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The Gains of Cooperation in a Fishery Duopoly

- The Namibian and South African Deep Water Hake Fishery

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Abstract

This study evaluates the potential gains of cooperation between South Africa and Namibia in the resource management of the valuable transboundary deep-water hake fish stock. Values of cooperation can be investigated by developing a theoretical model of strategic decisions when two countries manage the stock as shared and act interdependently when maximising profits within their Exclusive Economic Zone, and in terms of regional cooperation with joint management. By combining the game strategic Cournot model with the Gordon Schaefer bio-economic model, this study compares duopoly steady state equilibriums in the case of symmetric countries with the equilibrium solutions of a Sole Owner, the overall Stackelberg duopoly and Open Access. A numerical model is calibrated using observed values of the historic stock abundance and harvest, and available estimations of the costs and efforts in the period 2007-2015. The approach to evaluate the potential values of cooperation in a fishery duopoly is performed by 1) moving from a current scenario to a Cournot duopoly and 2) moving from a Cournot duopoly to regional cooperation. In assuming that we are initially in steady state, the study investigates the equilibrium effects of 1) an increase in costs and 2) an increase in catchability. The alternative Stackelberg duopoly when countries differ in harvest and efforts will be studied briefly. Finally, the asymmetric Cournot is explored further by looking at equilibrium effects of cases when countries differ in costs and catchability.

The findings in this paper suggest that there are potential gains of cooperation both in terms of cooperating in stock research and managing the stock as shared (Cournot), and in terms of active regional management (Sole Owner), when the numerical model is calibrated using the natural carrying capacity of the deep water hake stock as observed before any exploitation took place (1917 levels).

Contents

1 The Benguela Deep Water Hake Fishery

The Benguela Current Large Marine Ecosystem is a coastal upwelling ecosystem flowing north from the east of the Cape of Good Hope in South Africa, covering the entire Namibian coast and southern Angola (BCC 2011). The Benguela region's most valuable fish stock is the combined fishery of the shallow-water hake (Merluccius Capensis) and the deep-water hake (Merluccius Paradoxus) (OECD 2012, Lallemand, Bergh et al. 2016, Strømme, Lipinski et al. 2016). The hake fisheries are currently worth USD 570 millions in Namibia and South Africa.

Today, despite differences in prices and biological patterns, Namibia and South Africa manage the two species as one single stock in their national stock management. Although fisheries in Namibia and South Africa do not distinguish between the two species in their catches, both fisheries target the deep-water hake as it gives better price and is easier to handle for filleting (T. Strømme, personal comm., April 4, 2016). Moreover, South Africa and Namibia manage the combined stock as unshared between the countries, implying that they perform individual assessments of the stock within their Economic Exclusive Zone (EEZ).

While the shallow-water hake is believed to be unshared, there is a common belief in the scientific community that the deep-water hake is in fact shared, and should be managed according to its transboundary character. Although a move towards scientific cooperation in stock research has been made in recent years, there is no current regional cooperation of the management of the transboundary resource. Despite the fact that current fishery management may hinder the sustainability of the fishery biodiversity (Paterson and Kainge 2014), joint management has been argued to be premature until there is sufficiently strong evidence that the deep-water hake is, in fact, transboundary (Smith and Japp 2014). The lack of stock surveys confirming the transboundary character of the deep-water has thus hindered the development of a shared stock management (Strømme, Lipinski et al. 2016).

Given the transboundary character of the deep water hake and its economical importance, it is interesting to look closer at the potential gains of a shared stock management in which the two countries take each others actions into account, and moreover to investigate the value of a regional cooperation in which both countries agree upon the objectives of the fishery and split the returns.

The aim of this thesis is to evaluate potential gains of cooperation between South Africa and Namibia in the resource management of the transboundary deep water hake fish stock. Potential values of cooperation can be investigated by developing a theoretical model of strategic decisions when two countries act interdependently and in regional cooperation. In order to apply the theoretical approach, a numerical model can be calibrated using available data on observed values in the deep-water hake fishery.

Literature in fishery economics state that there are at least two levels of cooperation when dealing with transboundary resources (Gulland 1980, Munro 2002). The first level consists of cooperation in scientific research. This study will address this primary level of cooperation as a Cournot duopoly, in which the two countries introduce cooperation in stock assessments and manage the stock as a shared in their national management. Each country is assumed maximise the return of the fishery within their Exclusive Economic Zone (EEZ), by using their strategic choices of efforts to set the quantity of harvest.

Secondary cooperation, in terms of actively coordinated management regimes, is assumed to be successful only if the primary level of research cooperation is in place (Munro 2002). This level of cooperation will be modelled as regional cooperation and Sole Owner harvesting. In this scenario, the two countries act in joint management and maximise the economic rent of the overall deep-water hake fishery, agreeing on the objectives of the fishery and splitting the costs equally.

Commercial fishing industry is commonly separated into large scale (industrial) fishing and small-scale (artisanal) fishing. Resulting from the world fisheries being open to all, ocean resources have through history been threatened by overexploitation of fisheries - hindering the development of coastal nation’s fishing industry (Bjørndal and Munro 2012). It is therefore interesting to look closer at potential economic and biological benefits arising from the introduction of property rights through Exclusive Economic Zones (EEZ). In light of the deep-water hake resource in the Benguela – region, the research questions in this thesis are:

- Are there potential gains in profits of moving from the current management regime to a scenario where countries act interdependently and treat the deep -water hake as a shared and transboundary resource?
- Are there potential values of moving from a scenario in which the countries treat the hake stock as shared and maximize their profits individually, to a scenario of regional cooperation?

The theoretical approach to evaluate the potential value of cooperation in a fishery duopoly can therefore be done by 1) moving from a current scenario to a Cournot duopoly and 2) moving from a Cournot Duopoly to regional cooperation. The solutions of a Stackelberg duopoly and Open Access regulation will be discussed in comparison, although the emphasis is on the simultaneous Cournot as we assume that none of the countries has a first mover advantage and they are both quite similar in character. Moreover, the Cournot equilibrium will be further explored by looking at cases in which the countries differ in costs and catchability. Attention will be paid to the effects of an increase in costs or catchability on the four equilibrium solutions in the case of symmetric countries, followed by an analysis of the equilibrium effects in the Cournot duopoly when the countries differ such that one country becomes more efficient or more costly than the other.

Finally, a numerical model is calibrated using observed values of stock, harvest, costs and efforts. Following the steps of the theoretical discussion, the numerical findings will be compared to get an insight in whether there are potential gains of cooperation.

2 The South African and Namibian Fishery

The establishment of the intergovernmental Benguela Current Commission (BCC) may be seen as a progress towards cooperative management facilitating transboundary research. The BCC was first established as an interim agreement in January 2007, and later recognized as a permanent intergovernmental organization upon the signing of the Benguela Current Convention on 18th March 2013. The Convention is a formal treaty between Angola, Namibia and South Africa intending to promote and coordinate regional use of the marine resources Benguela-region.

In order to clarify the transboundary character of the deep-water hake, the Benguela Current Commission (BCC) has directed its research and requested field investigations towards this issue (Strømme, Lipinski et al. 2016). Among these studies, Armstrong and Sumaila (2004), demonstrated the potential losses due to non-cooperation between Namibia and South Africa when the hake stocks are treated as one stock and unshared (Armstrong and Sumaila 2004).

Notably, a recent study by Strømme, Lipinski and Kainge (2015) challenged the traditional view of the deep-water hake. In their study, requested by the BCC and funded by the Norwegian Nansen Programme, they collected findings from research surveys made by R/V

Dr Fridtjof Nansen in South Africa and F/V Blue Sea 1 in Namibia over a 9-year time period. Their finding is that the deep-water hake is, in fact, transboundary (Strømme, Lipinski et al. 2016).

2. 1 The Economic Importance of the Fishery

Namibia and South Africa are price takers. Revenues of the industry depend on the stock of natural capital, the harvest, international prices and the exchange rate. Fishing costs are driven by catch rates, fuel prices and wage rates (Kirchner, Kainge et al. 2012, Lallemand, Bergh et al. 2016). Globally, Spain and Chile are the biggest gross exporters of hake. Their exports are however linked to the stock status of other producing countries like Namibia and Argentina who supply hake for Spanish and Chilean re-export. By country the top exporters in 2013 were Argentina (26%), Namibia (12 %), USA (11%), Spain (10%), South Africa (9%), Canada (8%) and Chile (7%) followed by Uruguay, Peru and China (Lallemand, Bergh et al. 2016).

2. 1. 1 Namibia

The Namibian hake fishery is the most valuable of the Namibian fisheries, and the second largest earner of foreign currency after the mining sector. Around 67 % of the total landed value of the Namibian fishery was derived from the hake fishery (OECD 2012). The hake fishery employed 70 % of all Namibian fisheries workers in 2009/2010, employing 8956 people of which 8777 were Namibians (Wilhelm, Kirchner et al. 2015). In 2014 the hake industry is assumed to account for 63 % of all fisheries workers (Kirchner and Leiman 2014).

In 2012, Namibian export accounted for almost 45 % of the GDP (World Development Indicators 2016). (GDP 13 072 USD million). The Namibian GDP in 2013 was USD 12 755 million, of which the fishery sector contributed USD 365 million. Exports of fish and fishery products were valued at USD 787 million. (FAO 2016)

The hake fishery is almost entirely export-based. In 2010, about 97% by final value was exported, and 61% of exported products by value went to Spain. If not marketed in Spain, the export is distributed to other EU countries such as Italy, Portugal, France, Germany and Netherlands (around 3% each of the total Namibian exported hake products). Non-EU exports are to South Africa (16%), Australia (2%), Malaysia (1%), the Democratic Republic of Congo (2%) and the USA (2%). Namibia is the leading frozen hake supplier, in terms of volume and value, to the Spanish market, but face competition from South Africa, Argentina, Chile and Australia in other markets (Wilhelm, Kirchner et al. 2015). The value of all Namibian fishery exports accounted for 13 % -17 % of total export in the period 2007 – 2010 and the total contribution of the fishing industry to Namibian GDP was around 5 % in the period 2007-2009 (MFMR 2010). A weakened Namibian dollar increases export earnings, and the oil price decline contributes to lower fishing costs.

Historic links between Spain and Namibia is a source of difference in market opportunities between South Africa and Namibia. These links are strong and facilitated by vertical integration, making Namibia vulnerable to economic issues in Spain and collapses of the Spanish companies such as Pescanova. Unlike South Africa, Namibia benefits from « preferential tariffs » in the Spanish market and do not pay duty for exports of hake to Germany. In general, there is a strong Spanish influence in the development of the hake fisheries in the Southern Hemisphere (Chile, Argentina, Namibia, Uruguay and Argentina)(Lallemand, Bergh et al. 2016).

2. 1. 2 South Africa

South African export accounts for approximately 30 % of GDP (2012) (World Development Indicators 2016). Of the South African GDP in 2008 (USD 783 billion), all fisheries contributed with USD 323 million, and the value of fisheries exports was 538 million (World Development Indicators 2016). The South African deep-water hake industry employs around 35 % of the entire fishing industry. In 2012, this number was 37 % and accounted for 6653 employed workers, according to fishery industry itself (SADSTIA 2016). National authorities estimate that 8355 were employed in the entire hake industry. (Lallemand, Bergh et al. 2016)

South African hake is mostly exported to Southern European countries. Spain, Portugal and Italy accounted for 87. 6 % of South Africa's total exports up to 2011. In 2012, these countries imported only 65.4% due to an increase in hake exported and the opening of new markets. Spain and Namibia are main exporters to southern Europe, however the Spanish export is considered to be largely re-export. In northern Europe and Australia, South Africa is the main exporter with Namibia as the main competitor. The Marine Stewardship classification (MSC) opened access for South Africa into certain markets in Northern Europe, USA and Australia.   (Lallemand, Bergh et al. 2016)

2. 2 The Fishery Management

2. 2. 1 A General Note

In economic theory, fisheries are defined as a renewable resource (Perman 2011). Despite their renewability, ocean fisheries have still been threatened by resource overexploitation and economic waste. An important part of this issue is due to the mobility of marine life and fish stocks, which makes it hard to put in place effective private or public property rights. Consequently, ocean resources have been historically exploited as a «common pool», or a fishery open to all, affecting the development of coastal nations worldwide (Bjørndal and Munro 2012). If the fishery is not subject to property rights such that it can be regulated and treated as a common property resource, the fishery is a open-access natural resource. (Perman 2011)

The 1982 - UN-convention on the Law of the Sea and the establishment of territorial waters using a 200-mile Exclusive Economic Zone, served as an introduction of international property rights of the waters of coastal nations. Opening for the coastal states' effective property rights to their marine resources, limits the common-pool issue of the world fisheries and may promote renewability (Bjørndal and Munro 2012). For instance, before the introduction economic zones, both South Africa and Namibia experienced extensive fishing efforts made by foreign fleets, and total hake catches are reported to have peaked in 1972 with around 800 000 - 1,1 million hake. (SADSTIA 2016, Strømme, Lipinski et al. 2016). By introducing the EEZ, both countries aimed at eliminating foreign vessels.

Namibian and South African quotas are set on the basis of stock assessments of the spawning capacity of the hake resource, which is the share of the stock that is capable of reproduction (Bjørndal and Munro 2012). Although species-specific stock assessments have been in place in South Africa since 2006, this is not yet the case in Namibia (Kirchner et al., 2012). Higher quotas may be set if the stock is healthy, while if biological surveys point in the direction of a depleted resource, scientists recommend a reduction in the total allowable catch. Literature argues that while Namibian management authorities regularly disregarded scientific advice and set TACs above recommended levels, South African TAC's have been set in accordance with scientific advice (Kirchner and Leiman 2014, Lallemand, Bergh et al. 2016).

2. 2. 2 Individual and Overall Catches

Although Namibia and South Africa treat the deep-water hake and shallow-water hake as a single stock fishery (Kirchner, Kainge et al. 2012), both fisheries target the deep water hake as it gives better price and is easier to handle for filleting. The species based catch data in Namibia is measured by observer sampling, which provide data for splitting commercial catches into separate species, while in South Africa it is based on models (T.Strømme, pers. comm., April 4, 2016). The observer-sampling has been in place since 1997-1998 and consequently the catch has been separated for the two species (BCC 2011, Paterson and Kainge 2014). The South African and Namibian fisheries have close historic ties and South African catches in Namibia taken during their occupation in 1915-1990 were registered as South African catches (Baust, Teh et al. 2015).

Annual Namibian and South African catches are presented in tonnes in Table 1 on the next page. The catches for South Africa were provided for this thesis by Mr. Deon Durholtz, Head of the demersal research section at the Department of Agriculture, Forestry and Fisheries in South Africa. The data on the Namibian catches separated for the two species are collected from the Benguela Current Commission's Status of Stock report p.5 and p.11, (BCC 2011) (2011)). Data on the total Namibian harvest for the years 2010 and 2011 are collected from the 2012 - Evaluation of the Status of the Namibian Hake Resource (Kirchner et al. 2012). Since the SOS-report do not report data on the shallow-water catch for the year 2009, the data on deep-water hake was subtracted from the harvest reported by Kirchner et al (2012) as an estimate for the year 2009.

