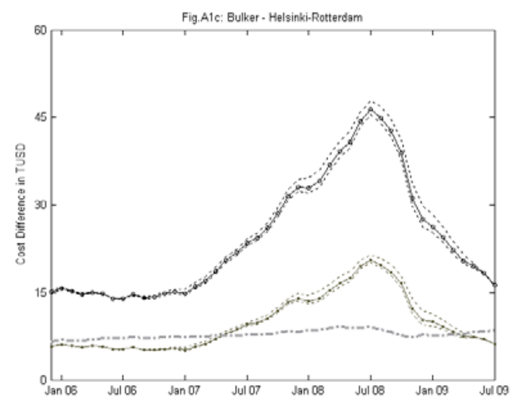
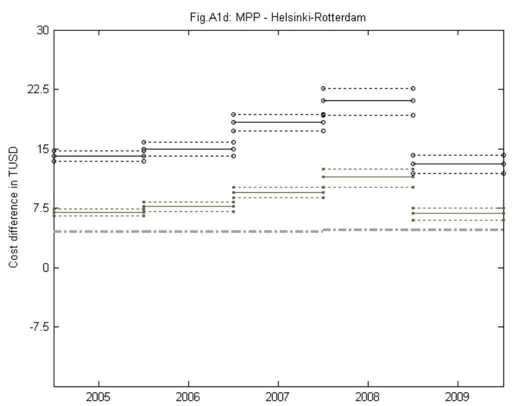
Appendix

Figures A1a to A11 show the mean cost differences obtained from the simulation with 95% confidence bounds, and for comparison, the actual Kiel Canal transit charge.









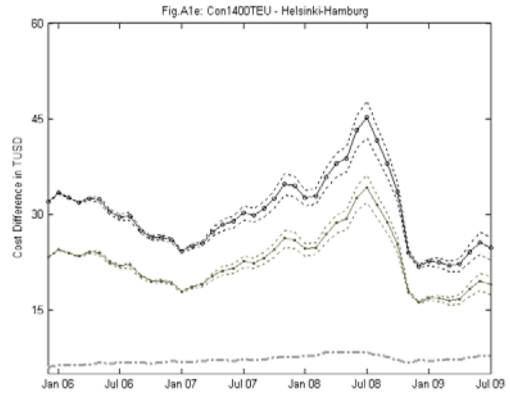


Fig.A1e: Con1400TEU - Helsinki-Hamburg
Cost Difference in TUSD
60
45
30
15
Jan 06
Jul 06
Jan 07
Jul 07
Jan 08
Jul 08
Jan 09
Jul 09

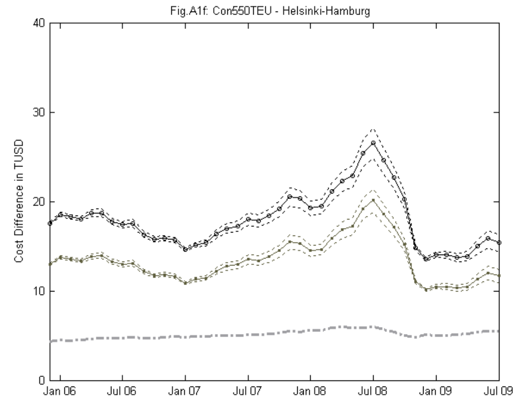


Fig.A1f: Con550TEU - Helsinki-Hamburg
Cost Difference in TUSD
40
30
20
10
0
Jan 06
Jul 06
Jan 07
Jul 07
Jan 08
Jul 08
Jan 09
Jul 09

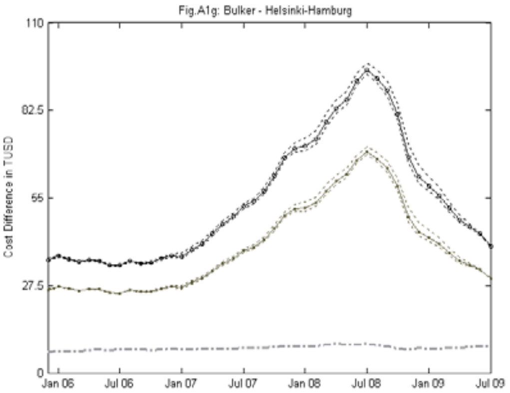


Fig.A1g: Bulker - Helsinki-Hamburg
Cost Difference in TUSD
110
82.5
55
27.5
0
Jan 06
Jul 06
Jan 07
Jul 07
Jan 08
Jul 08
Jan 09
Jul 09

