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University of Helsinki
Department of Economics and Management
Discussion Papers n:o 68
Helsinki 2015

Input-Efficiency of Fishing Cod in the Baltic Sea – Comparing Major EU Trawler Fleets

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Abstract

Under the concept of the European Union, common regulations allow management that is an outcome of cooperative decisions instead of the regular ‘race to fish’ situation. However, equal rights to participate in the common pool resource based on Total Allowable Catches given to asymmetric fleets translate into potential underutilization of the most efficient ones. These asymmetries imply that some participants have direct advantages in resource extraction that cannot be utilized, which is decreasing the overall efficiency of the industry. These advantages can be divided into two separate groups: on-site efficiency associated with fleet structure and regulations in place, and advantages accounted by spatial relation to the most productive fishing grounds. The asymmetries in on-site efficiencies combined with evaluated location advantages are expected to be crucial when evaluating the benefits of the potential international flow of quotas. Following economic principles, such a system would set incentives for fleet consolidation and allow benefits associated with smaller distances. However, the social concerns associated with applying the economic principle of full tradability may be undesirable or hard to overcome. Thus, the impact of other factors influencing national levels of efficiency is highlighted as guidance with respect to efficiency improvement best practices. An empirical application is provided for the case of the Baltic Sea demersal trawlers and seiners, mainly harvesting cod.

Key words: Atlantic Cod (*Gadus morhua*), Baltic Sea, EU fishing fleets, input-efficiency

JEL Code: Q22

1. Introduction

The concept of the European Union is an integrated Europe with common laws and regulations. This is in particular applicable to common pool resources such as fisheries. In case of fish stocks which inhabit and migrate between Exclusive Economic Zones (EEZ) of multiple countries, common regulations allow management based on cooperative decisions instead of a regular 'race-to-fish' situation. In this way, more effective management safeguarding the stocks' good biological state can be implemented. However, there are downsides of common regulations giving equal rights to all countries using the common pool resource. This is due to asymmetries between the countries that translate into direct advantages in resource extraction that cannot be utilized. These include development and restructuring of the fleets over past years resulting in current states that vary, and spatial relation to the most productive fishing grounds.

The paper compares the efficiency of major Baltic Sea demersal trawling fleet segments of Denmark, Germany, Poland and Sweden. The focus of this article is on the Eastern (ICES zones IIID: 25-32) and Western (ICES zones IIID: 22-24) Baltic Sea cod stocks, shared by all aforementioned countries.[1] It is preliminary research regarding the potential flow of individual cod quotas between countries in case the quota market would be open for free trade. Currently international trade is only available at the national level and contributes to the final Total Allowable Catch (TAC) amount. The national TAC is then distributed between individual vessels according to local regulations, in case of cod mostly in form of individual quotas.

Each vessel given a Baltic Sea cod quota is permitted to harvest it with no restrictions regarding location,[2] in particular it is allowed to fish in all Baltic Sea Exclusive Economic Zones (except the 12 nautical miles coastal zone, unless otherwise individually agreed). Thus, the best fishing grounds are shared by all member countries with limits only with respect to landings amount. In such a situation, the harvest of a given quota is conducted mostly in the same areas[3] as long as it is found profitable.[4] However, each vessel is harvesting the quota with its own individual efficiency that is expected to vary between vessels. Those asymmetries could contribute to increased efficiency[5] in the case of more flexibility in quota flow. The efficiency depends also on the decision regarding location choice implying specific distance from the country of origin. Thus, it is expected that some countries may enjoy the advantage of being situated closer to the most productive fishing ground and benefit from this fact when considering the trade-off between better catch per unit of effort and the distance to the specific area. This research is a starting point for efficiency comparison and looks into differences between aggregated fleet segments. Proven differences between segments indicate significant

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[1] However, as the sector is characterized by multiproduct production, the harvest of other species is accounted for.

[2] With the exception of certain grounds during the spawning season, applicable to all Baltic Sea fleets.

[3] Small vessels have less mobility and smaller fishing grounds range. Thus, they often stay in the closer proximity of the home ports.

[4] This includes subsidies.

[5] Increased efficiency within the same gear and length category is expected to be directly translating into lower fuel use implying lower environmental impact and potentially lower costs. However, the possibility to lower the costs highly depends on cost differences. The cost efficiency is a closely related topic that is possible to evaluate with techniques similar to those presented later in this paper, however due to data limitations, the topic is not further investigated.

asymmetries and imply that detailed analysis on individual vessel level would result in the possibility to derive an optimal allocation of quotas in the region.

The paper is structured as follows. The introduction is followed by the presentation of the case where the current situation of the Baltic Sea cod demersal trawler fleets is explained in the context of restructuring processes and regulations in place. The section also explains the importance of cod in the region giving arguments for validity of this study. The article proceeds with the methodology used to evaluate the asymmetries between investigated fleets, presents data and reveals the results. The model outputs are evaluated from three different perspectives, that is as a comparison of on-site efficiency, efficiency changes over time and efficiency in context of distance to the fishing grounds. The article concludes with remarks regarding differences in efficiency of harvesting cod in the Baltic Sea by the major fleets involved in this fishery and possible reasons behind it.

2. The Case Background

2.1. The Importance of the Baltic Sea Cod

The Baltic Sea cod (*Gadus morhua*) is an important species in the Baltic Sea: it plays an essential ecological role in the ecosystem and it is the commercially most valuable fish species in the Baltic Sea (ICES 2013). Thus, the cod stock variations impact both humans through the productivity of the stock utilized by commercial and recreational fishing, and environment through overall fish productivity and food web dynamics.

In the Baltic Sea cod has traditionally been divided into two stocks: the Eastern stock east of Bornholm island and the Western stock from west of Bornholm to the Sound and Danish Belts (Bagge et al. 1994). The Eastern and Western stocks differ in morphometric characteristics and genetics (Bagge et al. 1994; Hüssy, John, and Böttcher 1997; Nielsen et al. 2003). Thus, they are assessed and managed separately. The Eastern stock is larger in size and distribution, and contributes more to the EU harvest (ICES 2013). The two stocks overlap near Bornholm where some mixing occurs (ICES 2013). The spawning grounds, where cod migrates after maturation, are located in the deeper basins of the Baltic Sea (Köster et al. 2001).

Due to its semi-enclosed nature, the Baltic Sea ecosystem is heavily influenced by environmental conditions. Variations in temperature, salinity, oxygen and nutrient levels make the Baltic Sea fisheries management difficult as sustainable exploitation levels vary in response to environmental conditions (FAO 2011). Particularly cod has been affected by ecological stress.

The Eastern cod stock has adapted to the low salinity of the sea by producing eggs that are buoyant at the halocline and therefore its reproductive success depends on environmental variables, namely suitable hydrographic conditions in the spawning areas (Wieland, Waller, and Schnack 1994; Nissling and Westin 1997; MacKenzie et al. 2000; Köster et al. 2005). Salinity and oxygen concentration in the Baltic Sea are fluctuating with irregular salt- and oxygen-rich water inflows from the North Sea (Matthäus and Franck 1992). Anoxic conditions and low salinity adversely affect fertilization and cause severe mortality to the cod eggs in the deep-water layers (Wieland, Waller, and Schnack 1994; MacKenzie et al. 2000). Unfavorable hydrographic conditions also decrease the final survival rate by prey limitation for the larvae and juvenile stages (Hüssy, John, and Böttcher 1997; Hinrichsen et al.

2002; Köster et al. 2005), enhanced cannibalism (Sparholt 1994; Neuenfeldt and Köster 2000) and vertical overlap between the eggs and clupeids (herring and sprat), the main predators (Köster and Möllman 2000; Köster et al. 2005).

Changes in recruitment conditions together with anthropogenic factors have caused the Eastern cod stock to fluctuate significantly over the past decades (Figure 1). The cod stock increased to outstanding levels in the late 1970s when the fishing pressure was relatively low and hydrological conditions advantageous for reproduction (ICES 2013; Eero et al. 2011). The stock reached its peak in the 1980s (ICES 2013; Eero et al. 2011), which was attributed to the high frequency of inflows from the North Sea resulting in good recruitment years. The rapid decline of the population began in the mid-1980s. The salinity and oxygen conditions for recruitment deteriorated and fishing effort remained high, partly due to improvements in harvest technology (ICES 2013; MacKenzie et al. 2002; Eero et al. 2011). Degraded environmental conditions made the cod stock more vulnerable to fishing, and vice versa (Köster et al. 2005). The decline continued and the stock decreased to extremely low levels in the beginning of the 1990s. The major reasons were continuing fishing pressure, lack of major inflows from the North Sea, eutrophication (hypoxia) and increasing seal predation (ICES 2013; Eero et al. 2011). A major water inflow in 2003 substantially influenced the volume of water suitable for cod recruitment, resulting in a slight increase in stock size since 2005 (ICES 2013). However, the recent cod stock trend is still under study.

The Western cod stock fluctuations (Figure 1), reported by (ICES 2013), show similarities with the Eastern stock. The Western stock was at high levels in the early 1980s from when it started declining to the lowest recorded levels in early 1990s. Only the mid-1990s brought slight improvement and partial recovery. The high fishing effort has been in decline from year 2000, and recently recorded levels are below targets set by the management plan. Although the Western stock biomass has been increasing since the early 2000s, the recruitment has been close to the lowest recorded levels, with no noticeable fluctuations in recruitment success. The recent abundance of the adult Western stock is likely caused by spill-over effect from the Eastern stock which is expanding its distribution.

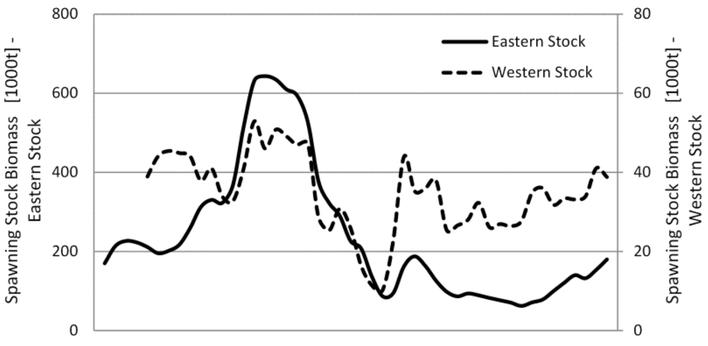

Figure 1: Fluctuation of Spawning Stock Biomass (SSB) of the Baltic Sea cod: Eastern Stock (1966-2013) and Western Stock (1970-2013) (ICES 2013).