Table 1: Harvest of Deep-Water and Shallow-Water Hake in tonnes

The Harvest of Hake				
	South Africa		Namibia	
Year	**Deep Water**	**Shallow Water**	**Deep Water**	**Shallow Water**
2000	113 148	44 278	111 000	74 000
2001	115 421	42 980	126 000	64 000
2002	113 218	34 369	156 000	31 000
2003	120 807	32 646	142 000	40 000
2004	121 713	31 971	116 000	71 000
2005	116 154	26 546	121 000	49 000
2006	109 699	23 823	88 000	45 000
2007	117 690	25 751	88 000	41 000
2008	106 294	23 209	90 000	39 000
2009	86 464	24 466	96 000	49 000*
2010	90 434	20 232	159 000	
2011	101 357	27 960	154 000	
2012	108 253	19 639		
2013	115 628	13 068		
2014	129 836	14 090		
2015	133 060	14 441		

Source: D. Durholtz, personal communication, March 16, 2016, *BCC Status of Stock (2011) and Kirchner et al (2012). *Found by combining data from the SOS-report and Kirchner et al (2012).*

From the table, we can see that the deep-water hake is targeted and that catch rates for deep-water hake show an increasing trend in South Africa. While catch rates are lower in Namibia. In a recent study, deep-water hake larger than 35 cm and smaller than 55 cm in size is argued to shared with a 40 % to 60 % split between Namibia and South Africa respectively, and that no larger fish are found Namibia. Extensive fishing in Namibia can be argued to have had a negative effect on the current stock. (Strømme, Lipinski et al. 2016)

2. 2. 3 Potential Illegal, Unreported and Unregistered fishing

Illegal, Unreported and Unregulated (IUU) - fishing may cause uncertainties in the data. It is argued that, with the exception of South Africa, the fishery management of the hake stock in development countries is insufficient or characterized by inaccurate reporting, threatening the sustainability of the resource (Lallemand, Bergh et al. 2016) Moreover, hakes are caught as by-catch in other fisheries (Wilhelm, Kirchner et al. 2015, SADSTIA 2016), as well as hake below the minimum size limit of fishable hake may be caught despite control measures (Wilhelm, Kirchner et al. 2015).

Although illegal fishing is the most serious offence in Namibian fisheries, along with catch misreporting and exceeding by-catch allowances, there have been raised concerns related to the presence of unlicensed vessel fishing in Namibia. Illegal catches in the entire Namibian fishery peaked at 157 000 tonnes in 1990 and has been reported to decrease to around 7 500 tonnes in 2010(Belhabib, Willemse et al. 2015).

Foreign vessels are also reported to appear in South African fisheries, including the deep water hake trawl where there are potential catch arrangements with Spain that are officially non-sanctioned and could be illegal (Baust, Teh et al. 2015).

2. 2. 4 The Namibian Fishery Management

Prior to independence, Namibia was administered by South Africa (Kirchner and Leiman 2014). Total Namibian catches (all fish) were dominated by South Africa (47%), the Russian Federation (25 %) and Spain (13%). The Namibian EEZ was declared in 1990 and covers 560 101 km^2 (Belhabib, Willemse et al. 2015). Namibian authorities manage deep-water hake and shallow-water hake as one single stock when setting quotas, and national stock assessments also consider the two species as one stock (Paterson and Kainge 2014). Future stock assessments are however anticipated to take the two-species nature into account as has been done in South Africa (Kirchner, Kainge et al. 2012).

The hake exploitation in Namibia started in the 1950s but became significant when foreign fleets entered in 1964 (Paterson and Kainge 2014) and exploited the resource as an open access fishery. Around 100 foreign fleets from South Africa, Spain, the USSR, Cuba, Israel, Italy, Japan, Poland, and Portugal exploited the Namibian hake. Soviet and Spanish vessels dominated the catches by around 90 % between 1968 and 1972. Historically, hake harvest peaked at 800 000 tons in 1972 (Wilhelm, Kirchner et al. 2015). From 1976, the fishery was managed by advice from the International Commission for Southeast Atlantic Fisheries (ICSEAF), who introduced a minimum mesh size in 1976 and a total allowable catch (TAC) in the period 1977-1989. The overall TAC was never reached, and it is argued that this is because it was set too high. Catches declined to around 170 000 tons by 1980, and in 1981 and 1989, catches ranged between 300 000 and 400 000 tons. Stock assessments show that the stock has not as yet recovered to its maximum sustainable yield level, despite the removal of foreign fishing efforts (Kirchner, Kainge et al. 2012).

Namibia declared the 200-meter Exclusive Economic Zone (EEZ) when they gained independence. Namibian authorities inherited a depleted resource and introduced limits on catch to 60 000 tons in order to rebuild the fishery (Paterson and Kainge 2014). However, in the years to come, the TAC was again increased. In the beginning of the 2000's, the fish stock was considered to be seriously depleted and the official quota was not landed. By 2006, the size of hake had been reduced, leading to large financial losses in the industry (Kirchner and Leiman 2014). The quota was cut by 50 000 tons to 130 000 tons in 2006 and due to the concern that fish smaller than the official minimum size (36 cm) were landed, further regulations were introduced – including a minimum mesh size, restricted fishing during the spawning season in October and limited access to certain depths and areas.

The key fisheries institution in Namibia is the Ministry of Fisheries and Marine Resources (MFMR). The TAC was 130 000 tonnes in 2006-2008 and raised to 149 000 tonnes in 2009 and 140 000 tonnes in 2010 (MFMR 2010).

In 2010, there were 50 right holders holding long-term rights for 7 – 15 years (MFMR 2010). Although rights are officially non-tradable, some holders lease out their shares, and some merge into joint ventures. Profits are argued to increase along the value chain and accrue to those processing hake rather than to those harvesting. Large vertically- integrated fishing companies enjoy economies of scale (Kirchner and Leiman 2014).

In 2008, 63 vessels of the 94 licensed vessels were fishing. Since 2006, the Namibian quota has increased, and the amount of vessels has decreased. This may be due to the establishment of joint ventures or effects of rising oil prices (Kirchner and Leiman 2014). Twenty years after independence, and despite Namibia's efforts to rebuild its most valuable fishery, the TAC is set higher than levels recommended by the scientific community and the stock level is assumed to be depleted (Kirchner and Leiman 2014).

Post-independence, Namibian authorities introduced a policy aimed towards the « Namibianisation» of the hake resource. The two objectives of the policy was increasing ownership and increasing economic benefits to Namibians. As a result, a majority of the TAC share is awarded wetfish vessels, as this sector can increase employment of unskilled and female labour and lengthen the value chain in favour of domestic employment. Today the share is 70 % for wetfish vessels and 30 % for freezer vessels (Kirchner and Leiman 2014).

The Namibianisation-policy is however argued to have failed and instead increased fishing effort and depressed hake stocks below optimal values, and to have caused a gap between the number of licensed vessels and the number of vessels in use (Kirchner and Leiman 2014) Potential resource rents are argued to be lost due to governmental support of the wet-fish sector and since freezer vessels are more profitable (BCC 2011, Kirchner and Leiman 2014). Reasons of the failed rebuilding of the Namibian resource are limitations in current stock assessments and a TAC set above scientific recommendations. (Paterson and Kainge 2014)

Data quality of stock assessments is important for the accuracy of setting quotas. Since 1998, the TAC has been set annually according to changes in the stock size, calculated based on the commercial catch per unit of effort (CPUE) and an abundance index from averaged annual scientific surveys (Paterson and Kainge 2014). Namibian stock assessments are assumed to be positively biased. There are contradicting trends in the inputs in the models (catch per unit effort increasing and survey data decreasing), due to lack of understanding of the stock, sampling errors and data inaccuracy. Moreover, the standardized CPUE data in use does not account for increased efficiency. Paterson and Kainge report that data quality may be improved if fishers more involved in research (Paterson and Kainge 2014).

2. 2. 5 The South African Management

South Africa's EEZ covers 374, 597 km^2 and was declared in 1977 (Baust, Teh et al. 2015), resulting in the removal of all foreign fishing vessels and the introduction of quotas in 1979. The South African hake fishery is managed as a species aggregated single stock, setting TAC's for the both species combined. In contrast to Namibia, South African stock assessments distinguish between deep-water hake and shallow water hake. In addition to the overall TAC, the South African hake is managed by an effort-control of a limit on number of days fishing per year.

Today, four different fisheries exploit the hake stocks; the offshore trawl and the longline fisheries (in the Benguela and Agulhas region) and the smaller inshore trawl and handline fisheries located only on the south coast (Agulhas system). Whereas the offshore trawl and longline sectors target both Cape hake and Deep–water hake, the inshore trawl and handline fisheries target only Cape hake. (BCC 2011)

The deep-sea trawl accounts for around 80% of the South African hake harvest (in 2008 and in the period since 2000). Today, there are 52 deep-sea trawlers, which is a decrease of 23 vessels since 2007. The fishing industry argues the reason for this reduction to be due to the regulations on efforts. (SADSTIA 2016)

The overall quota is shared across the four economic sectors of deep-sea trawl fishery, inshore trawl fishery, longline and handline. The deep-sea trawlers however catch the largest portion of the global hake TAC. According to the fishing industry, only 6 % of hake catches are caught by inshore trawlers and longline vessels (SADSTIA 2016) Moreover, the deep–sea trawl fishery has a 110mm mesh size limit and vessels are restricted from fishing in depths less than 110m in a certain geographical area. Effort limitations for both trawl sectors and hake longline were developed and implemented over the period 2007 – 2009. (BCC 2011)

Historically, and in contrast to Namibia, final TAC recommendations have been in line with scientific recommendations. Three non-governmental institutions play a role in driving the deep-water fishery towards a sustainable management. These are the Marine Stewardship Council's requirements for certifications, the Southern African Sustainable Seafood Initiative and the Responsible Fisheries Alliance (Lallemand, Bergh et al. 2016). Unlike Namibia, South Africa is certified via the Marine Stewardship Council (MSC Certification) (Kirchner and Leiman 2014, Lallemand, Bergh et al. 2016). The certification has been a way into the northern European markets since the financial crisis in 2008, and is argued to yield a higher price.

2. 2. 6 Fleet Characterization

Freezer and wetfish vessels dominate the South African and Namibian demersal fleets. Longliners target shallow-water hake in Namibia (Paterson and Kainge 2014), while in 2008 longliners catches only 3 % of deep-water hake in South Africa (according to data from D.Durholtz, personal communication, March 16, 2016). Freezer vessels process the catch on board and land frozen products, while wetfish-vessels return the catch, preserved on ice, to processing facilities on land. Most freezer product is landed whole, in the headed and gutted form, but some of the more sophisticated trawlers in the fleet produce frozen fillets at sea. The majority of hake products produced by freezer trawlers are exported (SADSTIA 2016). Wetfish vessels travel generally during 4-7 days, whereas freezer trawlers typically fish for 30 to 45 days at a time (Kirchner and Leiman 2014, SADSTIA 2016).
Freezer vessels process at sea, returning filleted frozen product ready for the market, while wetfish vessels return the fish to onshore processing facilities (Wilhelm, Kirchner et al. 2015). Increases in efficiency in Namibia has been possible due to improvements in fishing gear, larger net openings, and catchability has also been found to be affected by time of day, as well as seasons and cloud cover (Paterson and Kainge 2014).

2. 2. 7 Status of The Stock

The South African estimates of the historic stock abundance and spawning biomass is presented in tonnes Table 2 below. Fishing measures and stock assessments are commonly directed at the spawning stock biomass (Bjørndal and Munro 2012). The numerical model in this paper will be calibrated using the South African total abundance at pre – exploitation levels (1917) as the stock's natural carrying capacity. Two recalibrations of the model will briefly be discussed in the appendices, the first will use the spawning stock carrying capacity, and the second will use an average of the newer and lower levels of the total abundance. In 2008, the spawning stock was below the level maximum sustainable yield. Although the maximum sustainable yield is a reference point in Namibia and South Africa and measurements have been done to rebuild the stock towards higher sustainable levels (BCC 2011, Kirchner, Kainge et al. 2012), the deep-water hake is estimated to be below its MSY-levels in both Namibia and South Africa (BCC 2011).

Table 2: Spawning Biomass and Total Abundance of the South African Deep-Water Hake

The South African Deep-Water Hake in tonnes		
Year	**Spawning biomass**	**Total Abundance**
1917	1 021 000	2 251 510
2000	179 000	509 989
2001	163 000	487 315
2002	142 000	470 616
2003	124 000	450 509
2004	114 000	430 631
2005	106 000	431 756
2006	98 000	449 660
2007	99 000	475 851
2008	109 000	487 653
2009	129 000	511 367
2010	156 000	540 008
2011	181 000	559 091
2012	199 000	568 535
2013	200 000	562 572
2014	191 000	546 428
2015	177 000	516 701

*Source: The Spawning Biomass of the South African Deep Water Hak*e (D. Durholtz, personal communication, March 16, 2016). *Total Abundance of the South African Deep Water hake (R. Rademeyer, pers. comm., April 15, 2016).*

There is consensus that the management strategy for South African hake that has been in place since 2006 (renewed in 2010) is yielding positive results and that stocks of deep-water hake in particular are growing at a rate faster than anticipated (SADSTIA 2016).

3 The Theoretical Models

3. 1 The General Setup

3. 1. 1 Introduction to the Duopoly

The Benguela-region's deep-water hake is found within the economic zones of South Africa and Namibia. Today the two countries manage the deep-water hake as if it is unshared. Assuming the contrary, that the two countries managed the fishery as one shared stock, we can analyse their Cournot duopoly equilibrium.

An oligopoly is a market in which few players compete, and the market power is collectively shared. Given of the transboundary character of the Benguela deep-water hake, the harvest can be modelled as the outcome in a Cournot duopoly. A duopoly is a special case of an oligopoly, in which two players competes selling a homogenous product. When a player's profit-maximising behaviour is affected by their competitor's choices, game theoretic approaches can be applied to model their strategic interaction. Countries compete by setting quantity (harvest) using their strategic choices of efforts. The strategic interaction of quantity setting can be modelled as a Cournot duopoly (Belleflamme and Peitz 2010). We will investigate the optimal effort made by each country (the players) where payoffs are the profits of the fishery. The Gordon-Schaefer (1954) model will serve as the baseline for the bio-economic equilibriums in the fishery dynamics.

In Cournot, the countries have full information. They choose their annual level of harvest simultaneously and by maximising their profits within their individual zone. We will also investigate the alternative Stackelberg duopoly, which is a special case where one country has a first mover advantage. The duopoly equilibriums of Cournot and Stackelberg are special cases of an oligopoly, expected to be located between the benchmark equilibriums of a Sole Owner and Open Access.

Literature in fishery economics states that there are at least two main levels of cooperation regarding transboundary resources. (Gulland 1980, Munro 2002) The first level consists of cooperation in scientific investigations. In this thesis, this primary level of cooperation will be modelled as a Cournot duopoly. The second level is cooperation in the sense of coordinated management regimes, which are assumed to be successful if there is cooperation in research

(Munro 2002) In this thesis, this level of cooperation is modelled as regional cooperation where profits are split and the two countries maximise the economic rent in line with monopolistic behaviour.

Economic games are characterized by interdependency: One player's optimal behaviour depends on what she believes the other players will do. (Watson 2013). In the fishery duopoly, harvest is the output produced, and efforts are the strategic variables in each country's harvest decision. Information is symmetric and the countries will commit to their strategic action in a one period game: Each country has full knowledge about own costs of harvest and the neighbouring country's costs, the industry demand, the price, such that they can find best response functions.

3. 1. 2 General assumptions

Hake is an important white fish in the world market. Since the two countries' catch is sold in a competitive market with several close substitutes, neither country's supply is assumed to influence the world market price and the market demand is assumed to be the same regardless of whether the fish is harvested and sold by South Africa or Namibia. The deep-water hake stock is assumed to be transboundary between Namibia and South Africa: its migration pattern is limited to crossing each other's EEZ boundaries and remaining within this natural boundary.