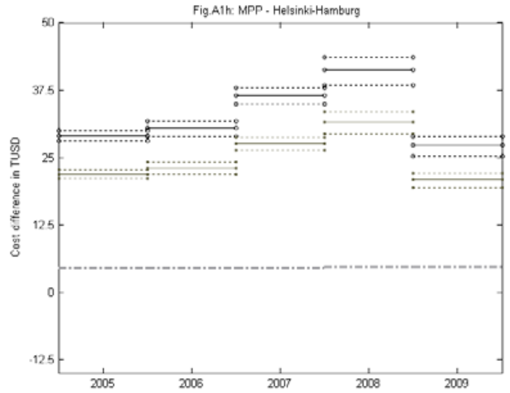


Fig.A1h: MPP - Helsinki-Hamburg
Cost difference in TUSD
50
37.5
25
12.5
0
-12.5
2005
2006
2007
2008
2009

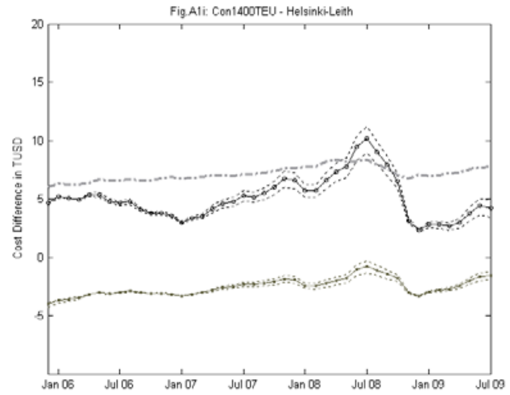


Fig.A1i: Con1400TEU - Helsinki-Leith
Cost Difference in TUSD
20
15
10
5
0
-5
Jan 06
Jul 06
Jan 07
Jul 07
Jan 08
Jul 08
Jan 09
Jul 09

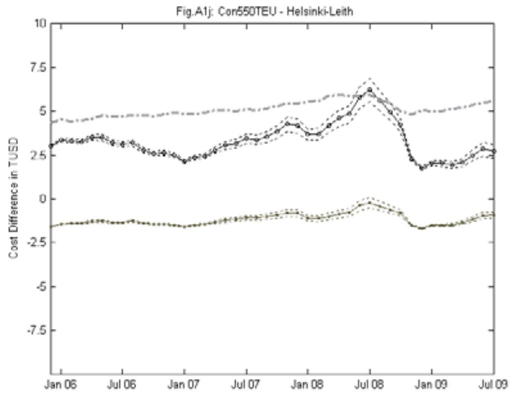


Fig.A1j: Con550TEU - Helsinki-Leith
Cost Difference in TUSD
10
7.5
5
2.5
0
-2.5
-5
-7.5
Jan 06
Jul 06
Jan 07
Jul 07
Jan 08
Jul 08
Jan 09
Jul 09

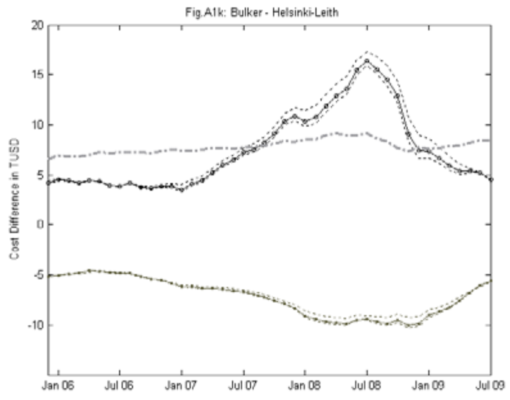


Fig.A1k: Bulker - Helsinki-Leith
Cost Difference in TUSD
20
15
10
5
0
-5
-10
Jan 06
Jul 06
Jan 07
Jul 07
Jan 08
Jul 08
Jan 09
Jul 09

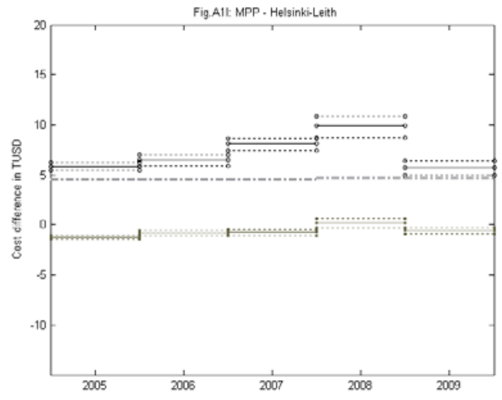


Fig.A1l: MPP - Helsinki-Leith
Cost difference in TUSD
20
15
10
5
0
-5
-10
2005
2006
2007
2008
2009