Cod has an important ecological role as a top predator balancing the food web (Casini et al. 2008), and thus maintaining the ecosystem functionality. The Baltic food web is relatively simple and the fish community is dominated by three species: cod, sprat and herring. During the last decades, major fluctuations in the cod abundance have been part of the large-scale Baltic Sea ecosystem changes related to climate, fisheries and eutrophication (Österblom et al. 2007; Casini et al. 2008; Möllmann et al. 2009). The major period of ecological stress and anthropogenic impacts such as overfishing of cod (1987-1993) pushed the biotic part of the central Baltic Sea into an altered state of reduced cod productivity. This, in turn, impacted the whole ecosystem due to the role of cod as the main predator of sprat and herring (Österblom et al. 2007; Casini et al. 2008; Möllmann et al. 2009). As the cod stock decreased, sprat stocks increased its abundance due to reduced predation supported by favorable environmental conditions at the time; a shift from a cod-dominated to a sprat-dominated regime took place. Then, the predator-prey feedback loop stabilized the system, as a high sprat stock formed an increased predation pressure on cod eggs and juveniles (Möllmann and Köster 1999; Köster and Möllman 2000; Österblom et al. 2007). A trophic cascade took place as the shift from cod to clupeids occurred in combination with climate-driven changes in zooplankton composition and altered regulation of phytoplankton (Möllmann and Köster 1999; Österblom et al. 2007; Casini et al. 2008). Changes in zooplankton composition influenced prey availability for both cod and sprat, and promoted algal blooms on the Baltic Sea (Möllmann and Köster 1999; Österblom et al. 2007; Casini et al. 2008). Economically, the shift from a cod-dominated to a clupeid-dominated state in the late 1980s decreased the value of the catch due to the relative composition of the fish species. It has been estimated that increasing the cod stock and reducing sprat abundance would be economically more profitable than the clupeid-dominated state (Döring and Egelkraut 2008; Nieminen, Lindroos, and Heikinheimo 2012; Waldo et al. 2013). The future major threats to cod stock sustainability and reproduction potential include pollution and climate change (MacKenzie et al. 2007; Niiranen et al. 2013; Lindegren et al. 2010).

The Western stock is mainly fished by Denmark, Germany and Sweden, whereas the Eastern stock is fished by Denmark, Sweden and Poland (ICES 2013). The profitability depends on the gear segment, as well as the vulnerability to the condition of the main target species (Blenckner et al. 2011). The secondary economic and social impacts include employment, retail, jobs and income at the dockyards, and work for local craftsmen (Blenckner et al. 2011). In many Baltic countries, fishermen have long fishing traditions and few job alternatives, so management actions are constructed to avoid the loss of jobs (Blenckner et al. 2011).

The latest (2013) Annual Economic Report of the EU Fishing Fleet reports the 2012 value of landings[6] generated by the EU Baltic Sea fleet in the amount of approximately 237 million EUR, of which Poland (56 million EUR), Sweden (51 million EUR), and Denmark (43 million EUR) collectively accounted for around 60%. Cod generated the highest value of landings (77 million EUR) followed by herring (63 million EUR) and sprat (45 million EUR), although the total volume of cod accounted for only 62 thousand tons (compared to 220 thousand tons of herring and 177 thousand tons of sprat). The total volume landed in 2012 was 510 thousand tons (2% decrease from 2011) (STECF 2013).

The above-described complex links between different parts of the ecosystem show the value of cod to the Baltic Sea. It is an economically valuable fish and it contributes to the Baltic Sea ecosystem

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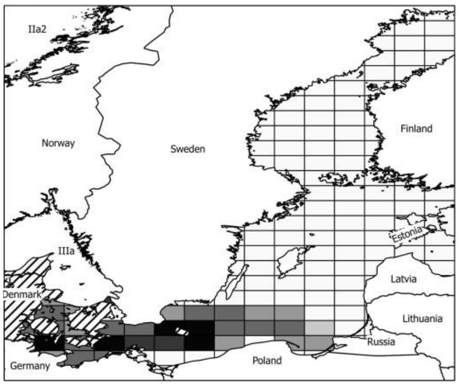
[6] Estonia is excluded from the analysis due to failed performance data for 2011. Total landings weight excludes the German pelagic trawl segment.

functioning. Cod forms a link between the social and ecological systems of the Baltic region both through ecosystem services and anthropogenic stressors.

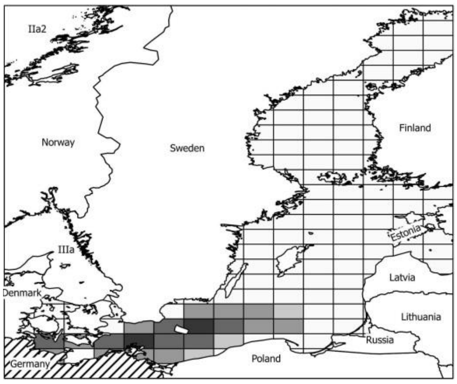
2.2. Fisheries Management of the Baltic Cod

In order to coordinate the interests of countries participating in the Baltic fisheries the International Baltic Sea Fisheries Commission (IBSFC) was established in 1973 as a result of the Gdansk Convention on Fishing and Conservation of the Living Resources in the Baltic Sea and the Belts in 1973 (TRE 535/1973). The signing countries were Denmark, Germany, Sweden, Finland, Poland and Russia, Estonia, Lithuania and Latvia as part of the USSR. The IBSFC was dissolved in 2005 when all countries except Russia had successively joined the European Union. From then on the management of the Baltic fishery has fallen under the Common Fisheries Policy (CFP) of the European Union for all member states. In 2006 the European Union called for a bilateral agreement concerning fishing activities with Russia (COM 868/2006) which came into force in 2009 (EC 439/2009). Prior to this, there have been bilateral agreements between Russia and the individual member states (Churchill and Owen 2010).

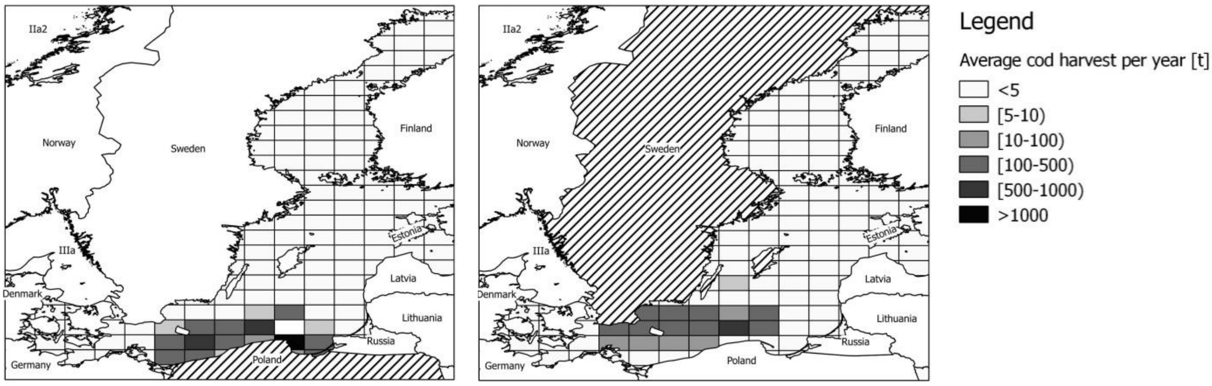
By the equal access principle defined in 1970 (EEC 2141/1970, modified in EC 2371/2002) all European Union member states have the same right to fish in all Community waters, including all shared EEZs, except for the 12 nm zone. Those terms are then manifested in bilateral agreements between member countries. In this setting all Baltic countries are able to choose the most profitable fishing grounds. Figure 2 shows that for the Baltic cod stock these fishing grounds are located in the south of the Baltic leading to a high concentration of fishing activity in that area (maps for the demersal trawlers and seiners sector; 8-40 m length, averages over 2004-2012).



2.a. Denmark



2.b. Germany



2.c. Poland

2.d. Sweden

Figure 2: Distribution of cod harvest by demersal trawlers ad seiners sector (8-40 m length) from Denmark, Germany Poland and Sweden (averages over 2004-2012).

The IBSFC and the CFP base their management decisions on the scientific input of the International Council for the Exploration of the Sea (ICES) and the Scientific, Technical and Economic Council of Fisheries (STECF) of the European Union. Since 2006, stakeholders are actively involved in the decision-making by the Regional Advisory Council for the Baltic Sea (EC 585/2004). In order to take the interests of individual states closer into account, the CFP encourages the cooperation of member countries with respect to fisheries management on a regional level (EU 1380/2013).

The main instrument in fisheries management used by the IBSFC and the CFP is TAC, which defines the amount of fish that is allowed to be caught from a specific stock in a year. TACs are usually set on an annual basis. The allocation of the TAC between countries is based on the principle of relative stability which states that each country receives a fixed share of the TAC (EC 2371/2002; Churchill and Owen 2010). For defining those shares three criteria are taken into account: (i) historical catch records, (ii) specific needs of areas particularly dependent on fishing and its dependent industries (Resolutions of The Hague) and (iii) the loss of fishing potential in the waters of third countries[7] (EEC 170/1983; EC 2371/2002; Churchill and Owen 2010). The TACs can be exchanged between member states (EC 2371/2002), but only on national level. Since 1976 the ICES has given recommendations for Baltic cod TACs. These have been exceeded regularly by the TACs set by the IBSFC (Radtke 2003). From 1982 to 1988 the IBSFC was even unable to set any TACs such that in this period the conditions resembled an open access fishery[8] (Kronbak 2005). From 1989 on, catches exceeded TACs to a lesser extent. However, substantial illegal, unregulated and unreported (IUU) fishing was a problem in the Baltic cod fishery until 2007 (OCEANA 2012). From 1993 to 1996 and from 2000 to 2007, the level of unreported landings has been between 35% and 40% (ICES 2013). Poland was to a large extent responsible for that fact which led to a penalty by the European Union for the Polish cod fishery (The Fisheries Secretariat 2009). As a consequence, the effort in monitoring and controlling has been increased. In recent years the level of misreporting has decreased to 6-7%. However, the problem of IUU remains (OCEANA 2012).

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[7] With (i) and (ii) being in particular relevant for the Baltic Sea.

[8] Some technical measures were present, e.g. regulation regarding mesh size, minimum landing size, closed season.

Since 2004 there is a separate assessment including separate TACs for the Eastern and the Western cod stock (ICES 2013). Additional management instruments are technical specifications regarding effort and gear regulations (i.e. mesh size, minimum landing size, type of nets, size of vessel, days at sea) (Churchill and Owen 2010). Such specifications for the fisheries in the Baltic Sea are given in regulation EC 2187/2005.