The Gordon-Schaefer model is a combination of Gordon's (1954) economic model of a fishery and Schaefer's biological model (1954). Schaefer assumed a logistic growth function of the stock, S, developed by Verhulst (1830's). (Bjørndal and Munro 2012).
The natural growth of the stock, S, is given by

$$G(S) = gS\left(1 - \frac{S}{S_{max}}\right) \tag{1}$$

where the constant g is intrinsic growth and S_{max} is the carrying capacity of the biomass, the natural equilibrium of the resource. (Bjørndal and Munro 2012)

The Gordon-Schaefer model assumes that harvest is proportional to effort and stock; there are constant returns to scale by efforts, and all things being equal, the larger the stock, the greater the harvest for any level of effort. (Perman 2011) Schaefer assumed the harvest functions to be functions of a catchability coefficient, effort and biomass,

$$H_1 = e_1 E_1 S \qquad (2)$$

$$H_2 = e_1 E_2 S \qquad (3)$$

where E_1 and E_2 are Country 1 and Country 2's individual efforts, and the individual catchability coefficients e_1 and e_2 are measures of the state of fishing technology or the successfulness of a fishing strategy. The Schaefer-harvest function is a special case of the Cobb-Douglas harvest production function, $H = eE^{\alpha}S^{\beta}$, where $\alpha = \beta = 1$. The implication is that the fish stock is spread uniformly over the geographical area in question, even when the resource is diminished. (Bjørndal and Munro 2012) A uniformly distributed fish stock will be assumed in our numerical model.

The total catch is the sum of the two countries' individual harvest decisions $H(E_1, E_2) = H_1(E_1) + H_2(E_2)$ and total fishing efforts are the sum of the two countries' individual efforts, $E = E_1 + E_2$. In steady state, the rate of change in the stock, S, is zero, $G(S) - H(E) = 0$, and remains constant across periods. The fish stock is sustainably harvested by the two countries if at a given level of the shared stock, S, being harvested, H, is equal to the amount of net natural growth of the resource. This level of harvest is defined as the sustainable yield (Perman 2011).

The sustainable yield for the overall harvest of the shared stock, is found by inserting for the harvest production function for each country, from equation (no) and (no) and the overall growth model.

$$H(E) = H_1(E_1) + H_2(E_2) = G(S) \qquad (4)$$

Clearly, there is an indefinite number of equilibrium where the harvest equals biological growth, as all harvest levels that catch as much as renewed will be sustainable. Historically, the maximum sustainable yield (MSY) (the top of the inverted U-curve) has been advised as an appropriate target in many fisheries (Bjørndal and Munro 2012, OECD 2013). The above equation proves that fishery dynamics is in essence a bio-economic exercise, combining a biological equilibrium (natural growth) of the stock and economic equilibriums (net benefits) of the harvest. Since the steady-state equilibrium is a joint equilibrium, it can be referred to as a bio-economic equilibrium. (Perman 2011)

Gordon (1954) combined the sustainable harvest function with a profit function with respect to effort, assuming that fishing effort has constant unit costs and reflects the social opportunity cost of fishing effort and the price of the harvest is constant and reflects the marginal benefit to society of harvested fish, exclusive fishing effort costs. Hence, total costs of harvest increase proportionally with effort. Denoting costs per unit effort for country 1 and country 2 by w_1 and w_2 and individual efforts as E_1 and E_2, the countries individual total cost equals w_1E_1 and w_2E_2. The strategic choices made by South Africa and Namibia are interdependent and will have an impact on steady state growth of the hake fishery. The sustainable stock is found by inserting the expressions for natural growth (4) and individual harvest functions (5) and (6) in equation (3) and rearranging:

$$e_1E_1S + e_2E_2S = gS\left(1 - \frac{S}{S_{max}}\right)$$

$$\frac{e_1}{g}E_1 + \frac{e_2}{g}E_2 = 1 - \frac{S}{S_{max}}$$

$$S = S_{max}\left(1 - \frac{e_1}{g}E_1 - \frac{e_2}{g}E_2\right) \qquad (5)$$

The function of the steady state stock is an expression of the two countries' individual efforts. All things constant, the stock decreases by an increase in efforts made by either country, as $\frac{\delta S}{\delta E_1} < 0$ and $\frac{\delta S}{\delta E_2} < 0$.

The catchability coefficient enters negatively in the steady state stock function. If Country 1 is more effective in terms of catchability than Country 2, Country 1's efforts will have a relatively larger, negative effect on the stock than the country with a lower catchability coefficient, all other things unchanged. In other words, the shared stock is relatively more responsive to a change in country 1's efforts when $e_1 > e_2$.

Inserting the expression of steady state stock from equation (5) in the individual harvest production functions (2) and (3), the sustainable yield for the two countries are,

$$H_1 = e_1 E_1 S_{max}\left(1 - \frac{e_1}{g}E_1 - \frac{e_2}{g}E_2\right) \tag{6}$$

$$H_2 = e_2 E_2 S_{max}\left(1 - \frac{e_1}{g}E_1 - \frac{e_2}{g}E_2\right) \tag{7}$$

The harvest functions reflect the stock interdependency between the two countries; increasing efforts by country 2 implies that country 1 should reduce its efforts to maintain sustainable harvest, and vice versa.

In the duopoly case, costs and catchability coefficients may be heterogeneous (fleets differ with respect to efficiency and costs) or homogenous (symmetric fleets). In the benchmark cases of a Sole Owner an Open Access, fleets are assumed to be symmetric.

3. 2 A Cournot Duopoly

Primary cooperation in terms of stock research, implies that the countries treat the hake resource as shared, but since there is no active management cooperation, they maximise the profits of their harvest within their EEZ. This can be modelled as a Cournot duopoly. An oligopolistic economic equilibrium is expected to be located between the Sole Owner and Open Access.

In the simultaneous Cournot game, the two countries set their strategic actions at the same time, producing a harvest sold to the global market. In this duopoly, the set of two players are the neighbouring coastal nations Country 1 and Country 2, who share a transboundary fish resource. The countries act profit maximising within their EEZ zone
and takes the other country's effort as given. They chose the optimal level of effort (the strategic choice) when producing the output (the harvest). The necessary condition is $\delta\pi_1/\delta E_1 = 0$ and $\delta\pi_2/\delta E_2 = 0$ for country 1 and country 2 respectively. The stock will vary according to efforts, and the price is set by the world market.

The optimal level of efforts is found din the Cournot-Nash equilibrium. The Nash Equilibrium is the solution in which the two countries' strategies represent the best answers to each other, and neither country regrets its choice.(Watson 2013)

3. 2. 1 The Best Response Functions

The individual countries act as sole owners within their EEZ. The total revenue of the harvest is the price of fish multiplied by the harvest. Costs are proportional with efforts.

A country maximizes its own profits while taking into account the other country's efforts. Country 1's net benefits are given by inserting the sustainable harvest function (8) in the individual profit function;

$$\pi_1 = PH_1 - w_1E_1$$

$$\pi_1 = Pe_1E_1S_{max}\left(1 - \frac{e_1}{g}E_1 - \frac{e_2}{g}E_2\right) - w_1E_1$$

$$\pi_1 = \left(Pe_1S_{max} - \frac{e_1}{g}Pe_1E_1S_{max} - \frac{e_2}{g}Pe_1E_2S_{max} - w_1\right)E_1 \qquad (8)$$

By symmetry, country 2's profits are

$$\pi_2 = \left(Pe_2S_{max} - \frac{e_1}{g}Pe_2E_1S_{max} - \frac{e_2}{g}Pe_2E_2S_{max} - w_2\right)E_2. \qquad (9)$$

Country 1 maximizes net benefits with regards to own efforts, given country 2's effort. The necessary condition for country 1 is $\delta\pi_1/\delta\, E_1 = 0$. [1] Differentiation yields the best response function for country 1:

$$\delta\pi_1/\delta\, E_1 = 0$$

$$Pe_1S_{max} - 2\frac{e_1}{g}Pe_1E_1S_{max} - \frac{e_2}{g}Pe_1E_2S_{max} - w_1 = 0$$

$$2\frac{e_1}{g}Pe_1E_1S_{max} = Pe_1S_{max} - \frac{e_2}{g}Pe_1E_2S_{max} - w_1$$

$$E_1 = \frac{1}{2}\frac{g}{e_1}\left(1 - \frac{e_2}{g}E_2 - \frac{w_1}{Pe_1S_{max}}\right)$$

$$BR_1(E_2) = E_1 = \frac{1}{2}\frac{g}{e_1}\left(1 - \frac{w_1}{Pe_1S_{max}}\right) - \frac{1}{2}\frac{e_2}{e_1}E_2 \qquad (10)$$

By symmetry, country 2's best response function is

$$BR_2(E_1) = E_2 = \frac{1}{2}\frac{g}{e_2}\left(1 - \frac{\square_2}{Pe_2S_{max}}\right) - \frac{1}{2}\frac{e_1}{e_2}E_1 \qquad (11)$$

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[1] The profit function is concave in the individual country's own action. $\delta^2\pi_1/\delta\, E_1 < 0$ and $\delta^2\pi_2/\delta\, E_2 < 0$.

The best response functions reflect the interdependency of the countries as efforts enter in each other's functions of profit maximizing behaviour. The best response function slopes downward: faced with larger quantity produced by the rival country, Country 1 optimally reacts by lowering its own quantity (and decrease efforts) This indicates that efforts are strategic substitutes. Since the countries' best responses of efforts move in opposite directions, they are strategic substitutes. (Belleflamme and Peitz 2010)

In Cournot, quantities (the strategic choices) are strategic substitutes when goods (output) are substitutes. (Belleflamme and Peitz 2010)

From equations (10) and (11) it follows that the best response functions of symmetric countries will be equal in the Nash-equilibrium,

$$BR_1(E_2) = BR_2(E_1) = \frac{1}{2}\frac{g}{e}\left(1 - \frac{w}{PeS_{max}}\right) - \frac{1}{2}BR(E) \qquad (12)$$

Note that the relationship $(\frac{e_2}{e_1})$ does no longer have an impact on Country 1's efforts. In the case of symmetric countries, best responses respond equally to a change in the other country's efforts.

3. 2. 2 The Degree of Substitution

In Cournot, when outputs are substitutes, the strategic choices are strategic substitutes. In the fishery duopoly, the strategic choice of input in the harvest production function is efforts, and the harvest (Cournot quantity) of hake is the output produced.

In game theory, the strategic actions of two players are called strategic substitutes if they mutually offset one another. [2] From equation (10) and (11) it can be seen that the best responses are *strategic substitutes*. Their degree of substitution can be determined by the relationship between the catchability coefficients,

$$\frac{\delta BR_1}{\delta E_2} = -\frac{1}{2}\frac{e_2}{e_1}$$

Since the catchability coefficients are assumed strictly positive, efforts are strategic substitutes as $\frac{\delta BR_1}{\delta E_2} < 0$. Notably, there is a degree of substitution, $\frac{e_2}{e_1}$. If $\frac{\delta BR_1}{\delta E_2} = 0$, efforts

[2] They are called strategic complements if they mutually reinforce one another.

would be independent of one another. If , $\frac{e_2}{e_1} = 1$ (which is the case when countries are symmetric) then $\frac{\delta BR_1}{\delta E_2} = -\frac{1}{2}$ and the best response of each country to an increase in the other country's efforts are the same. Efforts are then pure strategic substitutes. However, if the countries have different catchability coefficients, then the strategic choices are not equally substitutable: The relatively more efficient a country's fleet is, the less sensitive she will be to increases in the opponent's efforts.

Let's assume that the countries were initially symmetric such that $\frac{e_2}{e_1} = 1$. Then an increase in Country 1's efforts has the same negative impact on Country 2's efforts as an increase in Country 2's efforts would have on Country 1's efforts. Imagine next that the countries differ in catchability such that Country 1 has a higher catchability coefficient than Country 2 $e_1 > e_2$. This is a relative advantage for Country 1. For a marginal increase in Country 2's efforts, Country 1 now responds by producing *less* effort than Country 2 would do by a marginal increase in Country 1's efforts. In other words, although the strategic choice for both countries is still to reduce efforts when the neighbouring country increases its efforts on the margin, the scope of the reduction will vary if the catchability coefficients are asymmetric. This difference can be stated as,

$$\left|\frac{\delta BR_1}{\delta E_2}\right| < \left|\frac{\delta BR_2}{\delta E_1}\right| \text{ when } e_1 > e_2$$

The country with the highest catchability coefficient is less sensitive to a marginal change in the other country's efforts, while the country with the lowest catchability coefficient is more sensitive to a change in the neighbouring country's efforts.

If one country increases its efforts the stock is reduced. The lesser stock available to the fishermen, the smaller the catch per unit effort will be for the same effort as before the increase. In other words, if Country 2 increases efforts, Country 1 must increase efforts to catch the same amount of fish as before the increase in efforts made. The marginal cost increases. However, in a Cournot-duopoly, the countries act depending on each other's efforts, and bare in mind that the profits are affected by the sustainable stock, the optimal strategies for either country is affected by each others efforts: is Country 2 increases efforts, all other things alike, the profit maximising country 1's best response is to reduce its own efforts (relative payoff). Their responses will however differ according to the effort's degree of substitution

3. 2. 3 Cournot – Nash Equilibrium Solutions

3. 2. 3. 1 Steady State Efforts

The Cournot-Nash solution is where the countries solve their response functions simultaneously, taking the other country's efforts as given. In the Nash-equilibrium, the reaction functions from equation (10) and (11) intersect and the two countries do not regret their strategies once their choice of effort, and harvest, is revealed. (Watson 2013) This is where the countries solve their response functions simultaneously, taking the other country's efforts as given. Solving the individual Cournot - response functions simultaneously yields the Cournot - Nash solution. Since the countries have accurate believes, their strategies are mutual best responses.

Both countries act simultaneously and take each other's optimal decision into account. Inserting for country 2 in country 1's best response function gives country 1's Cournot-Nash equilibrium effort solution,

$$BR_1(E_2) = \frac{1}{2}\frac{g}{e_1}\left(1 - \frac{w_1}{Pe_1S_{max}}\right) - \frac{1}{2}\frac{e_2}{e_1}E_2$$

$$2E_1 = \frac{g}{e_1}\left(1 - \frac{w_1}{Pe_1S_{max}}\right) - \frac{e_2}{e_1}\left(\frac{1}{2}\frac{g}{e_2}\left(1 - \frac{w_2}{Pe_2S_{max}}\right) - \frac{1}{2}\frac{e_1}{e_2}E_1\right)$$

$$2E_1 - \frac{1}{2}E_1 = \frac{g}{e_1}\left(1 - \frac{w_1}{Pe_1S_{max}}\right) - \frac{1}{2}\frac{g}{e_1}\left(1 - \frac{w_2}{Pe_2S_{max}}\right)$$

$$\frac{3}{2}E_1 = \frac{g}{e_1}\left(1 - \frac{w_1}{Pe_1S_{max}} - \frac{1}{2} + \frac{1}{2}\frac{w_2}{Pe_2S_{max}}\right)$$

$$E_1 = \frac{1}{3}\frac{g}{e_1}\left(1 - \frac{2w_1}{Pe_1S_{max}} + \frac{w_2}{Pe_2S_{max}}\right) \tag{13}$$

By symmetry,

$$E_2 = \frac{1}{3}\frac{g}{e_2}\left(1 - \frac{2w_2}{Pe_2S_{max}} + \frac{w_1}{Pe_1S_{max}}\right) \tag{14}$$

Note that the parentheses in (13) and (14) must be positive for steady state efforts to be positive. Effects of changes in *w* and *e* on the equilibrium effort solution will be discussed in the theoretical part of this thesis.