As a reaction to the poor state of the Baltic cod stock in the beginning of the 90s the IBSFC put a lot of effort into the recovery of the stocks in addition to the TAC management. A new tool was the seasonal fishing ban from June to August introduced in 1995 (EC 3362/1994) which has been modified to a minimum duration of 2 months in 2007 (Kraus 2007). In 1997 a marine protected area (MPA) to protect spawning fish stocks has been implemented east of Bornholm (Suuronen, Jounela, and Tschenij 2010). This MPA has been increased several times and now covers most of Bornholm Deep. On top of this, in 2005 MPAs in the Gdansk Deep and in the Gotland Basin were implemented. There have also been a number of long term initiatives to support the recovery of the cod stock. In 1999 the IBSFC implemented a long term strategy for Eastern and the Western cod stocks in the Baltic Sea which had the aims to maintain a minimum spawning stock biomass (greater than 160000 t for the Eastern and greater than 9000 t for the Western stock) and to implement a long term management plan with TACs reflecting a precautionary fishing mortality rate (Apps and Lassen 2010). In 2001, a Recovery Plan for the Eastern Baltic Sea Cod was adopted, calling for a management that would reduce the fishing mortality rate. This plan also included area closures and seasonal fishing bans. However, the success of these initiatives was limited because of too high TACs, lacking control and unwillingness of the IBSFC members (Apps and Lassen 2010). Since 2005 each vessel greater than 8 m fishing for cod has had to hold a special fishing permit for cod (EC 27/2005). The cod permit is given if the vessel has been active in cod fishing the previous year and new vessels can only get a cod permit if another vessel with the same capacity is going to be inactive in exchange. In addition, special permits are necessary for fishing in the Gulf of Riga (EC 2187/2005). In 2007 the European Union implemented a multi-annual recovery plan for both cod stocks (EC 1098/2007). The goals of this plan are the recovery of the stocks (in terms of biomass) and a reduction of the fishing mortality rate by the implementation of a sustainable fishery based on maximum sustainable yield (MSY) criteria (target fishing mortality rate is 0.6 and 0.3 for the Western and the Eastern Baltic cod stock respectively; EC 1098/2007). The instruments used are limited variation of the TAC (maximum 15 % deviation from the previous year's TAC) and a 10 % reduction in days at seas as long as the fishing mortality rate is above the target value. Further limitations are the prohibition of driftnets in the cod fishery and exclusion of vessels below 8 m. The plan also includes the temporary closure of fishing areas (mainly Bornholm deep) and seasonal bans (West of Bornholm 1st – 30th April, East of Bornholm 1st – 31st August). Currently both Baltic cod stocks are managed according to these plans and they are considered to be quite successful (Bastardie et al. 2010).

The guidelines regarding fisheries of the IBSFC and the CFP respectively apply to all member countries in the same way. However, there are some differences in the national allocation mechanisms of TACs. The main approach of the member states is an individual quota (IQ) system (Blenckner et al. 2011) where a governmental institution allocates shares of the TAC (quota) to either fishermen or vessels. In the following section the focus is on the national fisheries management of the major trawling fleets for the Baltic cod, including Denmark, Germany, Poland and Sweden (ICES 2013).

2.3. National Management of the Baltic Sea Cod

Denmark introduced a vessel quota share (VQS) system for demersal species, including cod, in 2007. The system allows trading of quotas on national markets. VQS are given and bound to vessels with more than 30 000 EUR gross earnings per year. The actual quota share is based on the landings of the reference period 2003 to 2005. Initially the VQS could only be transferred with the vessel, but that regulation was abolished in 2009 (Andersen 2012). VQS vessels can join the coastal fleet if they are less than 17 m and at least 80 % of their fishing trips are less than 3 days long (Andersen, Andersen, and Frost, 2010). Then, they have to stay in the coastal fleet for at least three years (Bonzon et al. 2013). Coastal vessels can buy quota from vessels larger than 17 m but not the other way round. Small-scale fisheries vessels (less than 30 000 EUR gross earning per year) are managed by a ration system with a fixed share of the national quota of 10 % (Bonzon et al. 2010). In so called fish pools (voluntary cooperatives) fishermen can swap and lease VQS between vessels. Inactive vessels can lease their shares within these pools for the current year (Andersen 2012). Highgrading is not allowed. The Danish system allows fleet adaptation by VQS transfers even on a daily basis.

Germany, Poland and Sweden use an individual vessel quota (IVQ) system where the quotas are non-tradable. In Sweden IVQs are given to vessels greater than 8 m holding a special permit to fish for cod (Swedish Agency for Marine and Water Management, personal communication with Hannes Rasper). The cod permit is given to fishermen who have been active in cod fishery during 2005 to 2007. The cod permit allows for fishing in ICES zones 22 to 24 (25 to 28) for 147 (146) days and maximum 147 days in ICES zones 22 to 28. The quota share depends on the length and gross tonnage of the fishing vessel. However, currently the quota shares for Swedish vessels are unlimited, because it is not anticipated that the national TAC is going to be fully fished.

In Germany IVQs are allocated to the vessel owner. A license for fishing is only given to vessels that were active already in the fishing season 1986/1987 (SeeFishG/1984). IVQs are allocated based on previous year's quota. In addition, the relevant vessel has to be active for the past three years; otherwise it is not entitled to its IVQs (Justiz 2014). For the Baltic cod stock, individual licenses assign a specific amount of fish to each participating vessel depending on its historic catch.

In Poland the quota allocation between vessels with cod harvest permit (as in 2005) is based on vessel length (Dz. U. 225, poz. 1497/2008). Until 2008, IVQs were given to vessels greater or equal to 10 m, whereas units between 8 m and 10 m were subject to block quota. Vessels below 8 m, according to special European Union exemption, were allowed unlimited harvest (Dz. U. 225, poz. 1497/2008). Starting with 2009, the group of vessels between 8 m and 10 m joined the IVQ regulated fleet, whereas units below 8 m became subject to block quotas (Dz. U. 282, poz. 1653/2011). The IVQs are not transferable. Additionally, from 2009 to 2011 the Polish fleet was subject to a temporarily imposed regulation allowing only about one third of the vessels with cod harvest permits to receive quotas. The special three year management plan was a result of overfishing the TAC in 2007, which resulted in this penalty imposed by the European Union. Each year's group of vessels was selected according to the lottery with the possibility to win only once (Dz. U. 225, poz.

1497/2008). In order to reduce the overcapacity in the Baltic fleet, a new fleet policy was introduced after the reform of the CFP in 2002 (EC 2371/2002). This issue is examined in more detail in the following section.

2.4. Overcapitalization Tendencies and Reasons Behind

The past regulations regarding Baltic cod resulted in increasing capacity. Fleet capacity consists of the number, size and type of the vessel and gear, technical efficiency of the vessel for finding, handling and storing the fish on-board, the potential fishing time of each vessel, which is dependent on the distance to the fishing grounds, and the fishers' ability to catch fish (Smith and Hanna 1990). The fleet becomes overcapitalized if the number of vessels or capacity in a fleet exceeds the use potential of the fish stock (Blenckner et al. 2011). Overcapacity does not only have an adverse impact on the fish stocks but it also affects negatively the economic outcome of fishermen, thus it is important to balance the fishing effort and the existing resource in order for the fishery to be economically and biologically sustainable in the long-term.

In the Baltic cod fishery the main reason for the overcapitalization is the past management system that gave fishermen incentives to invest in larger vessels and new technologies. The EU introduced subsidies in the 1970s in order to help the economic situation of the fishing companies and to keep fish prices at a consumer-friendly level (Kirkley and Squires 1999; Blenckner et al. 2011). Subsidies reduce the costs of fishing and therefore encourage investments that would not occur without subsidies (Arnason, Kelleher, and Willmann 2009). Once the fleets were highly capitalized, TACs were intentionally set higher than the scientific recommendation due to the political pressure by fishing industries that were troubled by overcapacity (Apps and Lassen 2010). The decision-makers wanted to guarantee the social and economic welfare and keep the fishermen employed, but the management was driven by short-term perspective with conventional discounting which practically ignored the longer-run conservation goals (Edwards, Link, and Rountree 2004; Sumaila and Walters 2005; Apps and Lassen 2010). The decision-makers believed the socio-economic benefits were so high compared to the risk of negative effects on stocks that they justified exceeding the quotas (Aps, Kell, and Liiv 2007). On top of this, due to technological progress, even stricter capacity reductions were needed to ensure sustainable harvest (EC 2008).

Since the revision of the CFP in 2002 the Member States are responsible for keeping a balance between their fishing capacity and the existing fish stocks. This continues in the most recent revision of the CFP that came into force in 2014. The members are obligated to keep their capacity (both in tonnage and power) under the fixed maximum levels, whereas failing to achieve the targeted reduction may result in suspension of the financial support from the European Maritime and Fisheries Fund. The latest analysis shows that all Member States achieved the initial goal with the help of the long-term management plan introduced in 2007 by the EU, which included effort limitations in addition to quotas. Failing to achieve the balance requires construction of an additional action plan including adjustment targets and tools for retrieving the balance (EC 2014). The most commonly used tool for capacity reduction has been vessel scrapping financed by the European Fisheries Fund. Between 2007-2013 the fund allocated 1.3 billion EUR for permanent or temporary cessation in order to reduce the fishing capacity in European waters (EC 2013). Danish fishing fleet was reduced between 2000 and 2009 by 12% with the use of scrapping programs. Additional 24% reduction was attributed to the ITQ system applied in 2007. Reduction programs between 2004 and 2008 succeeded in decreasing the Polish fishery by 45% in tonnage. Sweden implemented two national scrapping campaigns in 2008 and 2009 aimed at demersal cod trawlers, which contributed to a 26% reduction in tonnage (EC 2013). Germany's fleet has been reduced in number due to the EU scrapping program by 33% between 1995 and 2010 (EC 2013). However, a major problem has been encountered throughout the adopted programs, e.g. a lack of clear rules regarding what happens to the fishing rights after the scrapping. Overall, some progress towards increasing balance between the fishing capacity and the fish stocks can be noticed (EC 2014). The regulations aiming at harvest control and capacity reduction had an important influence on the transitions of the fleet targeting cod over past years, including the major cod fleet, namely the demersal trawlers and seiners.

2.5. Demersal Trawlers and Seiners Sector

The demersal trawlers and seiners sector (DTS) accounts for the majority of the cod catches in the four Baltic Sea national fleets assessed in this study (table 1). Additionally, there has been a growing trend over the years strengthening its importance in the region.

Table 1: Demersal trawlers' and seiners' share of the live weight of the total national cod catches (%).

Country	2008	2009	2010	2011	2012
Denmark	62.0	65.8	67.3	67.3	69.2
Germany	83.8	91.2	88.5	89.3	89.3
Poland	51.9	49.2	51.7	64.8	64.5
Sweden	60.7	67.1	76.3	79.7	80.9

Source: STECF 2013.

The DTS sector accounted for the majority of the income in the Baltic Sea region in 2011 (101 million EUR), and the sector's economic performance in the longer vessel groups (12-18 m, 18-24 m, and 24-40 m) have been improving. However, the smaller vessels are still facing problems to generate economically positive returns in the fishery. A key factor influencing profits has been the increased productivity of the fleets, whereas rising fuel prices are slowing down the development (STECF 2013). The number of vessels is the highest in the length group 12-18 m, while the length category 24-40 m accounts for the biggest share of the catch. The Danish fleet is the biggest within the sector. However, not all the Danish vessels, nor the German, harvest only in the Baltic Sea; a large share is operating also in the North Sea and North Atlantic. The second biggest fleet within the sector is in Sweden (STECF 2013). The capacity in number of vessels has been showing mostly a negative trend in the DTS sector (table 2). The number of Danish demersal vessels was decreasing over past years while the sector was increasing its profits. This confirms that although the capacity decreased, the remaining vessels have sufficient technology to obtain higher catches, and thus, attain higher profits. Also, the German fleet capacity has been decreasing. In Poland, the excess capacity has been reduced especially among the bigger vessels. In 2012 a part of the Polish demersal fleet returned to the fishery after 3-year temporary suspension of cod fishing rights in 2009-2011, which shows in the number of smaller vessels. In Sweden the capacity in vessel number has been decreasing in all but smaller vessels (STECF 2013).

Table 2: Trends in of the DTS sector fishing capacity (2004-2012) [number of vessels].

	2004	2005	2006	2007	2008	2009	2010	2011	2012
Denmark									
0-10 m	37	34	12	12	12	10	12	14	NA
10-12 m					10	13	8	8	NA
12-18 m	317	286	271	217	184	177	168	156	NA
18-24 m					79	77	68	70	NA
24-40 m	NA	NA	NA	NA	51	46	42	39	NA
Germany									
0-10m	21	14	14	14	2	2	1	1	NA
10-12 m					14	13	15	15	10
12-18 m	75	76	77	78	41	39	37	33	27
18-24 m					31	28	30	29	20
24-40 m	24	27	26	26	12	17	16	13	10
Poland									
0-10 m	13	NA	NA	NA	NA	5	3	1	1
10-12 m					NA	7	12	15	15
12-18 m	141	124	91	93	59	45	46	55	58
18-24 m					34	22	20	16	34
24-40 m	74	48	44	32	25	10	10	4	5
Sweden									
0-10 m	64	65	71	63	10	9	15	21	22
10-12 m					50	53	48	48	49
12-18 m	160	149	158	160	105	100	89	80	74
18-24 m					55	58	49	43	46
24-40 m	30	30	27	33	32	31	31	31	28

Note: NA – not available. Source: STECF 2013.

The potential overcapacity of the DTS sector is assessed by comparing vessel utilisation ratios provided by STECF (STECF 2014) (table 3). This technical indicator illustrates a ratio of the average fishing time spent at sea to the maximum fishing time at sea in each fleet segment.[9] A value below 0.7 indicates under-utilisation of the fleet which may be caused by a structural overcapacity. The values between 0.7 and 1 indicate that the fleet may be considered in balance with the available resource. The values suggest that the majority of the DTS sector struggle with overcapacity. The optimal situation is observed only among bigger vessels, over 18 m, in Germany and Denmark, and among vessels over 24 m in Sweden. A recent positive trend is shown by Denmark and mid-sized vessels from Poland and Sweden, indicating a capacity reduction (STECF 2014).

Table 3: Vessel utilization ratios for DTS sector in 2008-2012.

Country	Length	2008	2009	2010	2011	2012
Denmark	10-12m	0.36	0.34	0.48	NA	0.45
	12-18m	0.47	0.49	0.50	0.50	0.59
	18-24m	0.60	0.64	0.69	0.64	0.69
	24-40m	0.88	0.97	0.91	0.88	0.90
Germany	10-12m	0.44	0.42	0.36	0.37	0.30
	12-18m	0.40	0.40	0.40	0.39	0.45
	18-24m	0.63	0.58	0.56	0.54	0.68
	24-40m	0.86	0.72	0.68	0.68	0.84
Poland	10-12m	NA	NA	0.23	NA	NA
	12-18m	0.26	0.36	0.34	0.45	0.57

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[9] Here 240 days, used to reflect the average working days in most economic sectors (365 days - weekends - holidays). The ratio includes potential fishing in other waters.

	18-24m	0.30	0.32	0.34	0.39	0.38
	24-40m	0.36	0.40	0.23	NA	NA
Sweden	10-12m	0.26	0.27	0.24	0.24	0.26
	12-18m	0.38	0.37	0.34	0.37	0.41
	18-24m	0.47	0.44	0.49	0.6	0.64
	24-40m	0.75	0.7	0.65	0.73	0.67

Note: NA – not available. Source: STECF 2014.

3. Methodology

3.1. General Context

The fishing industry can be considered a set of firms (vessels) clustered in fleet segments depending on main gear, vessel size, country of origin and fishing region (STECF 2013). These homogeneous[10] sub-divisions are often referred to as métiers (ICES, 2013). In each segment, the input-based technical efficiency (TE, referring to the full input based technical efficiency specification from herein) is dependent on the production of outputs, i.e. harvested species, using inputs in the form of fishing effort. The TE value gives information to what extent the production in a segment differs from the best-practice in the industry, i.e. how far it is from the established frontier. Deviation indicates that the accessible technology is not used to its full potential. The effort required for a certain level of harvest depends on the long-term strategy and short-term decision of the fishermen. The long-term strategy is associated mostly with capital investments, its type, size, etc. The short-term decision is on which species to target, whether to change gear or not, whether to fish on given day, and where to fish (Eales and Wilen 1986).

The choice of fishing ground is an important aspect of fishing (Pascoe, Koundouri, and Bjørndal 2007). Following modern biological studies, the fish population structure often exhibits properties like patchiness and heterogeneity, and this effect should not be disregarded in fisheries modeling (Holland et al. 2004; Smith, Sanchirico, and Wilen 2009). Patch, following Sanchirico and Wilen (1999), is a 'location in space that contains or has the potential to contain an aggregation of biomass.' A productive patch, abounding in a target species, in general implies higher catchability, lower on-site costs and higher rents.[11] Effort should be increased in such areas. In contrast, effort should be driven away from less productive patches (Sanchirico and Wilen 1999). Technical efficiencies are considered to differ with the productivity of different fishing grounds. Thus, the spatial dimension and explicit choice of fishing grounds adds new insight into comparing efficiency between métiers.

The distance between port and fishing ground is an important constraint in this context. The fisherman will not choose the most productive fishing ground if the travelling effort is too high. Thus, the fisherman faces the trade-off between TE on-site and travel distance. The fisherman's choice of fishing ground is subject to uncertainties in the stock dynamics, stock migration and locations of stock abundance (Mangel and Clark 1983; Schnier and Andersen 2006). Searching behavior provides

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[10] There is, of course, some degree of heterogeneity within the sector. However, for the purpose of this research, the differences within sector defined in this way are not considered.

[11] This consideration is of particular relevance for species whose harvest is density dependent. It may be not particularly applicable to schooling fish types whose aggregations can be targeted with use of modern technologies, including acoustic equipment.

reduction of such uncertainty. However, searching for information about stock abundance implies an opportunity cost equal to forgone payoffs which could have been realized by fishing (Marcoul and Weninger 2008). Many fisheries require substantial effort to gather enough information about where to set the net or start the trawl (Mangel and Clark 1983; Wilen 2004). Rent dissipation may occur as a consequence of excess effort involved in search itself, as well as through inefficient targeting (Eales and Wilen 1986). Thus, the fishing behavior can be thought of as a combination of searching activity, location choice and harvest, or a trade-off between exploration and exploitation, in addition to required travel distance.

3.2. Modeling Approach

Throughout this article, the technical efficiency in the fishing industry is evaluated as input based on-site technical efficiency subject to travel distance tradeoffs. The on-site TE, once the investment in capital is made, corresponds to the deviation from the minimum possible input given the output combination. The output is a composition of multiple fish species that are landed after returning to the port, and it generates revenue. The input is effective effort, measured as trawling time.

It is impossible to distinguish between effort involved in search and actual harvest. However, the trawling time in relation to the harvest indicates how efficiently the total on-site effort is utilized, i.e. how well effort is divided into search and harvest comparing to the best practice. It is assumed that the amount of effort required to harvest a certain fish composition depends on multiple factors describing the available technology. The affiliation to a particular fleet segment indicating main gear and size, and the specification of long-term strategy, is considered a major one. The TE is also dependent on national factors that include regulations, fleet structural changes, etc.

The role of technical progress in the fishing industry is acknowledged by accounting for time specific changes common to all observations (Squires and Vestergaard 2013). In this manner, it is assumed that general advancement in technology is wildly available, but fleet segments do not necessarily have to take an advantage of it, which is reflected in time-specific efficiency levels.

The on-site TEs are also considered to be specific for particular fishing grounds as those vary in fish density. However, the harvest location is associated with particular requirement with regard to travel time, here derived as distance to home country. Therefore, the fishing units face, each time, a spatial decision which implies certain on-site efficiency, but also a distance to cover. Moreover, the final productivity is only realized on-site, thus, adaptation and learning capacity when making the choice matters. Multiple empirical studies suggest that decisions regarding time and location of fishing are flexible, and can be adjusted relatively quickly (Wilen 2004). Often, it can be considered a discrete choice made on a daily basis (Smith 2000). The efficiency of harvest activity depends on experience and skills (Kirkley, Squires, and Strand 1998). There is also a great deal of heterogeneous responses to signals and varying learning patterns associated with the search outcomes. Thus, the spatial decisions, in particular tradeoffs between on-site efficiency and distance, are evaluated with respect to their rationality in the second stage analysis.

The TE is also influenced by stochastic factors which include any random processes affecting the final outcome, e.g., luck (Kirkley, Squires, and Strand 1995). The relation between elements determining the TE is depicted in figure 3. The TE in a short-run decision process can be estimated using a stochastic frontier analysis for the multiproduct distance function.

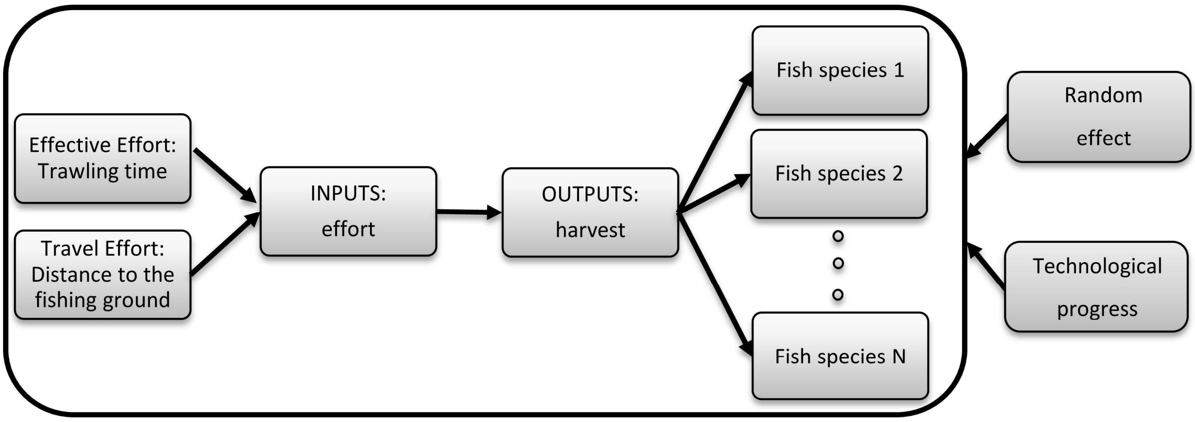

Figure 3: Elements of technical on-site efficiency in short-run decision process.