If the players chose their optimal levels of effort, the overall effort used under the shared stock regime in the Cournot-duopoly is found by the sum of the individual efforts,

$$E_1 + E_2 = \frac{1}{3} g \left(\frac{1}{e_1} \left(1 - \frac{2w_1}{Pe_1 S_{max}} + \frac{w_2}{Pe_2 S_{max}} \right) + \frac{1}{e_2} \left(1 - \frac{2w_2}{Pe_2 S_{max}} + \frac{w_1}{Pe_1 S_{max}} \right) \right) \quad (15)$$

From equation (13) and (14) it follows that the individual effort in the scenario of symmetric countries are

$$E_1 = E_2 = \frac{1}{3} \frac{g}{e} \left(1 - \frac{w}{PeS_{max}} \right) \quad (16)$$

and overall efforts is the sum of these

$$E_{cournot} = E_1 + E_2 = 2E_1 = \frac{2}{3} \frac{g}{e} \left(1 - \frac{w}{PeS_{max}} \right) \quad (17)$$

In order to have an interior solution, where efforts are strictly positive, the inequality $1 > \frac{w}{PeS_{max}}$ must hold. If this assumption does not hold, the cost of fishing would be so high that the country would not chose to fish. The linear curve, $H = \frac{w}{P} E$ will be steeper than the inverted U-curve of harvest when and there will be no intersection between the two curves.

The Nash equilibrium in the Cournot game is inefficient, as the countries over-utilise efforts relative to their joint optimal effort levels. This occurs because each country does not value the profit of the other country. (Watson 2013). In general, if there is a marginal increase in quantities in the Cournot duopoly, it expands the total quantity, but decreases the market price relative to costs. The players balances these opposing effects to maximise profits, however their individual costs and benefits of raising quantity do not equal the joint costs and benefits. In particular, an increase in one player's individual quantity has a negative effect on the other player's payoff through the price change. The two players understate the joint price effect and have an incentive to overproduce relative to their joint optimal levels.

This reasoning is not entirely applicable in our study, as the market price is set by the world demand. In this study, the harvest of one country affects the other country's decision via the growth of the stock. Although the two countries take changes in stock into account in their profit maximising decisions, they understate the joint effect on stock and set joint effort levels higher than what would maximise overall profits (Sole Owner).

3. 2. 3. 2 Steady State Stock

The stock in Nash-equilibrium is found by inserting for optimal efforts in in equation (5)

$$S_{cournot} = S_{max}\left(1 - \frac{e_1}{g}\left(\frac{1}{3}\frac{g}{e_1}\left(1 - \frac{2w_1}{Pe_1S_{max}} + \frac{w_2}{Pe_2S_{max}}\right)\right) - \frac{e_2}{g}\left(\frac{1}{3}\frac{g}{e_2}\left(1 - \frac{2w_2}{Pe_2S_{max}} + \frac{w_1}{Pe_1S_{max}}\right)\right)\right)$$

$$S_{cournot} = S_{max}\left(1 - \frac{1}{3}\left(1 - \frac{2w_1}{Pe_1S_{max}} + \frac{w_2}{Pe_2S_{max}}\right) - \frac{1}{3}\left(1 - \frac{2w_2}{Pe_2S_{max}} + \frac{w_1}{Pe_1S_{max}}\right)\right)$$

$$S_{cournot} = S_{max}\left(\frac{1}{3} + \frac{1}{3}\frac{w_1}{Pe_1S_{max}} + \frac{1}{3}\frac{w_2}{Pe_2S_{max}}\right)$$

$$S_{co\square rnot} = \frac{1}{3}S_{max}\left(1 + \frac{w_1}{Pe_1S_{max}} + \frac{w_2}{Pe_2S_{max}}\right) \tag{18}$$

The sustainable stock is a function of the two countries' strategic interactions by their fishing efforts produced.

In the case of symmetric players, the Nash equilibrium stock equals,

$$S_{cournot} = \frac{1}{3}S_{max}\left(1 + \frac{2w}{PeS_{max}}\right) \tag{19}$$

3. 2. 3. 3 Steady State Harvest

The optimal harvest decision for Country 1 is found by inserting the steady state Nash – Equilibrium solutions of individual effort (13) and stock (18) in the country's harvest production function (2).

$$H_1 = e_1\frac{1}{3}\frac{g}{e_1}\left(1 - \frac{2w_1}{Pe_1S_{max}} + \frac{w_2}{Pe_2S_{max}}\right)\frac{1}{3}S_{max}\left(1 + \frac{w_1}{Pe_1S_{max}} + \frac{w_2}{Pe_2S_{max}}\right)$$

$$H_1 = \frac{1}{9}gS_{max}\left(1 - \frac{2w_1}{Pe_1S_{max}} + \frac{w_2}{Pe_2S_{max}}\right)\left(1 + \frac{w_1}{Pe_1S_{max}} + \frac{w_2}{Pe_2S_{max}}\right)$$

$$H_1 = \frac{1}{9}g\left(S_{max} - \frac{w_1}{Pe_1} + \frac{2w_2}{Pe_2} - \frac{w_1w_2}{P^2e_1e_2S_{max}} - \frac{2w_1^2}{P^2e_1^2S_{max}} + \frac{w_2^2}{P^2e_2^2S_{max}}\right) \tag{20}$$

By symmetry, Country 2's harvest decision is

$$H_2 = \frac{1}{9}gS_{max}\left(1 - \frac{2w_2}{Pe_2S_{max}} + \frac{w_1}{Pe_1S_{max}}\right)\left(1 + \frac{w_1}{Pe_1S_{max}} + \frac{w_2}{Pe_2S_{max}}\right)$$

$$H_2 = \frac{1}{9}g\left(S_{max} - \frac{w_2}{Pe_2} + \frac{2w_1}{Pe_1} - \frac{w_1w_2}{Pe_1Pe_2S_{max}} - \frac{2w_2^2}{(Pe_2)^2S_{max}} + \frac{w_1^2}{(Pe_1)^2S_{max}}\right) \tag{21}$$

The overall harvest by the Cournot - duopolists is the sum of the individual harvest parametric solution equations (20) and (21)

$$H_{cournot} = H_1 + H_2$$

$$H_{cournot} = \frac{2}{9} g \left(S_{max} + \frac{w_1}{2Pe_1} + \frac{w_2}{2Pe_2} - \frac{w_1 w_2}{P^2 e_1 e_2 S_{max}} - \frac{w_1^2}{2P^2 e_1^2 S_{max}} - \frac{w_2^2}{2P^2 e_2^2 S_{max}} \right) \quad (22)$$

From equation (16) and (19), the individual harvest functions in the case of symmetric countries follows,

$$H_1 = H_2 = \frac{1}{9} g \left(S_{max} + \frac{w}{Pe} - \frac{2w^2}{P^2 e^2 S_{max}} \right) \quad (23)$$

and the overall harvest becomes,

$$H = 2H_1 = \frac{2}{9} g \left(S_{max} + \frac{w}{2Pe} - \frac{2w^2}{P^2 e^2 S_{max}} \right) \quad (24)$$

3. 2. 3. 4 Steady State Profits

The individual profits in the Cournot - duopoly equilibrium follow by inserting the optimal individual harvest from equation (20) and optimal efforts from equation (13) in each country's individual profit function,

$$\pi_1 = PH_1 - w_1 E_1$$

$$\pi_1 = P \frac{1}{9} g \left(S_{max} - \frac{w_1}{Pe_1} + \frac{2w_2}{Pe_2} - \frac{w_1 w_2}{P^2 e_1 e_2 S_{max}} - \frac{2w_1^2}{P^2 e_1^2 S_{max}} + \frac{w_2^2}{P^2 e_2^2 S_{max}} \right) - \frac{1}{9} g \frac{3w_1}{e_1} \left(1 - \frac{2w_1}{Pe_1 S_{max}} + \frac{w_2}{Pe_2 S_{max}} \right)$$

$$\pi_1 = \frac{1}{9} g \left(PS_{max} - \frac{w_1}{e_1} + \frac{2w_2}{e_2} - \frac{w_1 w_2}{Pe_1 e_2 S_{max}} - \frac{2w_1^2}{Pe_1^2 S_{max}} + \frac{w_2^2}{Pe_2^2 S_{max}} - \frac{3w_1}{e_1} + \frac{6w_1^2}{Pe_1^2 S_{max}} - \frac{3w_1 w_2}{Pe_1 e_2 S_{max}} \right)$$

$$\pi_1 = \frac{1}{9} g \left(PS_{max} - \frac{4w_1}{e_1} + \frac{2w_2}{e_2} - \frac{4w_1 w_2}{Pe_1 e_2 S_{max}} + \frac{4w_1^2}{Pe_1^2 S_{max}} + \frac{w_2^2}{Pe_2^2 S_{max}} \right) \quad (25)$$

By symmetry, individual profits of country 2 are

$$\pi_2 = \frac{1}{9} g \left(PS_{max} - \frac{4w_2}{e_2} + \frac{2w_1}{e_1} - \frac{4w_1 w_2}{Pe_1 e_2 S_{max}} + \frac{4w_2^2}{Pe_2^2 S_{max}} + \frac{w_1^2}{Pe_1^2 S_{max}} \right) \quad (26)$$

The overall profits follows by summing the individual profit for each country,

$$\pi = \pi_1 + \pi_2$$

$$\pi = \frac{1}{9} g \left(2PS_{max} - \frac{2w_1}{e_1} - \frac{2w_2}{e_2} - \frac{8w_1 w_2}{Pe_1 e_2 S_{max}} + \frac{5w_1^2}{Pe_1^2 S_{max}} + \frac{5w_2^2}{Pe_2^2 S_{max}} \right)$$

$$\pi = \frac{2}{9} g \left(PS_{max} - \frac{w_1}{e_1} - \frac{w_2}{e_2} - \frac{4w_1 w_2}{Pe_1 e_2 S_{max}} + \frac{2{,}5w_1^2}{Pe_1^2 S_{max}} + \frac{2{,}5w_2^2}{Pe_2^2 S_{max}} \right) \quad (27)$$

From equation (16.) and (23) it follows that the individual profits for symmetric countries are,

$$\pi_1 = \pi_2 = \frac{1}{9} g \left(PS_{max} - \frac{2w}{e} + \frac{w^2}{Pe^2 S_{max}} \right) \tag{28}$$

Total profits for the for the shared stock regime in a Cournot duopoly becomes,

$$\pi = \frac{2}{9} g \left(PS_{max} - \frac{2w}{e} + \frac{w^2}{Pe^2 S_{max}} \right) \tag{29}$$

3. 3 Regional Cooperation

Perfect regional cooperation can be modelled as managing joint efforts in such way that the total profits from harvest in both economic zones are maximised as a whole. This economic equilibrium is the Sole Owner steady state in the Gordon Schaefer model. In this case, the two coastal nations join the management of their fisheries and share the same management objectives. The establishment of coordinated joint management can be understood as secondary cooperation, or «active management» (Gulland 1980). The Sole Owner has exclusive rights to manage the resource. If one country originally had lower costs and/or efficiency constraints, these are now assumed to be improved to an equal level of technology and costs to that of her neighbouring country, in such way that the two fleets can be assumed as homogenous. We will assume a joint management in which profits are equally split. Prices are given by the world market and are unaffected by the supply of the monopolist.

The economics of the management of transboundary fish stocks dates back to Munro (1979). Munro (1979) combined fishery economics and Nash cooperative game theory of two countries' joint management of a transboundary resource. In his dynamic model of Sole Owner harvesting, he assumed equal harvesting functions between the two countries. Armstrong and Flaaten (1991) applied Munro's (1979) game theoretic approach to empirically investigate the bilateral management of the Arcto-Norwegian cod stock, shared between Russia and Norway, taking into account that the catchability coefficient differs between the countries. They found a cooperative solution to be profitable for both countries (Armstrong and Flaaten 1991).

A Sole Owner acts as a monopolist and maximises total profits of the shared stock fishery. Effort is the aggregate of all efforts produced by the fleet to realise the harvest (Bjørndal and Munro 2012). In order for an active and successful management regime to be in place, the primary level of cooperation in research on data and information must be in place initially.

(Munro 2002). A common example of such research is the scientific investigations that were in place between Norway and Russia before they implemented a Joint Fisheries Commission of the Atlantic Cod in 1976 setting joint harvest rules (Armstrong and Flaaten 1991).

The Sole Owner maximises the economic rent, $\pi = PH - TC$, with regards to effort and given the necessary condition, $\frac{\delta\pi}{\delta E} = 0$. The steady state effort follows,

$$\pi = \left(PeS_{max} - \frac{e}{g}PeES_{max} - w\right)E$$

$$\frac{\delta\pi}{\delta E} = PeS_{max} - 2\frac{e}{g}PeES_{max} - w = 0$$

$$E_{SO} = \frac{1}{2}\frac{g}{e}\left(1 - \frac{w}{PeS_{max}}\right) \tag{30}$$

The stock when the economic rent is maximised follows by inserting the optimal effort in the equation for steady stake stock,

$$S_{SO} = S_{max}\left(1 - \frac{e}{g}E_{SO}\right)$$

$$S_{SO} = \frac{1}{2}S_{max}\left(1 + \frac{w}{PeS_{max}}\right) \tag{31}$$

Increased effort on the margin reduces the steady state stock. The overall equilibrium harvest if found by inserting for efforts (30) and stock (31) in the harvest production function,

$$H(E_{SO}) = eE_{SO}S_{SO}$$

$$H(E_{SO}) = e\frac{1}{4}\frac{g}{e}S_{max}\left(1 - \frac{w}{PeS_{max}}\right)\left(1 + \frac{w}{PeS_{max}}\right)$$

$$H(E_{SO}) = \frac{1}{4}gS_{max}\left(1 - \left(\frac{w}{PeS_{max}}\right)^2\right) \tag{32}$$

The overall profit follows from inserting for the optimal harvest (32) and the optimal stock (31) in the profit function,

$$\pi = PH(E_{SO}) - wE_{SO}$$

$$\pi = P\frac{1}{4}gS_{max}\left(1 - \left(\frac{w}{PeS_{max}}\right)^2\right) - w\frac{1}{2}\frac{g}{e}\left(1 - \frac{w}{PeS_{max}}\right)$$

$$\pi_{SO} = \frac{1}{4}g\left(PS_{max} - \frac{2w}{e} + \frac{w^2}{Pe^2S_{max}}\right) \tag{33}$$

When overall efforts are equally split in the joint management, then each country will gain half of the overall profits,

$$\pi_1 = \pi_2 = \frac{1}{2}g\left(PS_{max} - \frac{2w}{e} + \frac{w^2}{Pe^2S_{max}}\right) \tag{34}$$

3. 4 Open Access

The Open Access fishery is a benchmark in contrast to that of a Sole Owner. In Open Access, the fishing industry is perfectly competitive and there are no property rights and no regulations governing the individual EEZ zones or the shared fish stock. The fishery is open to exploitation by any vessel. Hence, an open access scenario shares the characteristics of the perfect competition model as there is a large number of price-taking individual fishers exploiting the shared stock, and each vessel is free to enter or exit the fishery (Perman 2011).