3.3. Multiproduct Distance Function

The majority of econometric studies model multiple-output technologies by either aggregating all outputs into a single index (e.g. Paasche, Laspeyres, Fisher or Tornqvist) or using dual cost and profit functions (Coelli and Perelman 2000). However, it is rarely the case that the whole set of prices required for creating an index is available. On the other hand, dual functions require strict assumptions regarding either cost minimization or profit maximization that are often not met due to sectors under investigation being highly regulated or strongly influenced by tradition. The example of such industry is the European Union fishery. The remaining approaches include the factor requirement function (Diewert 1974) and the distance function. However, because the focus of the article is on the efficiency of the European fleets, the distance function approach seems most compelling (Färe and Grosskopf 1990).

The production technology $P(Y)$ represents all input vectors X that can produce output vector Y. As the fishing industry is considered to have better control over inputs rather than outputs, the multiproduct distance function with input oriented specification is considered more appropriate (Coelli and Perelman 2000) and can be defined as (Shephard 1970):

$$D(X,Y)^I = max\{\theta: (X/\theta) \in P(Y)\} \qquad (1)$$

where $D(X,Y)^I$ is the distance from the inner boundary of the input set with following properties: it is nondecreasing, positively linear homogenous and concave in X, and decreasing in Y. The frontier is where the lowest amount of input X is used to produce given output Y, whereas Θ indicates the level of efficiency. The maximum efficiency is realized at the frontier, which requires $D(X,Y)^I = \Theta = 1$ and therefore the function $D(X,Y)^I$ can only take values ≥ 1. Conversely, when $D(X,Y)^I$ is approaching infinity, the infinite amount of input is needed to produce a given output.

A full logarithmic specification for i outputs ($i \epsilon I$) and j inputs ($j \epsilon J$) for métier n at time t is given as:

$$lnD_{n,t} = \alpha_0 + \sum_{i\in I}\alpha_i \ln(y_{i,n,t}) + \sum_{j\in J}\alpha_j \ln(x_{j,n,t}) + \sum_{i\in I}\sum_{i'\in I}\alpha_{ii'}\ln(y_{i,n,t})\ln(y_{i',n,t}) + \sum_{i\in I}\sum_{j\in J}\alpha_{ij}\ln(y_{i,n,t})\ln(x_{j,n,t}) + \sum_{j\in J}\sum_{j'\in J}\alpha_{jj'}\ln(x_{j,n,t})\ln(x_{j',n,t}) \quad (2)$$

The choice of logarithmic form is dictated by its flexibility with respect to determining the structure of the technology (Kirkley, Squires, and Strand 1995). Imposing homogeneity of degree one in inputs requires: $\sum_{j\in J}\alpha_j = 1$, $\sum_{j\in J}\alpha_{jj'} = 0$ for all $j'\in J$, $\sum_{j\in J}\alpha_{ij} = 0$ for all $i\in I$, whereas symmetry requires $\alpha_{ii'} = \alpha_{i'i}$ and $\alpha_{jj'} = \alpha_{j'j}$. That, for the case of single input x,[12] implies:

$$ln(D_{n,t}/x_{n,t}) = \alpha_0 + \sum_{i\in I}\alpha_i \ln(y_{i,n,t}) + \sum_{i\in I}\sum_{i'\in I}\alpha_{ii'}\ln(y_{i,n,t})\ln(y_{i',n,t}), \quad (3a)$$

or:

$$lnx_{n,t} = -(\alpha_0 + \sum_{i\in I}\alpha_i \ln(y_{i,n,t}) + \sum_{i\in I}\sum_{i'\in I}\alpha_{ii'}\ln(y_{i,n,t})\ln(y_{i',n,t})) + lnD_{n,t} \quad (3b)$$

There are multiple concerns regarding the use of effort as a single input variable (Squires and Vestergaard 2012). However, it is a traditionally important measure (Cunningham and Whitmarsh 1980) which offers a convenient framework to examine TE. Moreover, the comprehensive data needs to be available, which is not the case for e.g., fuel use. This is a crucial issue with respect to the attempt to compare multiple countries.

3.4. Empirical Model

Extending the analysis by spatial component requires redefining panels in (3b) as segment-, location- and time-specific. Introducing *r* as a notation for location and including linear time trend (*t*) indicating technical progress, the final model takes form of:

$$lnx_{n,r,t} = -(\alpha_0 + \sum_{i\in I}\alpha_i \ln(y_{i,n,r,t}) + \sum_{i\in I}\sum_{i'\in I}\alpha_{ii'}\ln(y_{i,n,r,t})\ln(y_{i',n,r,t}) + \alpha_t t) + u_{n,r,t} + v_{n,r,t} \quad (4)$$

Fishing sensitivity to random factors is captured in the term $lnD_{n,t}$ (3b) that can be redefined to the composed error ($\varepsilon_{n,t}$) containing the normally distributed stochastic variable $v_{n,t}$ (statistical noise) and the strictly nonnegative inefficiency $u_{n,t}$.[13] After transformation, the $u_{n,t}$ term can be interpreted as efficiency (Jondrow et al. 1982):

$$TE_{n,t} = \exp\left(-E\left(u_{n,t}\middle|\varepsilon_{n,t}\right)\right). \quad (5)$$

In this paper we consider the (Battese and Coelli 1995) methodology designed for panel data, in which the inefficiency term $u_{n,r,t}$ is obtained by truncation at zero of the normal distribution with mean δ, which is an unknown parameter to be estimated.[14] This allows comparability of the TE scores between observations, whereas it shows no attempt to evaluate numerically the influence of other factors; rather it gives consistent scores for further analysis. The advantage of the method is also that the unbalanced character of the data does not pose an estimation problem (Battese and Coelli 1995).

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[12] For the multi-input case, the following restrictions imply (Coelli & Perelman, 2000):
$ln(D_{n,t}/x_{1,n,t}) = \alpha_0 + \sum_{i\in I}\alpha_i \ln(y_{i,n,t}) + \sum_{j\in J\neq 1}\alpha_j \ln(x_{j,n,t}/x_{1,n,t}) + \sum_{i\in I}\sum_{i'\in I}\alpha_{ii'}\ln(y_{i,n,t})\ln(y_{i',n,t}) + \sum_{i\in I}\sum_{j\in J\neq 1}\alpha_{ij}\ln(y_{i,n,t})\ln(x_{j,n,t}/x_{1,n,t}) + \sum_{j\in J\neq 1}\sum_{j'\in J\neq 1}\alpha_{jj'}\ln(x_{j,n,t}/x_{1,n,t})\ln(x_{j',n,t}/x_{1,n,t})$.

[13] With formally stated properties as follows (Stevenson 1980): $v_{n,t} \sim N[0, \sigma_v^2]$ and $u_{n,t} \sim N[\delta, \sigma_u^2] \perp v_{n,t}$.

[14] The 'sfpanel' package for Stata developed by Belotti F., Daidone S., Atella V. and Ilardi G.

The estimates of the multiproduct distance function give the specific on-site TE of each country at a given time and in a defined location. This efficiency, combined with information on location distance for each segment, presents a unique base for comparing overall efficiency of multiple fleet segments and the incurred tradeoffs.

4. Data

The analysis is based on data on harvest (landings) and effective effort given by administrative rectangles[15] for specific year, gear, country and length category, originating from supplementary material for 'The 2013 Annual Economic Report on the EU Fishing Fleet' (STECF 2013).[16] Effective effort is measured as the number of hours trawling. Harvest is divided into three groups reflecting the Baltic Sea species composition and includes: cod (c), pelagic species (p) with herring and sprat, and group of other species (o). The groups are formed by linear aggregation of tons of fresh weight. The dataset used is limited to major European fleets fishing in the area of the Baltic Sea using demersal gear over the period 2004-2012. The study considers DTS sector fleets from Denmark, Germany, Poland and Sweden. These countries account for over 80% of total cod harvest during the period under investigation and therefore are the most important for the analyses, and the DTS sector is the most important for harvesting cod in the Baltic Sea. Each demersal fleet is described by country of origin and length range. The dataset is restricted to five vessel length categories: 8-10m (1), 10-12m (2), 12-18m (3), 18-24m (4) and 24-40m (5). Smaller vessels are excluded as they are less mobile units and highly restricted to coastal areas neighboring the home port. Big trawlers of length over 40m were excluded as very mobile and performing their fishing activity often outside of the Baltic Sea which is our area of focus. The data for length category 1 for 2004 in Germany was not available. Year 2004 was chosen as a starting period, as since then, all countries under investigation are members of the EU and subject to the principle of relative stability in the context of setting TACs.

The spatial distribution of cod harvest, the main target species of the DTS sector, summed over the investigated length categories is presented in figure 2 (as the average of harvest over the investigated period 2004-2012). The observations with exceptionally low reported effort (less than 12 h per year) were excluded as of low importance for the analysis. During the period under investigation, the data was recorded for 102 rectangles with fishing activity of minimum 12h during the year. In total there are 2705 observations with a summary given in table 4.

The distances to the fishing grounds are calculated as the length of a straight line from the middle of the rectangle's offshore area (polygon's centroid) to the nearest feature of the country of origin mainland or island with road connection (bridge). The results are derived in nautical miles with a use of GIS software (QGIS). Within this research framework the possibility of landing the harvest on the islands with only a water-based connection was excluded. However, it is acknowledged that some of the landing occurs on Bornholm and Gotland.

Whereas Swedish Gotland is situated outside of the major cod fishing areas, fish landed on Danish Bornholm, located in the most productive cod fishing areas, may influence the results. However, the

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[15] The exact location of each ICES statistical rectangle can be viewed as interactive map available through ICES Spatial Facility under following address: http://geo.ices.dk/viewer.php?add_layers=ices_ref:ices_rectangles.

[16] Available online: http://stecf.jrc.ec.europa.eu/data-reports.

Danish landing statistics (Ministry of Food, Agriculture and Fisheries of Denmark 2014) suggest decreasing importance of Bornholm ports. The difference in distance is also expected to be reflected in prices, as Bornholm is not the primary place of the final demand and thus most of the processed product has to be transported to the mainland.

Table 4: Summary Statistics for the Data Used

Country of origin	Length category	Observations	Rectangles fished	Effort mean [days]	Harvest of cod mean [t]	Harvest of pelagic species mean [t]	Harvest of other species mean [t]
Denmark	8-10m	77	17	377.88	7.90	0.00	6.74
				(508.41)	(17.07)	(0.00)	(12.15)
	10-12m	160	27	1339.96	46.52	0.15	16.25
				(1475.21)	(80.86)	(1.84)	(22.88)
	12-18m	277	43	4379.39	235.29	256.70	78.06
				(6366.04)	(422.26)	(649.99)	(144.87)
	18-24m	238	42	1611.53	130.64	42.07	28.99
				(2399.03)	(183.39)	(181.59)	(72.17)
	24-40m	201	51	419.30	69.96	86.89	8.83
				(595.17)	(142.99)	(160.88)	(27.63)
Germany	8-10m	25	7	335.80	9.99	0.13	3.51
				(238.01)	(9.09)	(0.45)	(3.63)
	10-12m	112	19	735.46	35.69	60.77	28.38
				(828.09)	(39.07)	(128.77)	(39.40)
	12-18m	136	25	1588.05	111.43	148.82	76.60
				(2362.02)	(181.62)	(246.11)	(133.20)
	18-24m	163	27	991.26	110.85	85.91	45.48
				(1665.71)	(183.70)	(201.23)	(85.68)
	24-40m	162	44	435.16	68.38	117.17	11.50
				(725.19)	(102.30)	(312.58)	(25.29)
Poland	8-10m	45	9	1474.47	5.91	30.11	14.66
				(3280.58)	(10.73)	(74.69)	(24.51)
	10-12m	70	16	667.94	25.62	10.52	40.02
				(850.09)	(45.51)	(33.37)	(61.49)
	12-18m	159	23	3538.07	138.05	40.62	162.80
				(4860.05)	(197.75)	(101.36)	(311.15)
	18-24m	152	22	2193.49	95.04	37.45	66.96
				(3605.90)	(161.10)	(105.76)	(102.28)
	24-40m	159	31	2639.49	110.41	42.55	121.93
				(5280.47)	(183.69)	(101.02)	(250.34)
Sweden	8-10m	21	3	187.48	0.00	4.36	0.01
				(106.27)	(0.00)	(4.82)	(0.02)
	10-12m	79	18	403.70	0.80	33.55	0.09
				(445.83)	(3.58)	(49.04)	(0.25)
	12-18m	188	46	345.81	32.87	233.44	0.83
				(491.19)	(109.56)	(489.28)	(3.19)
	18-24m	167	40	462.16	101.70	329.32	1.43
				(616.46)	(249.97)	(554.70)	(4.24)
	24-40m	114	36	277.11	69.08	271.91	0.67
				(338.19)	(149.99)	(412.77)	(1.99)

Note: Standard deviations in parentheses.

5. Results

5.1. Distance function estimates

The estimation is performed over panels with observations for the DTS sector specified by country, administrative rectangle and time, separately for each length category. Due to lack of more detailed data on capital, there is no possibility to compare directly métiers of different sizes. Therefore the comparison will be relevant only within each length category and the production technology that is common for such a group is estimated (Vestergaard et al. 2003). For the purpose of estimation, data have been scaled through dividing each parameter by sample mean prior to estimation (Coelli and Perelman 2000). The results of the distance function estimation, together with robust standard errors adjusted for clusters on country and area, are presented in table 5.

The majority of coefficients are statistically significant indicating good fit of the proposed model for each length category. Additionally, an alternative structure of the model in the form of the Cobb-Douglas function was tested and rejected for each length category. All first-order terms have expected negative signs. The first-order output coefficients, with exception of the category including the biggest vessels, sum to an absolute value smaller than one, indicating increasing returns to scale. The opposite, decreasing returns to scale, are found for vessels between 24 and 40m. The coefficient α_t in each length category is significant and indicates a common positive time trend. In general, it shows increasing production at the same level of input over time. The ratio of σ_u to σ_v exceeded a value of one and was statistically different from zero at 1% level of significance for each length category. This suggests the existence of a stochastic frontier function and that the deviations from the frontier are dominated by input inefficiencies. The model inefficiency levels suggest a higher degree of heterogeneity between small vessels.

Table 5: Estimated Parameters of the Distance Functions

	Len1: 8-10 m			Len2: 10-12 m			Len3: 12-18 m			Len4: 18-24 m			Len5:24-40 m		
Coefficient	Value	SE		Value	SE		Value	SE		Value	SE		Value	SE	
α_c	-0.327	0.108	***	-0.358	0.097	***	-0.405	0.087	***	-0.441	0.054	***	-0.515	0.077	***
α_p	-0.245	0.115	**	-0.004	0.069		-0.196	0.072	***	-0.185	0.043	***	-0.259	0.053	***
α_o	-0.197	0.170		-0.281	0.063	***	-0.299	0.071	***	-0.198	0.037	***	-0.353	0.044	***
α_{cc}	-0.120	0.029	***	-0.124	0.024	***	-0.114	0.024	***	-0.095	0.014	***	-0.096	0.015	***
α_{cp}	0.016	0.012		0.022	0.012	*	0.015	0.011		0.022	0.006	***	0.016	0.007	**
α_{co}	0.045	0.022	**	0.048	0.018	***	0.052	0.018	***	0.047	0.007	***	0.029	0.009	***
α_{pp}	-0.035	0.027		0.007	0.021		-0.051	0.023	**	-0.045	0.013	***	-0.057	0.015	***
α_{po}	0.030	0.022		0.026	0.010	***	0.028	0.012	**	0.024	0.004	***	0.006	0.007	
α_{oo}	-0.061	0.027	**	-0.076	0.030	***	-0.072	0.016	***	-0.069	0.009	***	-0.076	0.011	***
α_t	0.049	0.023	**	0.045	0.016	***	0.069	0.014	***	0.092	0.012	***	0.082	0.014	***
α_0	-0.029	0.268		0.455	0.336		-0.112	0.146		-0.372	0.138	*	-0.305	0.158	*
σ_u	5.180	1.994	***	1.053	0.466	**	4.257	2.023	*	2.576	4.115		3.493	0.677	***
σ_v	0.467	0.098	***	0.497	0.141	***	0.686	0.135	***	0.566	0.046	***	0.585	0.047	***
Estimated inefficiencies $\widehat{u_{n,r,t}}$															
Mean	0.573			0.915			0.489			0.343			0.404		
SD	0.495			0.550			0.326			0.193			0.259		
Min	0.119			0.147			0.105			0.097			0.093		
Max	3.186			3.081			2.647			1.517			2.461		
Log-likelihood	-178.14			-512.99			-939.72			-717.59			-1175.37		

Note: Significance levels: *** 1%, ** 5% and * 10%.

5.2. Efficiency on-site comparison

The technical efficiency estimates in form of mean and standard deviation are reported at national level for each length category in table 6. The overall TE for a given fleet segment is formed by weighting site specific values with associated effort. Thus, the final TE measure incorporates the effect of fishing ground choice.

Among analyzed countries Germany is the most efficient, except being closely behind Poland in length category 2. The least efficient fleet belongs to Sweden looking at units below 18 m, and to Poland considering the fleet consisting of larger vessels. The biggest differences are observed among small vessels (length category 2), where the best score, for Poland, is over 60% higher compared to Sweden, the last in the group. The differences between TEs fade away with increasing size of the vessel. The smallest efficiency asymmetries are observed among the largest vessel group where the most efficient, Germany, is only about 20% ahead of Poland which is closing the group. The biggest vessels are also characterized by the smallest variation of efficiency within the group, again suggesting that the small vessels are considerably more heterogeneous.

Table 6: Efficiency Estimates: Mean (M), Standard Deviation (SD) and Efficiency Weighted (EW).

	Len1: 8-10m			Len2: 10-12m			Len3: 12-18m			Len4: 18-24m			Len5:24-40m		
Country	M	SD	EW	M	SD	EW	M	SD	EW	M	SD	EW	M	SD	EW
Denmark	0.60	0.15	0.53	0.34	0.15	0.32	0.62	0.11	0.62	0.70	0.12	0.67	0.67	0.14	0.63
Germany	0.65	0.10	0.62	0.56	0.11	0.50	0.72	0.07	0.71	0.78	0.06	0.77	0.75	0.08	0.71
Poland	0.65	0.23	0.47	0.60	0.15	0.52	0.64	0.11	0.60	0.67	0.13	0.56	0.63	0.14	0.57
Sweden	0.53	0.25	0.44	0.40	0.24	0.19	0.61	0.21	0.53	0.75	0.10	0.75	0.70	0.12	0.65

Note: Efficiency Weighted (EW) using effort as weighting factor.

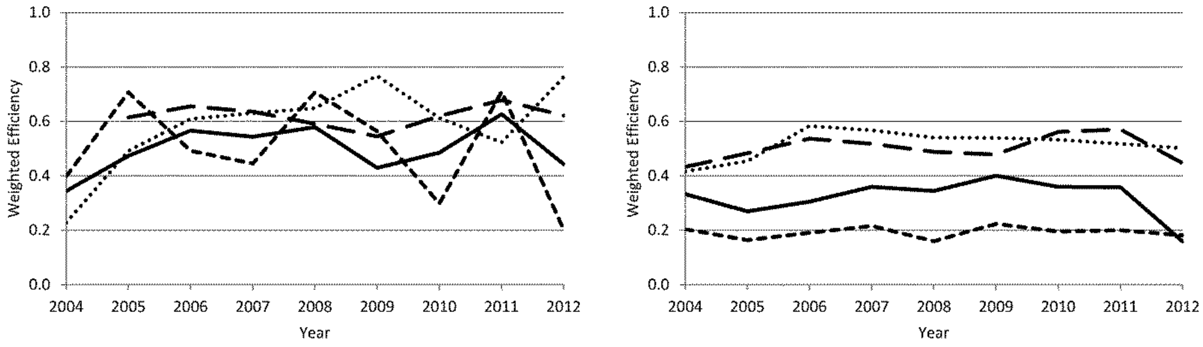
5.3. Changes over time

The model results suggest a negative time trend for effort requirement in the investigated part of the European fishing industry. The most probable explanation is the combination of technological progress in European fisheries, less competition in the sector, decreasing size of the EU fleets and improving cod stock condition (from 2005). The biggest increase in efficiency is observed among vessels over 18m.

Disregarding the common time trend and looking at individual country changes over time (figure 4, specific values in table A1), the fleet below 10m presents considerably more variation over years compared to bigger vessels. The simple explanation may be that the small scale fleet lacks capacity for fast adaptation to variation of external factors. This is in line with conclusions of other authors, who have found that mobile fleets adjust faster to catch per unit of effort compared to small-scale, sedentary fleets fishing in close proximity to the home port (Hilborn and Ledbetter 1979).

The biggest differences between nations can be observed in length category 2, in which, in contrast to length category 1, the technical efficiencies stay at similar levels over years. Regarding length category three and over, one interesting feature is a substantial drop of efficiency in 2012 within Danish vessels, which is a big contributor to lower overall efficiency of this country. One probable reason behind is the decrease of total landings in 2012 compared to 2011 by 31% along with an effort drop of only 3%. The major factor causing it was a decrease by about 80% in the sandeel quota which is an important species for the Danish industrial fisheries, as well as a significant drop in the harvest of other pelagic species, sprat (64% drop) and herring (20% drop) (STECF 2013; ICES 2013).

The harvest of demersal and pelagic species is interconnected, as they are often targeted by the same vessels, i.e. vessels in the DTS sector have the option to allocate some of their effort to pelagic harvest through flexible gear changes (Hutniczak 2014). It is expected that this fact contributed to demersal segment performance whereas the available data is not sufficient predict the future trend with respect to this fleet. One can also notice a temporary peak for Polish vessels in length category 3-5 during the period 2009-2011. That could be explained by higher on average individual vessel quotas and less competition due to restricting access to the fishery as a consequence of the EU's punishment for overfishing cod in earlier years (Regulation 1497/2008). Furthermore, the landing volumes for earlier years are probably underestimated due to problems with illegal landings and misreporting (ICES 2013). Moreover, the visible increasing trend in the efficiency of Polish vessels above 12 m can be a result of the major fleet restructuring process that is outrunning other countries.