Open access is the competitive equilibrium where the average revenue will be equal across vessels. Vessels will enter the fishery if revenue per unit of effort is greater than the cost, and exit the fishery if cost per unit is higher than revenue. Hence the most efficient vessels, or the most efficient fleet, will harvest the resource. In the Gordon-Schaefer model, perfect competition leads to a misallocation of resources (market failure) due to the common pool nature of fish (Bjørndal and Munro 2012). A static open access equilibrium leads to dissipation of the economic rent and is characterized by excessive use of capital, labour and stock. Total profits are driven to zero, $\pi = PH - wE = 0$, which implies that average costs equal marginal costs. Total profits are 0 for constant marginal costs. However, if there are limits on capacity or increasing marginal costs, there may be some economic rents accrued to the fleet or the fishermen with the smaller than equilibrium marginal costs.

By solving for overall efforts, E,

$$\pi = P\left(eS_{max} - eES_{max}\frac{e}{g}\right) - wE = 0$$

$$E_{OA} = \frac{g}{e}\left(1 - \frac{w}{PeS_{max}}\right) \tag{35}$$

The level of stock in open access is found by inserting for the solution of equilibrium effort,

$$S_{OA} = \left(1 - \frac{eE_{OA}}{g}\right)S_{max}$$

$$S_{OA} = \left(\frac{w}{Pe}\right) \tag{36}$$

Similarly, the total harvest is found by inserting for equilibrium solutions of stock and effort,

$$H_{OA} = eE_{OA}S_{OA} = e\frac{g}{e}\left(1 - \frac{w}{PeS_{max}}\right)\frac{w}{Pe}$$

$$H_{OA} = \frac{wg}{Pe}\left(1 - \frac{w}{PeS_{max}}\right) \tag{37}$$

In open access, marginal cost of effort equals the average revenue. At this level, the resource rent is zero. Effort is higher than the level of effort that maximises the resource rent, and the stock is reduced until the average revenue equals the marginal cost of effort.

3. 5 The Stackelberg Duopoly

In Stackelberg, one leader has a first mover advantage and can chose its strategic effort first, which the follower observes and takes into account when deciding her level of efforts. In this sense, the duopoly is a variation of Cournot, as the countries moves sequentially rather than simultaneously (Watson 2013). The leader cannot deviate from his choice, and must be able to commit to her move. In the fishery in this study, the leader may inherit a natural advantage that places her in a position to decide the choice of efforts first, and the scope of its harvest, while the follower observes this choice and then decides on her harvest level (optimal effort). In sequential games, backward induction will be used to find the Nash-equilibrium, hence the decision of the follower will be the taken into account by the leader (Belleflamme and Peitz 2010).

Let's assume that the leader, Country 1, knows that the follower, Country 2, will follow. First, the leader takes the followers response function as given and maximises its economic rent given the necessary condition $\frac{\partial \pi_1}{\partial E_1} = 0$:

$$\pi_1 = \left(\frac{1}{2} PeS_{max} - \frac{1}{2}\frac{e}{g} PeE_1S_{max} + \frac{1}{2}w - w\right) E_1$$

$$\frac{e}{g} PeE_1S_{max} = \frac{1}{2} PeS_{max} - \frac{1}{2}w$$

$$E_L = \frac{1}{2}\frac{g}{e}\left(1 - \frac{w}{PeS_{max}}\right) \tag{38}$$

Country 2 observes takes the leader's efforts as given and maximises profits of its own fishery resource using the Cournot-response function as before. Solving Country 2's best response function is done by inserting for the leaders choice of effort, E_L in the equation (no.)

$$E_F = \frac{1}{2}\frac{g}{e}\left(1 - \frac{w}{PeS_{max}}\right) - \frac{1}{2}E_L$$

$$E_F = \frac{1}{2}\frac{g}{e}\left(1 - \frac{w}{PeS_{max}}\right) - \frac{1}{4}\frac{g}{e}\left(1 - \frac{w}{PeS_{max}}\right)$$

$$E_F = \frac{1}{4}\frac{g}{e}\left(1 - \frac{w}{PeS_{max}}\right) \tag{39}$$

The leader has a first-mover advantage, and chooses a level of effort for Country 1 higher than the optimal level of effort for Country 2, $E_L > E_F$. The overall efforts made in the Stackelberg-duopoly is the sum of the strategic choices of efforts made by the leader (38) and the follower (39),

$$E_L + E_F = \frac{3}{4}\frac{g}{e}\left(1 - \frac{w}{PeS_{max}}\right) \tag{40}$$

The Stackelberg stock-equilibrium is found by inserting for the optimal efforts,

$$S_{Stackelberg} = \left(1 - \frac{e}{g}E_L - \frac{e}{g}E_F\right)S_{max}$$

$$S_{Stackelberg} = \left(1 - \frac{1}{2}\left(1 - \frac{w}{PeS_{max}}\right) - \frac{1}{4}\left(1 - \frac{w}{PeS_{max}}\right)\right)S_{max}$$

$$S_{Stackelberg} = \frac{1}{4}\left(1 + \frac{3w}{PeS_{max}}\right)S_{max} \tag{41}$$

As in the models of Cournot, a Sole Owner and Open Access, the equilibrium stock increases with costs, and is reduced for higher levels of the catchability coefficient.

The Stackelberg leader's harvest is found by using the steady state stock (41) and the leader's optimal effort (38),

$$H_L = eE_LS$$

$$H_L = e\frac{1}{2}\frac{g}{e}\left(1 - \frac{w}{PeS_{max}}\right)\frac{1}{4}\left(1 + \frac{3w}{PeS_{max}}\right)(S_{max})$$

$$H_L = \frac{1}{8}g\left(1 + \frac{2w}{PeS_{max}} - \frac{3w^2}{(PeS_{max})^2}\right)S_{max} \tag{42}$$

The Stackelberg follower's harvest follows from inserting her optimal effort (39) and steady state stock (41) in her harvest production function,

$$H_F = eE_FS$$

$$H_F = \frac{1}{4}\frac{1}{4}gS_{max}\left(1 - \frac{w}{Pe_2S_{max}}\right)\left(1 + \frac{3w}{PeS_{max}}\right)$$

$$H_F = \frac{1}{16}gS_{max}\left(1 + \frac{2w}{PeS_{max}} - \frac{3w^2}{(PeS_{max})^2}\right) \tag{43}$$

The overall harvest in the symmetric Stackelberg scenario follows from the parametric solution equations of the individual harvests,

$$H = H_L + H_F = \frac{3}{16}gS_{max}\left(1 + \frac{2w}{PeS_{max}} - \frac{3w^2}{(PeS_{max})^2}\right) \tag{44}$$

Individual profits are found by inserting for harvest and efforts in the individual profit functions. The Stackelberg leader's profits is

$$\pi_L = PH - wE_L$$

$$\pi_L = \frac{1}{8} g \left(1 + \frac{2w}{PeS_{max}} - \frac{3w^2}{(PeS_{max})^2}\right) S_{max} - w \frac{1}{2} \frac{g}{e} \left(1 - \frac{w}{PeS_{max}}\right)$$

$$\pi_L = \frac{1}{8} g \left(PS_{max} + \frac{2w}{e} - \frac{3w^2}{Pe^2 S_{max}} - \frac{4w}{e} + \frac{4w^2}{Pe^2 S_{max}}\right)$$

$$\pi_L = \frac{1}{8} g \left(PS_{max} - \frac{2w}{e} + \frac{w^2}{Pe^2 S_{max}}\right) \quad (45)$$

and the Stackelberg follower's profit becomes,

$$\pi_F = P \frac{1}{16} g S_{max} \left(1 + \frac{2w}{PeS_{max}} - \frac{3w^2}{(PeS_{max})^2}\right) - w \frac{1}{4} \frac{g}{e} \left(1 - \frac{w}{PeS_{max}}\right)$$

$$\pi_F = \frac{1}{16} g \left(PS_{max} + \frac{2w}{e} - \frac{3w^2}{PeS_{max}} - \frac{4w}{e} + \frac{4w^2}{Pe^2 S_{max}}\right)$$

$$\pi_F = \frac{1}{16} g \left(PS_{max} - \frac{2w}{e} + \frac{w^2}{PeS_{max}}\right) \quad (46)$$

The Stackelberg leader's profits are twice the size of the Stackelberg follower's profits, $\pi_L > \pi_F$, reflecting the leader's first mover advantage. Total profits follows from the sum of the individual profits,

$$\pi = \pi_L + \pi_F = \frac{3}{16} g \left(PS_{max} - \frac{2w}{e} + \frac{w^2}{Pe^2 S_{max}}\right) \quad (47)$$

3. 6 Four Symmetric Equilibrium

3. 6. 1 The Parametric Equations Summarized

Effort

Cournot	$E_{Cournot} = \frac{2}{3}\frac{g}{e}\left(1 - \frac{w}{PeS_{max}}\right)$
Stackelberg	$E_{SE} = \frac{3}{4}\frac{g}{e}\left(1 - \frac{w}{PeS_{max}}\right)$
Sole Owner	$E_{SO} = \frac{1}{2}\frac{g}{e}\left(1 - \frac{w}{PeS_{max}}\right)$
Open Access	$E_{OA} = \frac{g}{e}\left(1 - \frac{w}{PeS_{max}}\right)$

Stock

Cournot	$S_{Cournot} = \frac{1}{3}S_{max}\left(1 + \frac{2w}{PeS_{max}}\right)$
Stackelberg	$S_{Stackelberg} = \frac{1}{4}S_{max}\left(1 + \frac{3w}{PeS_{max}}\right)$
Sole Owner	$S_{SO} = \frac{1}{2}S_{max}\left(1 + \frac{w}{PeS_{max}}\right)$
Open Access	$S_{OA} = \frac{w}{Pe}$

Harvest

Cournot	$H_1 + H_2 = \frac{2}{9}gS_{max}\left(1 + \frac{w}{PeS_{max}} - \frac{2w^2}{(PeS_{max})^2}\right)$
Stackelberg	$H_L + H_F = \frac{3}{16}g\left(1 + \frac{2w}{PeS_{max}} - \frac{3w^2}{(PeS_{max})^2}\right)S_{max}$
Sole Owner	$H_{SO} = \frac{1}{4}gS_{max}\left(1 - \left(\frac{w}{PeS_{max}}\right)^2\right)$
Open Access	$H_{OA} = \frac{wg}{Pe}\left(1 - \frac{w}{PeS_{max}}\right)$

Profits

Cournot	$\pi = \frac{2}{9}g\left(PS_{max} - \frac{2w}{e} + \frac{w^2}{Pe^2S_{max}}\right)$
Stackelberg	$\pi_L + \pi_F = \frac{3}{16}g\left(PS_{max} - \frac{2w}{e} + \frac{w^2}{Pe^2S_{max}}\right)$
Sole Owner	$\pi_{SO} = \frac{1}{4}g\left(PS_{max} - \frac{2w}{e} + \frac{w^2}{Pe^2S_{max}}\right)$
Open Access	$\pi_{OA} = 0$

3. 6. 2 Steady State Efforts

Overall efforts are highest in the Open Access (35), followed by Stackelberg (40), Cournot (17) and then the Sole Owner (30):

$$E_{OA} > E_{Stackelberg} > E_{Cournot} > E_{SO} \quad (48)$$

In other words, joint efforts are lowest if the countries cooperate and act as a Sole Owner. This bio economic finding is in line with economic literature on strategic choices and output in a duopoly: If there is regional cooperation, the countries' joint efforts would be lower than if they are acting as profit maximising Cournot-duopolists (Belleflamme and Peitz 2010). The Open Access equilibrium occurs at higher efforts and lower stock than the regulated scenarios of a Sole Owner, a Cournot and Stackelberg duopoly. Moreover, the level of fishing effort in Open Access is found to be twice the fishing effort associated with the Sole Owner.

A general theoretic finding is that the individual strategic choice of the level of production in the simultaneous Cournot-game is lower than the leader's level of production, but higher than the follower's level of output (Belleflamme and Peitz 2010). In our case, this is true for efforts: the strategic level of individual efforts made by the Cournot duopolists (16) are lower than the Stackelberg leader's efforts (38), but higher than the follower's efforts (39):
$E_L > E_{1,Cournot} > E_F$

$$E_L = \frac{1}{2}\frac{g}{e}\left(1 - \frac{w}{PeS_{max}}\right) > E_{Cournot} = \frac{1}{3}\frac{g}{e}\left(1 - \frac{w}{PeS_{max}}\right) > E_F = \frac{1}{4}\frac{g}{e}\left(1 - \frac{w}{PeS_{max}}\right)$$

Overall Stackelberg efforts are larger than overall Cournot efforts. The reason for this is that the leader will use more efforts than she would in Cournot, and the Stackelberg follower will not reduce her efforts as much as the leader will increase her efforts (Belleflamme and Peitz 2010). Efforts made by the leader are larger than her efforts would be under regional cooperation, but smaller (and half of) the overall Open Access efforts.

3. 6. 3 Steady State Harvest

Overall efforts under regional cooperation will always be lower than efforts yielding MSY when costs are positive (30). Thus, we expect overall harvest in the Sole Owner scenario to be at lower levels than the MSY. It is unclear whether efforts in Cournot, Stackelberg and Open Access and are higher or lower than the MSY[3], and thus how the harvest will change by increases in costs or catchability. The leader's harvest will however always be higher than the follower's harvest, due to profitability. We find that both the harvest and the profit of the leader is twice as large as the follower's catch:

$$H_L = \frac{1}{8} gS_{max} \left(1 + \frac{2w}{PeS_{max}} - \frac{3w^2}{(PeS_{max})^2}\right) > H_F = \frac{1}{16} gS_{max} \left(1 + \frac{2w}{PeS_{max}} - \frac{3w^2}{(PeS_{max})^2}\right)$$

3. 6. 4 Steady State Stock

It follows from the steady state solutions of stock (19), (31), (36) and (41) that it must be highest in the case of a Sole Owner, followed by the Cournot solution, then Stackelberg and lastly, the Open Access solution is characterized by the smallest size of stock. The steady state stock function is an expression of the two countries' individual efforts, and decreases by an increase in efforts made by either country, as $\frac{\delta S_{sy}}{\delta E_1} < 0$ and $\frac{\delta S_{sy}}{\delta E_2} < 0$.

$$S_{SO} > S_{Cournot} > S_{Stackelberg} > S_{OA}$$

$$\frac{1}{2} S_{max} \left(1 + \frac{w}{PeS_{max}}\right) > \frac{1}{3} S_{max} \left(1 + \frac{2w}{PeS_{max}}\right) > \frac{1}{4}\left(1 + \frac{3w}{PeS_{max}}\right) S_{max} > \frac{w}{Pe}$$

3. 6. 5 Steady State Profits

The order of the overall profits are follow from (28), (33) and (47) and is $\pi_{SO} > \pi_{Cournot} > \pi_{Stackelberg} > \pi_{OA}$. When countries cooperate, joint profits are highest and efforts are minimized. The Sole Owner's catch maximises the overall resource rent and this is a Pareto-efficient equilibrium as it is not possible to make one player better off except at the expense of the other player. Optimality here is similar to a case with maximising net present value with no discount rate. (Perman 2011)

The individual profits of the Stackelberg-leader equals the individual profits in the benchmark scenario of a joint management regime when overall profits are equally spilt across countries.

[3] Proof: From equations (5) and (6) we find that $H = G$ in the symmetric scenario yields $H = eS_{max}E - \frac{1}{g} e^2 E^2 S_{max}$. In knowing that $\frac{\delta H}{\delta E} = 0$ is the necessary condition for maximum sustainable harvest, we find: $\frac{\delta H}{\delta E} = eS_{max} - 2\frac{e^2}{g} ES_{max} = 0$, $E_{msy} = \frac{1}{2}\frac{g}{e}$.

This profit is twice the size of the Stackelberg follower's profits $(\pi_{1,SO} = \pi_L = 2\pi_F)$. However, in the Stackelberg steady state, overall profits are not maximised. Overall efforts are large and overall stock is reduced and close to Open Access. The leader's profits are higher than the individual Cournot profits and the follower's rent is the smallest. $\pi_{1,SO} = \pi_L > \pi_{1,cournot} > \pi_F$. This is in line with general Stackelberg findings (Belleflamme and Peitz 2010). In our case, the leader's profits are twice as large as the follower's profits:

$$\frac{1}{8}g\left(PS_{max} - \frac{2w}{e} + \frac{w^2}{Pe^2S_{max}}\right) > \frac{1}{9}g\left(PS_{max} - \frac{2w}{e} + \frac{w^2}{Pe^2S_{max}}\right) > \frac{1}{16}g\left(PS_{max} - \frac{2w}{e} + \frac{w^2}{PeS_{max}}\right)$$

The leader will be better off than the follower in terms of gains in profits, but overall profits are reduced, which highlights the first mover advantage and the importance of interdependency of strategies. (Belleflamme and Peitz 2010) For the society as a whole, there is a theoretic economic incentive for 1) cooperation in stock research and Cournot – behaviour and 2) active regional management cooperation and joint profit maximation, in line with literature on fishery economics and transboundary fish stocks (Munro 2002).

4 A Closer Look at the Cournot Equilibrium

This section deals with the Cournot-duopoly, strategic behaviour and the effects of the parameters *w* and *e* on equilibrium effort, harvest, stock and profits. First, there will be a theoretical discussion on changes in a country's costs, followed by a discussion about the effects of changes in the catchability coefficient. Then there will be a short discussion on a scenario in which Country 1 is more efficient than Country 2.

4. 1 Changes In A Country's Costs [a]

In this section, the effect of a change in the individual costs of Country 1 on individual and overall efforts, harvest and profits, and the shared stock will be analysed. When the countries are symmetric, an increase in costs applies for both countries.

4. 1. 1 Effect on Individual and Total Efforts

Individual Efforts

An increase in a country's individual costs will have opposite effects on the two countries' efforts. The two effects are derived from equations (13) and (14)

$$\delta E_1/\delta w_1 = -\frac{2}{3}\frac{g}{e_1}\left(\frac{1}{Pe_1 S_{max}}\right) < 0$$

Country 1's steady state efforts are reduced. An increase in own costs implies that own efforts are less profitable: The same level of effort yesterday is more costly today. The reduction in efforts will then be relatively less the higher her catchability is.

Since efforts in the fishery duopoly are strategic substitutes, we know that if Country 1 reduces her efforts, Country 2 should increase her efforts. The second effect of the cost increase is thus not surprising. The proof follows by differentiating equation (14)

$$\delta E_2/\delta w_1 = \frac{1}{3}\frac{g}{e_2}\left(\frac{1}{Pe_1 S_{max}}\right) > 0$$

An increase in Country 1's costs is a relative advantage for Country 2 and implies that Country 2's best response is to increase her efforts.

If the countries have equal catchability coefficients, then Country 1 would reduce her efforts more than Country 2 will increase her efforts, which is also the case if the catchability coefficients differ such that $2e_1 > e_2$. If Country 2 has the least efficient fleet, then she is more sensitive to Country 1's cost-increase than Country 1 would be to an increase in Country 2's costs.

Total Efforts

The total effect of the changes in efforts depends on the catchability. The direction of efforts is equal to the sum of the two opposing effects,

$$\delta E/\delta w_1 = \delta E_1/\delta w_1 + \delta E_2/\delta w_1$$

$$\delta E/\delta w_1 = \frac{1}{3}\frac{g}{e_1}\left(\frac{1}{Pe_2S_{max}} - \frac{2}{Pe_1S_{max}}\right)$$

$$\delta E/\delta w_1 < 0 \; for \; \frac{e_1}{e_2} < 2$$

$$\delta E/\delta w_1 > 0 \; for \; \frac{e_1}{e_2} > 2$$

$$\delta E/\delta w_1 = 0 \; for \; \frac{e_1}{e_2} = 2$$

Overall efforts will be reduced for $e_1 = e_2$. In general, efforts are reduced by an increase in costs if the inequality $e_1 < 2e_2$ holds. In the open access and sole owner equilibrium, an increase in costs will imply that efforts are reduced.(Perman 2011)

In the symmetric case, efforts are pure strategic substitutes. One country's unit change in effort can be replaced by the other country's unit effort. A change in costs will have an equal effect on the direction of both individual and total efforts is the sum of the two equal effects. The result is derived from equation (17)

$$\delta E/\delta w = -\frac{2}{3}\frac{g}{e}\left(\frac{1}{PeS_{max}}\right) < 0$$

An increase in either country's cost per unit of effort will imply that individual and total efforts will be reduced.

4. 1. 2 Effect on Steady State Stock

An increase in one country's individual costs, will lead to an increase in the steady state stock. This proof can be derived from equation (18)

$$\frac{\delta S_{Cournot}}{\delta w_1} = \frac{1}{3}\frac{1}{Pe_1} > 0$$

Note that steady state stock will increase by an increase in costs, even though overall effort can be increased for $e_1 > 2e_2$. This special case will be exemplified later in the numerical model.

When Country 2 has the least efficient fleet, then Country 2 is more sensitive to Country 1's cost-increase than Country 1 would be to an increase in country 2's costs. The derivation, $\frac{\delta S_{Cournot}}{\delta w_1}$, then proves that the stock will respond less to a change in Country 1's cost-increase, than to an increase in Country 2's costs.

$$\frac{\delta S_{Cournot}}{\delta w_1} < \frac{\delta S_{Cournot}}{\delta w_2}$$

Also in the symmetric steady state stock will increase by an increase in costs. This result is found by differentiating the parametric equilibrium solution (19),

$$\frac{\partial S}{\partial w} = \frac{2}{3Pe} S_{max} > 0$$

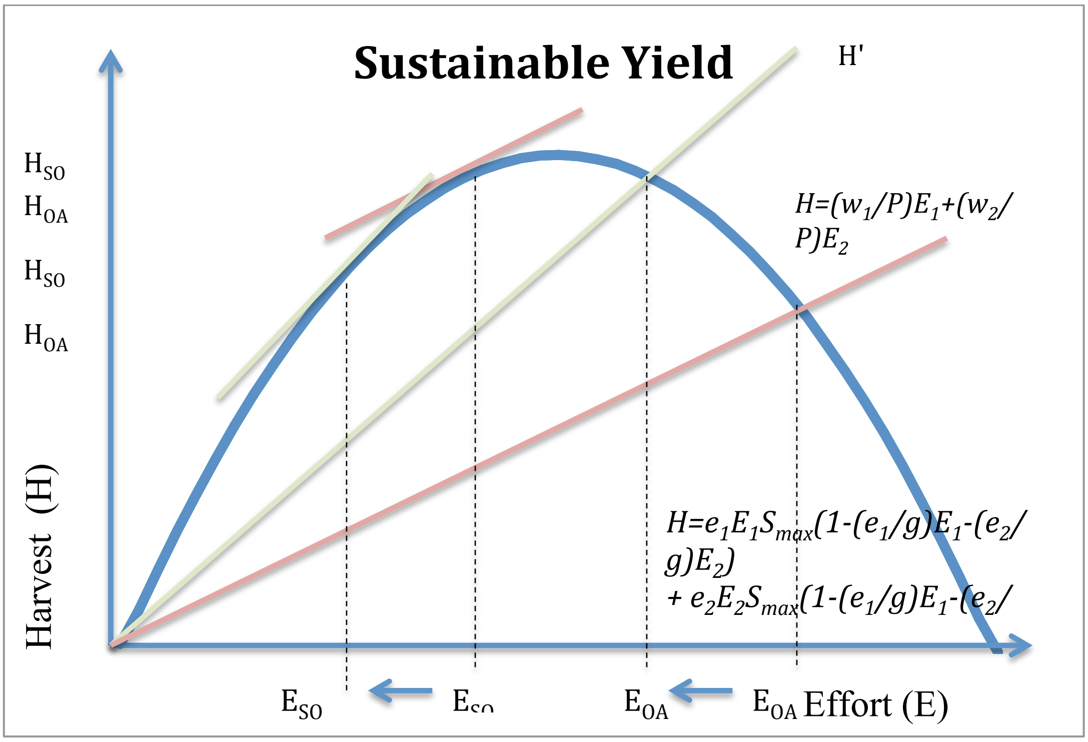
The steady state stock is increased if there is an increase in costs. Open Access stock will increase most, followed by Stackelberg, Cournot and then the Sole Owner.

$$\frac{\delta S_{OA}}{\delta w} > \frac{\delta S_{Stackelberg}}{\delta w} > \frac{\delta S_{cournot}}{\delta w} > \frac{\delta S_{SO}}{\delta w}$$

The Sole Owner will to the largest extent take into account effects on the shared stock, affecting profitability.

The sustainable level of harvest (inverted U-curve) and the linear costs of the fishery is presented in Figure 1 below. Imagine an initial level of costs such that efforts in the Open Access equilibrium is located at higher levels than those giving rise to MSY. As we can see from the figure, there are no economic rents accrued to the Open Access solution, where the two curves intersect. The rent is however maximised at the effort level where the space between the revenues (overall harvest) and the costs is the largest. As stated before, the duopoly scenario is expected to be located between the two benchmark equilibriums. Hence, we expect efforts in Cournot and the Stackelberg to be higher than Sole Owner, but lower than in Open Access. An increase in costs rotates the cost curve towards the left, as illustrated by the curve H'. Accordingly, Cournot efforts are reduced for equal catchability coefficients. Since the Sole Owner is placed to the left of the MSY, her harvest is reduced, and accordingly, the economic rent is reduced. On the other side, the harvest in Open Access is increased as it is on the right side of the maximum sustainable yield. The same reasoning can be applied to the direction of harvest in Cournot, depending on whether her location was to the left or to the right of MSY-efforts.

Figure 1: Sustainable Harvest and a Change in Costs Illustrated



4. 1. 3 Effect on Individual and Total Harvest

Individual Harvest

The effect of a change in Country 1's costs on individual harvests follow from equations (20) and (21),

$$\frac{\partial H_1}{\partial w_1} = -\frac{1}{9}\frac{g}{Pe_1}\left(1 + \frac{w_2}{Pe_2 S_{max}} + \frac{4w_1}{Pe_1 S_{max}}\right) < 0$$

Country 1's harvest is reduced by an increase in its own costs,

$$\frac{\partial H_2}{\partial w_1} = \frac{1}{9}\frac{g}{Pe_1}\left(2 + \frac{2w_1}{Pe_1 S_{max}} - \frac{w_2}{Pe_2 S_{max}}\right) > 0$$

Country 2's steady state harvest is increased.

These directions follow from equation (14), which proves that $\left(1 + \frac{2w_1}{Pe_1 S_{max}} - \frac{w_2}{Pe_2 S_{max}}\right)$ must be positive for efforts be strictly positive Moreover, the result also follows from the harvest production function. The marginal increase in costs implies an increase in both overall stock and Country 2's efforts. Since the catchability coefficient remains constant, it follows from Country 2's harvest function, $H_2 = e_2 E_2 S$, that also Country 2's harvest must increase.

Total Harvest

The effect of an increase in Country 1's costs on the total harvest is ambiguous and depends on which side of the MSY equilibrium the Cournot equilibrium is located. This effect is equal to the sum of the changes in the individual harvests $\left(\frac{\partial H_1}{\partial w_1} + \frac{\partial H_2}{\partial w_1}\right)$. The effect of an increase in costs on total harvest also follows from equation (22),

$$\frac{\partial H}{\partial w_1} = \frac{1}{9}\frac{g}{Pe_1}\left(1 - \frac{2w_1}{Pe_1 S_{max}} - \frac{2w_2}{Pe_2 S_{max}}\right)$$

The MSY is characterized by $1 = \frac{2w_1}{Pe_1 S_{max}} + \frac{2w_2}{Pe_2 S_{max}}$. If $1 > \frac{2w_1}{Pe_1 S_{max}} + \frac{2w_2}{Pe_2 S_{max}}$ harvest will increase if there is a marginal increase in costs, $\frac{\partial H}{\partial w_1} > 0$. If overall efforts are reduced, and harvest increases, then Cournot efforts are initially higher than efforts that yield MSY. If the inequality breaks, overall efforts are reduced and harvest is reduced as Cournot is located at smaller effort levels than MSY.

In the case of symmetric countries, the effect of a change in costs on individual and overall harvest is derived from equation (23) and (24).

$$\frac{\partial H_1}{\partial w} = \frac{1}{9}\frac{g}{Pe}\left(1 - \frac{4w}{PeS_{max}}\right)$$

$$\frac{\partial H}{\partial w} = \frac{2}{9}\frac{g}{Pe}\left(1 - \frac{4w}{PeS_{max}}\right)$$

If $1 = \frac{4w}{PeS_{max}}$, the steady state is located at levels of stock and efforts of maximum sustainable harvest. We can read from the equation, that when there is an increase in costs, steady state harvest will increase if $1 > \frac{4w}{PeS_{max}}$ and decrease if the inequality breaks. If the steady state stock is located at a smaller level than MSY, then more effort will imply a higher harvest, while if it is located above the MSY-levels, more effort will imply less harvest.

In general, an increase in costs will rotate the linear cost curve towards the left, making it more profitable to cut the initial the harvest of stock. If the Cournot-equilibrium is located at the right side of the MSY-equilibrium, then an increase in costs will reduce efforts and thus increase the harvest. On the other side, if the Cournot-equilibrium is located on the left side of the MSY-equilibrium, and efforts and harvest will be reduced.

4. 1. 4 Effect on Individual and Total Profits

Individual Profits

Individual profits go in opposite directions. The changes in profits follow from equations (25) and (26).

$$\frac{\partial \pi_1}{\partial w_1} = -\frac{4}{9}\frac{g}{e_1}\left(1 + \frac{w_2}{Pe_2S_{max}} - \frac{2w_1}{Pe_1S_{max}}\right) < 0$$

$$\frac{\partial \pi_2}{\partial w_1} = \frac{2}{9}\frac{g}{e_1}\left(1 + \frac{w_1}{Pe_1S_{max}} - \frac{2w_2}{Pe_2S_{max}}\right) > 0$$

While Country 1's profits are reduced, Country 2's profits are increased. It follows from equation (13) and (14) that the parentheses must be positive. In the Cournot model with homogeneous outputs, a player's equilibrium profits increases when the firm becomes relatively more cost-efficient than its rivals (Belleflamme and Peitz 2010).

Total Profits

The direction of overall profits depends on differences between the two countries. The effect of a cost increase on total profits is derived from equation (27).

$$\pi = -\frac{2}{9}\frac{g}{e_1}\left(1 + \frac{4w_2}{Pe_2S_{max}} - \frac{5w_1}{Pe_1S_{max}}\right)$$

The direction of the effect on profits is not clear. If costs increase, the strategic choice of Country 1 is to reduce her efforts and Country 2 will respond by increasing her efforts (strategic substitutes), but how much depends on their individual catchability. The increase in costs implies that Country 1 loses profits when efforts and harvest is reduced, while Country 2 will increase efforts and harvest and gain profits. The overall direction of profits depends on the catchability coefficients.