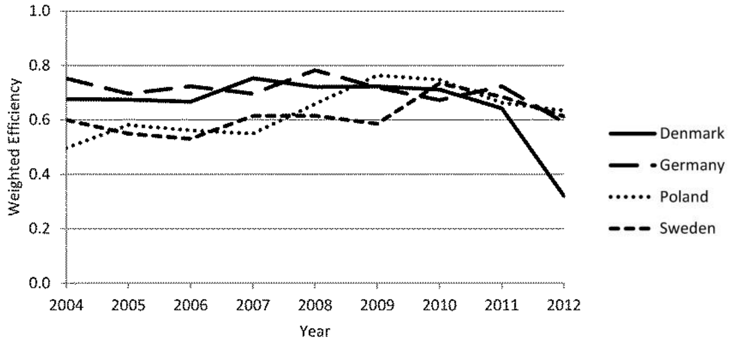


2.a: Length 1: 8-10m.

2.b: Length 2: 10-12m.

2.c: Length 3: 12-18m.

2.d: Length 4: 18-24m.



2.e: Length 5: 24-40m.

Figure 4: Efficiency estimates by year, weighted by effort, presented graphically.

5.4. Spatial consideration

The model presents significant differences in on-site TE depending on the choice of fishing ground. The specific results compiled with distances for the most important cod fishing grounds are presented in the appendix (table A2). The efficiencies were calculated as weighted with effort average over the period 2004-2012.[17]

There is a big overlap between countries with respect to fishing ground choice for the bigger vessels. Considering top rectangles, bigger vessels (over 12 m) from all countries share the most productive fishing grounds. In particular, the largest vessels are observed to be fishing the same few rectangles. In the case of length category 5, 88% of cod is harvested in merely 12 rectangles. Harvest by small vessels is much more spread, showing the limitations in location choice. This fact is most visible in length category 1, but also noticeable for category 2. This conclusion is in line with findings by other authors that suggest vessel size significantly influences trip choice behavior (Pradhan and Leung 2004).

The tradeoffs between on-site efficiency and distance to the fishing ground is evaluated by comparing weighted TE and distances for the whole fishing activity with the equivalent parameters for the most efficiently utilized effort and the area with the most effort applied. The results for 2011 are presented in table 7. Year 2011 was chosen as the most recent after eliminating 2012 due to results for Denmark outside of general trend.[18] The table shows that in many cases the tradeoffs are well established and the majority of effort is often utilized in the areas of closer proximity to home country, even despite the lower on-site efficiency. Potential for TE improvement by better location choice can be observed in column denoted by 'Top 10%'. Here the results are derived for the 10% of effort utilized at the highest efficiency level. Although in a few cases it would require significant increase of distances, there are many instances in which the potential for improvement, both from the perspective of on-site TE and distance, is noticeable. In relation to weighted distance, that includes: Denmark in category one; whole category two; Denmark and Germany in category three; Poland in category four; and category five with exclusion of Germany. Thus, better management, defined here as more optimal site choice, gives a potential for higher input efficiency.

Table 7: Technical Efficiency and Distance Tradeoffs in 2011.

	Weighted Average		Max Effort		Top 10%	
	TE	Distance	TE	Distance	TE	Distance
Length category 1: 8-10 m						
Denmark	0.63	40.6	0.67	98.5(1)	0.77	11.2
Germany	0.68	4.7	0.67	2.2	0.71	12.4
Poland	0.52	3.2	0.65	1.3	0.70	3.6
Sweden	0.71	6.9	0.71	6.9	0.71	6.9
Length category 2: 10-12 m						
Denmark	0.36	45.7	0.46	98.5(2)	0.53	6.1
Germany	0.57	13	0.59	5.7	0.67	12.9

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[17] No significant differences over years when it comes to choice of harvest grounds by each length category were observed, whereas the time trend was excluded.

[18] Despite the arguments explaining the low efficiency scores for Denmark in 2012, due to unsufficient data it cannot be established whether the situation has a temporary or permanent character. On contrary, the data for 2011 fits into consistent trend.

Poland	0.52	17.3	0.29	1.3	0.71	14.7
Sweden	0.20	8.6	0.11	7	0.50	2.9
Length category 3: 12-18 m						
Denmark	0.66	47.8	0.70	98.5(3)	0.70	35.6
Germany	0.71	16.4	0.71	9.6	0.76	16.1
Poland	0.69	19.4	0.70	9.9	0.76	24.1
Sweden	0.58	18.5	0.66	13.3	0.89	91
Length category 4: 18-24 m						
Denmark	0.66	84.5	0.55	103.3(4)	0.77	103.8
Germany	0.77	27.3	0.76	9.6	0.81	60.6
Poland	0.75	18.5	0.74	3.6	0.81	15.1
Sweden	0.78	34	0.76	13.3	0.82	76
Length category 5: 24-40 m						
Denmark	0.64	131.1	0.61	132.1(5)	0.76	73
Germany	0.72	53.5	0.72	5.7	0.79	102.6
Poland	0.66	27.4	0.70	28.6	0.77	21.6
Sweden	0.68	41.7	0.72	13.3	0.76	39.9

Note: Distance in nautical miles. Max Effort indicates score for the area where the most effort was applied. Top 10% indicates 10% share of effort utilized at the highest levels of efficiency.

(1) The distance for Bornholm rectangle. The scores for the next in line that is not in the area of Bornholm are as follows: TE=0.66, Distance=2.2.

(2) The distance for Bornholm rectangle. The scores for the next in line that is not in the area of Bornholm are as follows: TE=0.53, Distance=6.1.

(3) The distance for Bornholm rectangle. The scores for the next in line that is not in the area of Bornholm are as follows: TE=0.67, Distance=6.1.

(4) The distance for Bornholm rectangle. The scores for the next in line that is not in the area of Bornholm are as follows: TE=0.66, Distance=12.8.

(5) The sector is almost exclusively fishing in the distant to the mainland waters.

6. Concluding remarks

The article addresses a potential shortcoming of the vast literature on fishery resource exploitation, namely the assumption about the uniformly distributed effort (Smith & Wilen, 2003). The modeling system takes advantage of a richer data set and incorporates spatial and intertemporal dimensions. These exhibited features build into general efficiency that can be compared between countries. The study moves away from the obsolete views that treat fish populations as spatially uniform or the state of technology over time as constant (Smith, et al., 2009). The paper compares multiple fleet segments taking into account different accessibility of the most productive fishing grounds, the state of current technological progress, efforts undertaken in the fleet restructuring process, and advantages created by applied management systems.

The major argument for different levels of technical efficiency that comes to mind is uneven access to the most productive fishing grounds. However, the equal access principle in the European Union gives all member states the same right to fish in the whole Baltic Sea.[19] Hence, there is no legal discrimination of vessels regarding access to fishing grounds. The article shows that vessels of length over 12 m (and partially vessels of length 10-12 m) take full advantage of this fact and conduct their activity in the same areas. The lack of technical limitations (capital feasibility) cause strong spatial overlap of fishing grounds. The advantages of fishing in particular areas are shown by derived area-specific TEs that present considerable asymmetries. On the other hand, for smaller vessels it is more risky, costly or even unfeasible, to go all the way to the main cod fishing areas and thus the harvest activity is more localized. Thus, tradeoffs between on-site efficiency and travelled distance, especially

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[19] Except for the 12 nautical mile zone. In these zones bilateral agreements define access rights.

in the case of bigger vessels, are necessary to be considered when comparing efficiencies of European fleets' with respect to utilization of national TACs.

The paper investigates the travelled distances to the fishing grounds in comparison with on-site efficiencies specified for given area per length category. This can be considered second order frontiers of the industry with two inputs, effective effort and travel effort. The smallest vessels (category 1) travel mostly up to 20 nm (on average 5-10 nm, depending on country) and are not able to reach the most productive fishing grounds.[20] The landings of this category are also not substantially contributing to the total Baltic Sea production of cod. Considering TE, the results for the smallest vessels show high variability which means vulnerability to local variations of fishing conditions, i.e. changes in the distribution of fish. Thus, it is difficult to draw specific conclusions besides the high sensitivity of this fleet sector to surrounding circumstances. Considering quota exchanges within this group, the high responsiveness to surrounding conditions suggest that short-term quota leases might be efficiency improving. They would allow the more flexible participants to take an advantage of favorable conditions.

Certainly a different situation occurs in the case of bigger vessels (category 2 only partially). These can travel longer distances (more than 100 nm, up to 200 nm) and are more flexible in their choice of fishing site. Their fishing activities overlap and are concentrated in the most productive South part of the Baltic Sea, around the island of Bornholm. Given that those vessels fish in the same area, the differences in TE are expected be more likely resulting from differences in the structure and the utilization of the national fleets.[21] Fisheries management is also an important factor in this context as national implementation of CFP varies between countries. This holds especially for the way in which the TAC is allocated between resource users.

The differences between estimated TEs among bigger vessels are more visible and allow comparison as the levels are rather stable. Based on the model results the following conclusion can be made. The stage of the fleet restructuring process seems to have the highest impact on the on-site catch efficiencies of the single fleet segments. If the restructuring process is in an advanced stage (as e.g. in Germany or Denmark) and the capacity utilization high, the catch efficiencies are higher. On the other hand, a country still undergoing major structural changes and struggling with overcapacity is reflected in a low level of catch efficiency (as e.g. in Poland), which does however give the potential of faster improvement. The outstanding result for Poland (vessels over 12 m, especially category 4) showing faster improvement than other countries suggests an increase in performance over last years. That can be explained again by the big restructuring process in the Polish fleet – between 2004 and 2011 almost 500 vessels were removed. The use of tradable quotas seems to be improving efficiency (as e.g. in Denmark), although it is expected that its main contribution is in supporting the restructuring process. A flexible quota system that allows quota swapping (i.e. ITQs) is expected to have a positive impact on the catch efficiency through incentives given to less efficient vessels to leave the market by selling their quota shares and thus increasing the catch efficiency of the sector. However, the differences in TE have faded away in recent years, implying that the fleets in the DTS sector in the Baltic Sea are becoming more competitive.

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[20] The exceptionally high distances for Denmark within category 1 accounts for the harvest located in rectangle directly bordering the island of Bornholm. This part of harvest is, most probably locally landed in Bornholm.

[21] The effects of restructuring process, here meaning the adjustment of the fleets to requirements of the EU.

Moreover, the article findings suggest that efficiency can be improved by the optimal choice of fishing grounds. The results show significant differences in TE between harvest areas which are often not well utilized. In many instances the overall efficiency would increase by changing effort allocation patterns, not necessary at the cost of further distances. Moreover, being situated closer to the productive grounds is shown to be beneficial. Countries like Poland and Germany take advantage of it. This fact is expected to influence the potential direction of international quota flow.