From the individual profits, we know that overall profits must go down if they were equal before the increase. This is because Country 1's profits are reduced more than those of Country 2. This can be demonstrated in the figure of the inverted U-Harvest curve above.

In the case of symmetric players, profits are reduced by an increase in the cost per unit effort. The effect of changes in costs on individual and overall profits follow from equations (28) and (29).

$$\frac{\partial \pi_1}{\partial w} = -\frac{2}{9}\frac{g}{e}\left(1 - \frac{w}{PeS_{max}}\right) < 0$$

$$\frac{\partial \pi}{\partial w} = -\frac{4}{9}\frac{g}{e}\left(1 - \frac{w}{PeS_{max}}\right) < 0$$

This is because the inequality $1 > \frac{w}{PeS_{max}}$ must hold for an interior solution (positive efforts) (16, 17). A change in costs will have a larger negative effect on the Sole Owner, followed by the effect on the Cournot equilibrium, and then on the overall Stackelberg profits.

$$\frac{\partial \pi_{SO}}{\partial w} < \frac{\partial \pi_{cournot}}{\partial w} < \frac{\partial \pi_{stackelberg}}{\partial w}$$

4. 2 Changes In A Country's Catchability Coefficient [b]

In this subchapter, we will take a closer look at the effects of a positive change in Country 1's catchability coefficient on the shared stock, and on individual and overall efforts, harvests and profits.

4. 2. 1 Effect on Individual and Total Efforts

Individual Efforts

An increase in one country's individual catchability coefficient affects both countries' efforts. The effect on Country 1's own efforts is found by differentiating equation (13)

$$\delta E_{1,Cournot}/\delta e_1 = -\frac{1}{3}\frac{g}{e_1^2}\left(1 - \frac{4w_1}{Pe_1S_{max}} + \frac{w_2}{Pe_2S_{max}}\right)$$

Country 1's efforts will decrease if $1 > \frac{4w_1}{Pe_1S_{max}}$. If the inequality does not hold, the effect will be ambiguous. The direction of efforts of Country 2 however is negative and found by deriving equation (14)

$$\delta E_2/\delta e_1 = -\frac{1}{3}\frac{g}{e_2}\left(\frac{w_1}{Pe_1^2S_{max}}\right) < 0$$

Total Efforts

The effect on total efforts is ambiguous and follows from equation (15).

$$\delta E/\delta e_1 = -\frac{1}{3}\frac{g}{e_1^2}\left[1 - \frac{4w_1}{Pe_1S_{max}} + \frac{w_2}{Pe_2S_{max}} + \frac{w_1}{Pe_2S_{max}}\right]$$

$$\delta E/\delta e_1 > 0 \text{ if } \left(1 - \frac{4w_1}{Pe_1S_{max}} + \frac{w_1+w_2}{Pe_2S_{max}}\right) < 0$$

$$\delta E/\delta e_1 < 0 \text{ if } \left(1 - \frac{4w_1}{Pe_1S_{max}} + \frac{w_1+w_2}{Pe_2S_{max}}\right) > 0$$

$$\delta E/\delta e_1 = 0 \text{ if } \left(1 - \frac{4w_1}{Pe_1S_{max}} + \frac{w_1+w_2}{Pe_2S_{max}}\right) = 0$$

Even though the stock is reduced, it is not clear that overall efforts are increased. Overall efforts will decrease if $1 > \frac{4w_1}{Pe_1S_{max}}$ if not the effect is ambiguous. The effect of an increase in the catchability on efforts is also ambiguous in the case of Open Access and the Sole Owner (Perman 2011).

Also when countries are symmetric, an increase in the catchability coefficient has an ambiguous effect on efforts. The effects follow from equations (16) and (17). Overall efforts are reduced if $1 > \frac{2w}{PeS_{max}}$

$$\delta E_1/\delta e = -\frac{1}{3}\frac{g}{e^2}\left(1 - \frac{2w}{PeS_{max}}\right)$$

$$\delta E_{cournot}/\delta e = -\frac{2}{3}\frac{g}{e^2}\left(1 - \frac{2w}{PeS_{max}}\right)$$

4. 2. 2 Effect on Steady State Stock

Steady state stock decreases if there is an increase in a country's catchability coefficient. The result follows from equation (18),

$$\frac{\partial S}{\partial e_1} = -\frac{w_1}{3Pe_1^2} < 0$$

This is also the case in Open Access and Sole Owner. (Perman 2011) and when countries are symmetric. The latter proof follows from equation (19),

$$\frac{\partial S}{\partial e} = -\frac{2w}{3Pe^2} < 0$$

An increase in the catchability coefficient reduces the steady state stock. The stock is reduced more in an Open Access scenario, followed by the Stackelberg, Cournot and lastly the Sole Owner steady state stock.

$$\left|\frac{\delta S_{OA}}{\delta e}\right| > \left|\frac{\delta S_{Stackelberg}}{\delta e}\right| > \left|\frac{\delta S_{cournot}}{\delta e}\right| > \left|\frac{\delta S_{SO}}{\delta e}\right|$$

4. 2. 3 Effect on Individual and Total Harvest

Individual Harvest

The effect of a change in the catchability coefficient on individual harvest are found by differentiating equations (20) and (21).

Country 1's harvest will be increased.

$$\frac{\partial H_1}{\partial e_1} = \frac{1}{9}\frac{gw_1}{Pe_1^2}\left(1 + \frac{w_2}{Pe_2S_{max}} + \frac{4w_1}{Pe_1S_{max}}\right) > 0$$

Country 2’s harvest will be reduced

$$\frac{\partial H_2}{\partial e_1} = -\frac{1}{9}\frac{gw_1}{Pe_1^2}\left(2 - \frac{w_2}{Pe_2S_{max}} + \frac{2w_1}{Pe_1S_{max}}\right) < 0$$

The directions of individual harvest follow from equation (14), which proves that the expression $\left(1 + \frac{2w_1}{Pe_1S_{max}} - \frac{w_2}{Pe_2S_{max}}\right)$ must be positive for efforts to be strictly positive. The marginal increase in catchability implies a reduction in the stock and in Country 2’s efforts. Since Country 2’s catchability coefficient remains constant, it follows from her harvest function $H_2 = e_2E_2S$ that also her harvest must be reduced.

Total Harvest

The change in overall harvest is the sum of the two opposite changes found in the above equations, and follows from equation (22)

$$\frac{\partial H}{\partial e_1} = -\frac{1}{9}\frac{gw_1}{Pe_1^2}\left(1 - \frac{2w_1}{Pe_1S_{max}} - \frac{2w_2}{Pe_2S_{max}}\right)$$

This effect is unclear which is also the case of open access, but not Sole Owner where harvest will increase. (Perman 2011) As before, we find that MSY is characterized by $1 = \frac{2w_1}{Pe_1S_{max}} + \frac{2w_2}{Pe_2S_{max}}$. Harvest changes depending on where Cournot is located according to the MSY and will decrease if $1 > \frac{2w_1}{Pe_1S_{max}} + \frac{2w_2}{Pe_2S_{max}}$.

Since the symmetric total harvest is twice the size of a country’s individual harvest, the effect of the catchability coefficient on the direction of the individual and total harvest is the same. This effect is ambiguous and depends on where the equilibrium is located according to MSY. The result is derived from equations (23) and (24),

$$\frac{\partial H_1}{\partial e} = -\frac{1}{9}\frac{gw}{Pe}\left(1 - \frac{4w}{PeS_{max}}\right)$$

$$\frac{\partial H}{\partial e} = -\frac{2}{9}g\frac{w}{Pe}\left(1 - \frac{4w}{PeS_{max}}\right)$$

The steady stock is located to the left of MSY is the harvest increases, and on the right of the MSY if harvest decreases. If $1 = \frac{4w}{PeS_{max}}$, steady state stock and effort is located at the maximum sustainable yield. Harvest will decrease if the inequality $1 > \frac{4w}{PeS_{max}}$ holds and increase if it breaks. If the steady state stock is located at a smaller level than the MSY-level, then more effort will imply a higher harvest. If the stock is located on the right of the MSY, more efforts will imply less harvest. Based on the results for efforts and harvest, a general rule is that efforts will decrease and harvest will increase if $4w > PeS_{max} > 2w$.

4. 2. 4 Effect on Individual and Total Profits

Individual Profits

Changes in individual profits have opposite directions. While Country 1's profits will increase, Country 2's profits will decrease. These effects follow from eq. (25) and (26)

$$\frac{\partial \pi_1}{\partial e_1} = \frac{4}{9}\frac{gw_1}{e_1^2}\left(1 - \frac{2w_1}{Pe_1S_{max}} + \frac{w_2}{Pe_2S_{max}}\right) > 0$$

$$\frac{\partial \pi_2}{\partial e_1} = -\frac{2}{9}\frac{gw_1}{e_1^2}\left(1 - \frac{2w_2}{Pe_2S_{max}} + \frac{w_1}{Pe_1S_{max}}\right) < 0$$

While Country 1's profits are increased, Country 2's profits are reduced when there is an increase in Country 1's catchability. It follows from equations (13) and (14) that the parentheses must be positive, as there is an interior solution.

Total Profits

The effect on overall profits is ambiguous and follows from equation (27)

$$\frac{\partial \pi}{\partial e_1} = \frac{2}{9}\frac{gw_1}{e_1^2}\left(1 + \frac{4w_2}{Pe_2S_{max}} - \frac{5w_1}{Pe_1S_{max}}\right)$$

Profits will increase when there is a positive change in Country 1's catchability if the inequality $\frac{4w_2}{e_2} > \frac{5w_1}{e_1}$ holds.

Individual and overall profits will increase by an increase in the catchability coefficient if countries are symmetric. The result follows from equation (28) and (29)

$$\frac{\partial \pi_1}{\partial e} = \frac{2}{9}\frac{gw}{e^2}\left(1 - \frac{w}{PeS_{max}}\right) > 0$$
$$\frac{\partial \pi}{\partial e} = \frac{4}{9}\frac{gw}{e^2}\left(1 - \frac{w}{PeS_{max}}\right) > 0$$

This must be the case since efforts are positive and the inequality $1 > \frac{w}{PeS_{max}}$ must hold, according to equations (16) and (17).

Profits will be increased if the catchability coefficient is increased and reduced if there is an increase in costs. A change in the catchability coefficient will have a larger effect on the Sole Owner (33) than on the overall Cournot-profit (29) and the effect on the overall Stackelberg-profits (47) is the smallest.

$$\frac{\partial \pi_{SO}}{\partial e} > \frac{\partial \pi_{cournot}}{\partial e} > \frac{\partial \pi_{stackelberg}}{\partial e}$$

5 The Numerical Models

In order for an active and successful management regime to be in place, cooperation in research such as scientific stock investigations must be in place initially (Munro 2002). An emphasis in this analysis is therefore be placed on the current scenario to Cournot, and Cournot to Regional Cooperation.

5. 1 Assuming Symmetry

In order to look at gains of moving from a current scenario to a scenario in which the countries act interdependently and then to regional cooperation, I will assume that the countries are symmetric. One can argue that the countries are symmetric since they have somewhat similar harvest levels (Table 1) and fleet capacity, as discussed in the background chapter. This assumption is in line with a study by Sumaila and Armstrong (2004), where the countries are assumed to have equal costs due to the character of the fishing companies. In their study, only market prices of hake differ between the two countries.

Due to the lack of transparency in information about the operating costs of the South African and Namibian deep-water trawls, I will focus on the fishing period of 2007-2009 of which Kirchner presents an estimation of the costs and efforts of the Namibian wetfish and freezer fleets. Both the Namibian and the South African fleet consist of wetfish and freezer vessels. In Namibia however, freezer vessels are granted only 30 % of the TAC. Weighted averages will therefore be taken in order to get an approximation of costs and efforts across vessel type.

The number of deep-sea vessels operating in the two economic zones is quite similar. Since 2007, both fleets have experienced a decrease in number of vessels. In 2007 there were 75 vessels operating in South Africa and 63 vessels operating in Namibia in 2008 (Kirchner and Leiman 2014, SADSTIA 2016). In comparison, today the South African fleet consists of around 27 wetfish trawlers and 25 freezer trawlers and in Namibia in 2010 there were close to 55 vessels fishing (Kirchner and Leiman 2014, SADSTIA 2016)

From Table 1 we can read that the individual catch by country is somewhat similar. In 2008, the overall catch of deep-water hake was 196 294 tonnes, of which Namibia is coarsely estimated to have harvested 90 000 tonnes and South Africa accounted for 106 294 tonnes. The South African deep-sea trawl fishery catches predominantly deep-water hake, which comprises an estimated 80% of the fleet's catch (data from D.Durholtz, personal communication, March 16, 2016).

The estimated total abundance of the stock at 1917-levels, before any exploitation of the resource, was 2 251 510 tonnes (Table 2). This serves for a carrying capacity of the South African Stock, and an understanding of the stock's natural potential. According to Table 2, the natural carrying capacity of the spawning deep-water stock at pre-exploitation levels was 1 021 000 tonnes at 1917 levels, which is close to 45 % of the total abundance. A short study of the spawning stock is presented in Appendix A.

The natural deep-water hake stock levels pre-exploitation in the 20^{th} century can serve as the carrying capacity in our model, keeping in mind that historic values rely on estimates and data quality. This method, using the reported natural biological level of the stock before any exploitation, is in line with the study by (Armstrong and Sumaila 2004)

5. 2 Assuming Uniformly Distributed Fish

Moreover, I will make the simplistic assumption that the deep-water hake is uniformly split across the two economic zones. This assumption implies that the spawning and migration patterns are such that the exploitable fish (i.e fish larger than 36 cm) is equally split between the two economic zones. This could be similar to a "fish-for-fish"-scenario, in which the economic zones are opened up in order to let both countries equally participate in fishing the exploitable fish according to its spawning and mitigation patterns. Similar policies have been put in place in other transboundary fisheries in order to avoid over-depletion of a fish stock. The previously mentioned fisheries agreement between Norway and Russia may serve as an example(MTIF 2016). The uniformly distributed fish assumption is in line with the main assumptions of the harvest functions in the Gordon Schaefer model, (2) and (3).

In the long run, the distribution of the fish can be affected by environmental factors, climate change and exploitation of the resource. A recent study on the transboundary character of the deep-water hake finds that Namibia has 40 % of the deep-water hake sized between 35 cm – 55 cm, and that there is an absence of fish larger than 55 cm in Namibia (Strømme, Lipinski et al. 2016).

5. 3 Calibrating The Baseline Model

In order to address the potential gains of cooperation in the fishery duopoly, it will be assumed that we are in a steady state, which means that the catch is at a sustainable level according to the Gordon Schaefer model. This implies that a steady state expression of the stock must be calibrated in accordance with the observed harvest and estimated efforts presented above. Since countries are assumed symmetric, they have equal catchability coefficients, harvests, efforts and profits.