Concluding, the asymmetries in on-site efficiencies combined with evaluated location advantages are expected to be crucial when evaluating the benefits of the potential international flow of quotas. Allowing quota trade between the countries could diminish the discrepancies in efficiency and simultaneously increase the overall efficiency. Following economic principles, such a system would set incentives for the less efficient vessels to sell their shares while the more efficient vessels enlarge their harvest by buying additional quotas, and contribute to overall efficiency by moving it closer to the established technological frontier. Better spatial management and benefits associated with optimal fishing ground choice in the context of the advantage of being located closer to generally more productive grounds could be utilized as well. Such a system would show in practice the true distance vs. on-site capital utilization tradeoff. This kind of trans-border management is also in line with the current CFP, whose latest reform promotes the idea of regionalization of the fishing management (EU 1380/2013). The aim is to re-allocate responsibility from the EU level and allow the member states to freely coordinate their activities as long as the overall goals of the CFP are taken into account.

Nevertheless, the social concerns associated with applying pure economic principle (Kjærsgaard 2010), e.g. lack of fairly distributed benefits from common pool resource, may be hard to overcome. Such a state also may not be desirable to individual countries. Thus, the impact of other factors influencing national levels of efficiency is highlighted here, which can be considered as guidance with respect to efficiency improvement best practices.

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Appendix

Table A1: Efficiency Estimates by Year, Weighted by Effort.

Country	2004	2005	2006	2007	2008	2009	2010	2011	2012
Length category 1: 8-10 m									
Denmark	0.345	0.473	0.567	0.543	0.579	0.429	0.485	0.627	0.443
Germany	*	0.614	0.655	0.636	0.591	0.545	0.620	0.678	0.622
Poland	0.228	0.491	0.609	0.631	0.648	0.768	0.612	0.523	0.763
Sweden	0.399	0.707	0.492	0.445	0.707	0.564	0.298	0.709	0.203
Length category 2: 10-12 m									
Denmark	0.333	0.270	0.306	0.360	0.344	0.400	0.360	0.358	0.159
Germany	0.433	0.483	0.537	0.518	0.488	0.478	0.562	0.571	0.447
Poland	0.416	0.454	0.584	0.568	0.541	0.540	0.533	0.518	0.502
Sweden	0.204	0.163	0.191	0.216	0.160	0.224	0.195	0.200	0.182
Length category 3: 12-18 m									
Denmark	0.643	0.614	0.640	0.661	0.634	0.625	0.641	0.656	0.466
Germany	0.691	0.719	0.751	0.727	0.715	0.715	0.701	0.708	0.653
Poland	0.506	0.560	0.561	0.576	0.640	0.680	0.722	0.688	0.655
Sweden	0.473	0.471	0.501	0.502	0.466	0.461	0.592	0.579	0.561
Length category 4: 18-24 m									
Denmark	0.703	0.690	0.712	0.732	0.698	0.681	0.688	0.662	0.310
Germany	0.777	0.767	0.806	0.782	0.794	0.770	0.774	0.774	0.689
Poland	0.454	0.546	0.506	0.521	0.653	0.713	0.724	0.747	0.695
Sweden	0.716	0.677	0.695	0.694	0.650	0.674	0.790	0.779	0.781
Length category 5:24-40 m									
Denmark	0.677	0.675	0.667	0.753	0.722	0.723	0.711	0.643	0.321
Germany	0.752	0.696	0.723	0.696	0.783	0.719	0.673	0.723	0.592
Poland	0.497	0.581	0.561	0.549	0.658	0.763	0.748	0.663	0.635
Sweden	0.599	0.550	0.530	0.615	0.615	0.586	0.734	0.685	0.613

Note: * indicates missing data.

Table A2: Efficiency Scores and Distances for the Baltic Sea Rectangles with the High Cod Harvest

Rectangle	Sum of cod harvest	Share within length category	Efficiency Denmark	Distance Denmark	Efficiency Germany	Distance Germany	Efficiency Poland	Distance Poland	Efficiency Sweden	Distance Sweden
Length category 1: 8-10m										
39G5(2)	182	0.16	0.70	98.5	*	*	0.66	55.7	*	*
38G0	145	0.13	0.56	6.1	0.86	16.2	*	*	*	*
37G2(1)	125	0.11	*	*	0.62	2.2	*	*	*	*
37G1	119	0.11	*	*	0.63	9.6	*	*	*	*
37G5(1)	102	0.09	*	*	*	*	0.80	9.9	*	*
Length category 2: 10-12m										
39G5(2)	2827	0.21	0.41	98.5	0.58	75.4	0.70	55.7	*	*
38G5(2)	1591	0.12	0.25	103.3	0.60	64.4	0.69	33.0	*	*
39G4(2)	1505	0.11	0.48	66.5	0.55	49.9	0.49	70.8	0.61	14.3
38G4(2)	1193	0.09	0.30	69.1	0.61	30.7	0.63	44.0	*	*
38G3	1148	0.09	0.22	35.4	0.40	5.7	0.56	56.3	*	*
38G0	1046	0.08	0.36	6.1	0.53	16.2	*	*	*	*
Length category 3: 12-18m										
39G5(2)	17029	0.16	0.68	98.5	0.75	75.4	0.68	55.7	0.65	42.4

38G5(2)	13349	0.12	0.60	103.3	0.69	64.4	0.70	33.0	0.65	59.0
39G4(2)	9915	0.09	0.69	66.5	0.66	49.9	0.62	70.8	0.72	14.3
38G0	9767	0.09	0.64	6.1	0.77	16.2	*	*	*	*
38G2	6091	0.06	0.65	12.8	0.73	14.9	*	*	*	*
37G1	5872	0.05	0.66	19.7	0.70	9.6	*	*	*	*
38G4(2)	5762	0.05	0.63	69.1	0.69	30.7	0.69	44.0	0.75	39.6
38G3	4817	0.04	0.65	35.4	0.72	5.7	0.66	56.3	0.70	34.7
38G8(1)	4277	0.04	*	*	*	*	0.46	3.6	*	*
39G7	4267	0.04	0.51	166.0	*	*	0.65	28.6	0.74	68.0
40G4(1)	3065	0.03	0.67	67.0	*	*	*	*	0.68	13.3
39G0(1)	2239	0.02	0.58	5.2	0.71	35.4	*	*	*	*
37G5(1)	2232	0.02	0.70	108.2	0.60	49.8	0.66	9.9	0.80	76.8
41G2(1)	2085	0.02	0.61	10.7	*	*	*	*	*	*
39G8	1999	0.02	0.64	199.9	*	*	0.48	25.7	0.70	90.6
39G2(1)	1789	0.02	0.65	6.0	*	*	*	*	*	*
39G3(1)	1787	0.02	0.62	35.9	0.74	30.9	0.73	80.2	0.74	10.1
39G6	1345	0.01	0.55	132.1	0.64	106.1	0.54	39.8	0.74	55.0
38G1(1)	1242	0.01	0.65	5.1	0.80	15.6	*	*	*	*
40G5(1)	1181	0.01	0.64	96.2	0.84	95.0	*	*	0.66	22.8
38G9(1)	1060	0.01	0.72	239.2	0.77	191.0	0.47	18.5	*	*
Length category 4: 18-24m										
39G5(2)	9963	0.12	0.70	98.5	0.79	75.4	0.67	55.7	0.81	42.4
39G7	8160	0.10	0.62	166.0	0.73	138.6	0.63	28.6	0.82	68.0
37G1	6954	0.09	0.71	19.7	0.77	9.6	*	*	*	*
39G8	6507	0.08	0.71	199.9	0.77	169.0	0.42	25.7	0.81	90.6
38G5(2)	5816	0.07	0.62	103.3	0.80	64.4	0.71	33.0	0.81	59.0
38G2	4909	0.06	0.60	12.8	0.79	14.9	*	*	*	*
39G6	4696	0.06	0.64	132.1	0.80	106.1	0.61	39.8	0.81	55.0
38G3	4638	0.06	0.69	35.4	0.77	5.7	*	*	0.82	34.7
38G4(2)	3706	0.05	0.68	69.1	0.74	30.7	0.74	44.0	0.78	39.6
39G4(2)	3595	0.04	0.71	66.5	0.75	49.9	0.62	70.8	0.79	14.3
38G8(1)	3009	0.04	0.72	209.6	*	*	0.55	3.6	*	*
40G5(1)	2489	0.03	0.74	96.2	0.82	95.0	*	*	0.78	22.8
38G0	2256	0.03	0.67	6.1	0.79	16.2	*	*	*	*
41G2(1)	1926	0.02	0.72	10.7	*	*	*	*	0.84	2.8
39G3(1)	1825	0.02	0.73	35.9	0.78	30.9	0.79	80.2	0.78	10.1
40G6(1)	1489	0.02	0.65	130.0	0.77	120.5	*	*	0.76	27.0
37G2(1)	1307	0.02	0.62	17.2	0.79	2.2	*	*	*	*
40G8(1)	1225	0.02	0.73	197.8	0.81	180.6	0.41	55.4	0.82	74.2
40G4(1)	1188	0.01	0.83	67.0	0.83	76.4	*	*	0.76	13.3
Length category 5: 24-40m										
39G8	8675	0.17	0.67	199.9	0.78	169.0	0.43	25.7	0.73	90.6
39G5(2)	6185	0.12	0.62	98.5	0.71	75.4	0.64	55.7	0.73	42.4
39G6	6094	0.12	0.58	132.1	0.76	106.1	0.65	39.8	0.73	55.0
39G7	6024	0.12	0.57	166.0	0.77	138.6	0.65	28.6	0.73	68.0
38G5(2)	3953	0.08	0.48	103.3	0.74	64.4	0.75	33.0	0.76	59.0
38G4(2)	3612	0.07	0.69	69.1	0.63	30.7	0.72	44.0	0.69	39.6
38G3	2483	0.05	0.71	35.4	0.74	5.7	0.72	56.3	0.76	34.7
38G8(1)	1963	0.04	0.72	209.6	*	*	0.50	3.6	0.85	113.2
40G6(1)	1760	0.03	0.68	130.0	0.72	120.5	0.70	66.5	0.77	27.0
40G8(1)	1646	0.03	0.57	197.8	0.70	180.6	0.30	55.4	0.79	74.2
39G4(2)	1446	0.03	0.71	66.5	0.76	49.9	0.46	70.8	0.73	14.3
39G3(1)	1099	0.02	0.71	35.9	0.75	30.9	0.52	80.2	0.73	10.1

Note: The rectangles with high cod harvest are defined as administrative areas where cod harvest was over 1000t within length category and minimum 100t for length category 1 over the investigated period. * indicate no harvest activity in given rectangle within the length category.

(1) indicates rectangles that are not top cod harvest locations (less than 10000t in total for all length categories over the investigated period).

(2) indicates rectangles surrounding the island of Bornholm.

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ISSN 1459-9996
Helsinki 2015