5. 3. 1 Biological parameters

5. 3. 1. 1 Carrying capacity and intrinsic growth

Actual estimates of pre-exploitation levels of stock will be used as an estimate of the natural carrying capacity. According to Table 2, the total abundance of deep-water hake in South Africa before any exploitation of the resource is estimated to be 2 251 510 tonnes. This observed natural value of the stock will be used as an estimate of the potential carrying capacity. The level of stock giving rise to MSY and the carrying capacity for the overall fishery in our model is,

$$S_{max} = 4\ 503\ 020 \text{ tonnes}$$
$$S_{msy} = \frac{S_{max}}{2} = 2\ 251\ 510 \text{ tonnes}$$

Current estimates of harvest for a stock at maximum sustainable yield allow me to find an expression of the intrinsic growth rate. Given the natural carrying capacity, we can run the Gordon Schaefer model to find the intrinsic growth rate. The proof of the expression for intrinsic growth $g = \frac{4H_{msy}}{S_{max}}$ is demonstrated in the footnote[4]. South African stock assessments estimates the harvest that ensures a maximum sustainable stock to be 118 912 tonnes in South Africa (Rademeyer and Butterworth 2015). The overall H_{MSY} in this numerical model is thus 237 824 tonnes. The intrinsic growth rate is,

$$g = \frac{4 \times 237\ 824}{4\ 503\ 020} = 0{,}211$$

[4] Given the expression in equation (no.) on page (no), $G(S_{msy}) = H_{msy} = gS_{msy}(1 - \frac{S_{msy}}{S_{max}})$, and inserting for $S_{msy} = \frac{1}{2}S_{max}$, we find that $H_{msy} = g\frac{1}{4}S_{max}$. Rearranging gives the expression for the intrinsic growth rate $g = 4 * \frac{H_{msy}}{S_{max}}$

5. 3. 1. 2 Calibrating Steady State Stock

Assuming that we are in steady state, natural growth must equal the overall harvest. By inserting for the observed harvest level of 196 294 tonnes presented in Table 1 in the background chapter and the biological parameters S_{max} (Table 2) and g (calibrated), in the polynomial equation of natural growth G(S) expressed in equation 1, two expressions of the stock will follow. [5]

The two levels of steady state stock are 1 313 361 tonnes and 3 189 658 tonnes. The total current stock as estimated from stock assessments is used as an indicator of which of the two levels of stock is the most appropriate to use in the numerical model. Since we assume a uniformly distributed stock, the stock closest to the twice the size of the stock as estimated by South African stock assessments presented in Table 2 in the first chapter of the thesis will be used. In 2008, twice the South African stock level is 975 306 tonnes. This implies that at natural capacity, the lowest levels of stock are most appropriate. Note that the observed stock values vary over time from 863 000 tonnes in 2005 to 1. 1 million tonnes in 2011.

5. 3. 2 Economic Characteristics

In contrast to the availability of statistics on averages of the Norwegian fishing fleet and vessel's operating costs, ref. the profitability survey of the Norwegian fishing fleet, cost-estimates related to the South African and Namibian hake fishery are less transparent.

Averages based on estimates from literature will be made to express efforts and costs. Since freezer vessels and wetfish vessels account for 30 % and 70 % of the Namibian TAC respectively, weighted averages will be made to represent the costs and efforts of an average deep-water hake trawler.

2008, 63 Namibian vessels were fishing. The weighted average hour of fishing effort for the Namibian fleet was 13. 9 hours, and the weighted average of trawling days was 185. 2 days. These averages are calculated using the reported numbers of 16 and 13 hours a day for freezer and wetfish vessels respectively and 202 trawling days for freezer vessels and 180 wetfish days. (Kirchner and Leiman 2014) Since the countries are assumed symmetric, overall fishing efforts in hours are twice the sum of the estimated overall efforts for the Namibian fleet.

$$E = 2 \times 63 \times 13.9 \times 185.2 = 324\ 359\ hours$$

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[5] From G(S)=H, the abc-rule $\frac{-b \pm \sqrt{b^2-4ac}}{2a}$ is expressed by $a = -\frac{g}{S_{max}}$ and $b = g$ and $c = -H$.

Hourly costs are found by dividing the annual costs expressed in US dollars by annual efforts (hours). Annual operating costs per vessel in the period 2007-2009 is reported by Namibian stock researchers to be 50 and 15 million Namibian dollars for the freezer and wetfish fleet respectively (Kirchner 2014). This estimate is based on information obtained from the fishing industry in the period 2007-2009, and assuming that the freezer fleet is around four times more costly than the wetfish fleet. Using a World Bank annual average exchange rate for 2008, the weighted annual operating costs per Namibian deep-water vessel is calculated to be around 3 million USD[6] and total annual costs for 63 vessels is close to 195 million USD. The overall cost for the two fisheries is almost 389 million USD.

Since countries are assumed symmetric, dividing overall costs by overall efforts, or dividing the annual cost of the Namibian fleet by annual Namibian efforts yields the hourly cost per vessel. There is support for assuming equal costs in Sumaila and Armstrong (2004) under the argument that similar companies operate in both waters. Hourly costs are,

$$w = \frac{388\,983\,042}{324\,359\,hours}\,USD = 1199\ \text{USD/hrs.}$$

In 2008, the FAO-price from the export value of frozen hake was 3345 USD. This is similar to the UN Comtrade price of 3412,12 USD for Namibia and 3220,24 USD for South Africa[7]. The March 2010 EU Globefish report on export prices quotes Namibian export prices to the EU being in the range 2990-3740 USD per ton (headed and gutted) and 4010 – 4960 USD/t (skin-on filets and frozen)(FAO-Globefish 2010). The weighted average FAO price of 3345 USD will be used for the basis of this model. Prices similar to the FAO-prices and high prices were used in Sumaila and Armstrong (2004) as first-hand prices for Namibia and South Africa respectively. The weighted average export prices of South African MSC-certified hake are 2290 USD (non-filets) and 5260 USD (fillets) (Lallemand, Bergh et al. 2016). In Wilhelm, Kirchner et. al, (2015) the average price of hake from freezer vessels is stated to be US$ 1639 per tonne and that from wetfish vessels is US$ 2037 per tonne. The weighted average of these prices, 1917 USD, can serve as an estimate of low prices. A high price of

[6] World Bank annual average exchange rates were 8.26 NAD= 1USD in 2008, 7.05NAD in 2007 and 8.47NAD in 2009 http://data.worldbank.org/indicator/PA.NUS.FCRF?page=1

[7] Average values of frozen hake from http://comtrade.un.org/data/

5000 USD is set to represent the higher prices close to the highest Namibian and South African hake. 5000 USD is close to a 50 % increase from FAO-prices.

$$P_{FAO} = 3345 \text{ USD}$$

$$P_{LOW} = 1917 \text{ USD}$$

$$P_{HIGH} = 5000 \text{ USD}$$

The choice of price does not affect the calibration of the parameters[8]. The catchability coefficient is found by inserting for the observed harvest and effort of 2008 and their calculated level of steady state stock, in the overall harvest function. Since countries are assumed symmetric, the catchability coefficient is equal across countries, which is also the case for harvest, efforts and costs. The catchability coefficient is,

$$e = \frac{H}{ES} = \frac{196\ 294}{324\ 359 * 1\ 313\ 361} = 4{,}60784\text{E} - 07$$

5. 4 Numerical results

5. 4. 1 The Baseline Model

A summary of the biological and economic parameters and prices used in the numerical model are presented in Table 3.

Table 3: The Baseline Numerical model

Hourly cost (w)	1199 USD
Intrinsic growth (g)	0,211
Carrying capacity (S_{max})	4 503 020 tonnes
Catchability Coefficient (e)	4,60784E-07
P_{FAO}	3345 USD
P_{LOW}	1917 USD
P_{HIGH}	5000 USD

The numerical results for the overall fishery (both countries combined) at FAO-prices for effort, stock, harvest and profits in the economic equilibriums for symmetric countries are presented in Table 4. Effort values are expressed in thousand hours, harvest in thousand tonnes, stock in million tonnes and profits in million US-dollars. The steady states are found using the parametric equilibrium solutions developed in the theoretical chapter of this thesis. A country's individual profits, efforts and harvest will be half of the presented values in the

[8] The inequality $1 > \frac{w}{PeS_{max}}$ holds for all prices, ref. equations (16) and (17).

equilibriums of the Sole Owner, MSY, Cournot, Current and Open Access. In Stackelberg, the individual solutions are not symmetric.

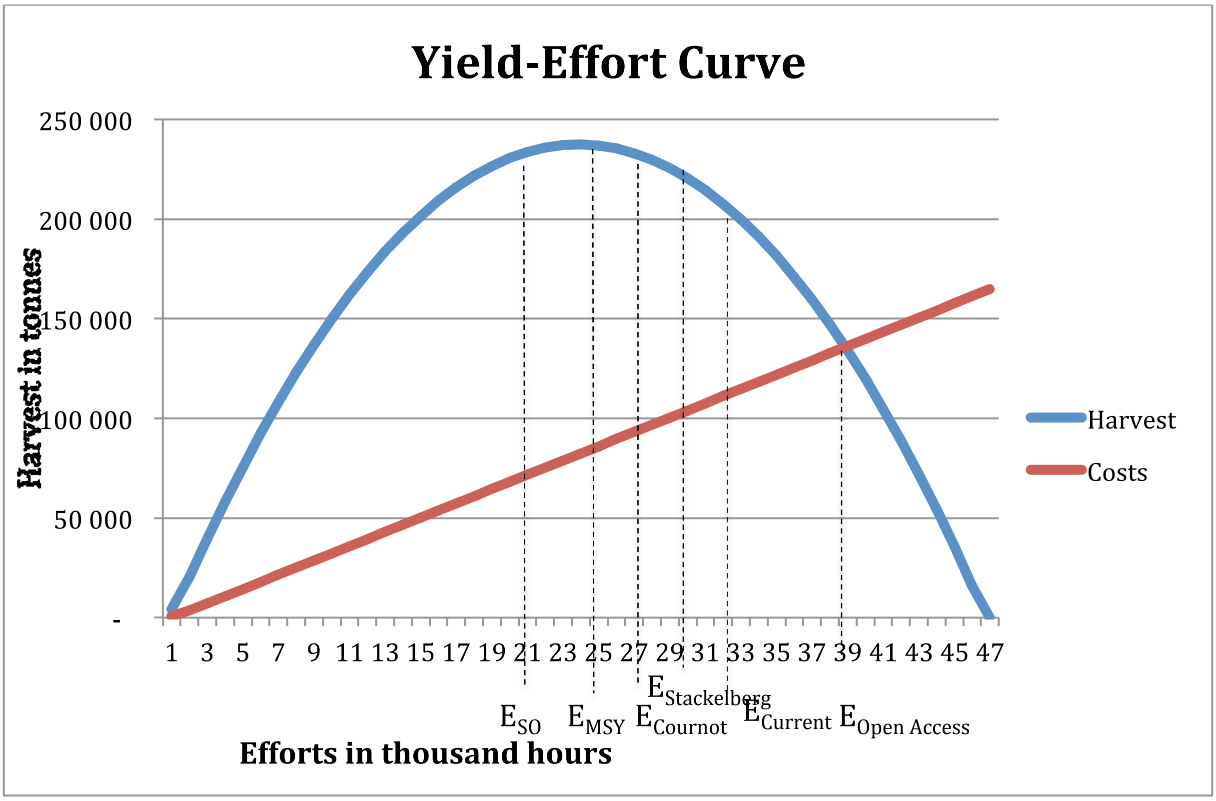
Table 4 Baseline Steady State Solutions - P_{FAO}

Steady State Solutions at P_{FAO}						
	Sole Owner	**MSY**	**Cournot**	**Stackelberg**	**Current**	**Open Access**
Effort	189’	229’	253’	284’	324 ’	379’
Stock	2. 64 M	2. 25 M	2. 02 M	1. 71 M	1. 31 M	0. 78 M
Harvest	231’	238’	235’	224’	196’	136’
Profit	544 M	521 M	483 M	408 M	268 M	-

As expected, the duopoly solutions are located between Sole Owner and Open Access (Belleflamme and Peitz 2010). Overall efforts are highest in the Open Access, followed by Stackelberg, Cournot and lastly the Sole Owner. The locations of the steady states are illustrated in Figure 2 on the next page.

Profits are maximised in the Sole Owner equilibrium, which can be seen as the distance between the Sole Owner equilibrium and the linear cost curve in the figure. In accordance with equation (5), higher efforts are associated with lower stock. In Open Access, efforts are over-exploited and the equilibrium occurs at higher effort-levels and lower stock-levels than the regulated scenarios of a Sole Owner and a Cournot Duopoly. The steady state stock in the equilibriums of Cournot, Stackelberg, Current and Open Access are located below the level yielding maximum sustainable harvest, and their efforts are at higher levels than the effort levels giving rise to MSY. The implication for this is that an increase in effort will reduce harvest (in the figure the equilibriums are located to the right of E_{MSY}), and a reduction in efforts implies a move towards the efficient Sole Owner and an increase in profits. Harvest would increase until the effort level equals the effort levels at MSY, and decrease thereafter (harvest decreases by a reduction in efforts if the equilibrium is on the left side of the MSY).

Figure 2: The Bell Shaped Sustainable Yield and the Four Equilibriums



5. 4. 1. 1 Current Scenario and Open Access

Current efforts are located between Cournot and Open Access, being closest to the Open Access. Current efforts are lower than in an unregulated scenario, and the catch of hake, profits and stock are higher. Except for in the equilibrium of regional cooperation, stock levels are smaller than those yielding maximum sustainable harvest.

Both Namibian and South African stock assessments report that the stock is below the maximum sustainable yield (Kirchner and Leiman 2014, D. Durholtz, personal communication, March 16, 2016). An MSY-target would yield larger profits than the current management regime and Cournot (individual management based on shared stock assessments). Despite MSY being a reference point in both Namibia and South Africa and measurements have been done to rebuild the stock towards its higher sustainable levels, the stock is reported by scientists to still be below the MSY (BCC 2011, Kirchner, Kainge et al. 2012).

The deep-water hake in the Benguela-region was exploited as an Open Access before the introduction of EEZ zones. The benefit in this numerical model, of moving from an overall open access regime to the current regime is calculated to be 268 million US

5. 4. 4. 2 Current scenario to Cournot

The Cournot yield-effort equilibrium is located to the right of the MSY, therefore the harvest level in Cournot is higher than in Open Access. The level of harvest in Cournot compared to MSY-levels was theoretically ambiguous, however we found [ab] by differentiating the overall harvest (24) with respect to costs or catchability, that if the inequality $1 > \frac{4w}{PeS_{max}}$ holds, then Cournot is located to the right of MSY and an increase in efforts is associated with a decrease in harvest which proves to be the case in the numerical model.

More efforts are utilised in the current scenario than in the Cournot-steady state, and it follows that the current steady state stock, profit and harvest is lower than in the case of a Cournot-duopoly. The observed estimates of overall harvest levels of the deep-water hake used in this model are associated with the current management regime in which countries treat the deep-water hake stock as unshared. Since there is an unshared stock management, stock assessments are made individually by country. This may be understood as there being a lack of cooperation in stock assessment research, and moreover, that the countries do not take into account the strategic choices of one another. Currently the deep-water hake is not exploited in pure Open Access since both South Africa and Namibia regulate their stock. However, the stock is not managed in research cooperation despite its claimed transboundary characteristic. This can be a reason for the location of the current steady state.

There is a gain of introducing primary cooperation, as the countries would increase profits by moving from the current scenario to a Cournot-duopoly in which they act interdependently in their management regimes and act as if the stock is shared. At FAO-prices, the value of moving to Cournot is 215 million USD. This difference represents 80% of the current profits. An unsurprising observation is that both countries would increase profits if the fishery management moved from an unregulated scenario with free entry/exit in their economic zones, and directly to a regulated scenario in which the two countries maximise their profits within their economic zones and act interdependently. This gain is calculated to be 483 million USD at FAO-prices.

5. 4. 1. 3 Cournot to Regional Cooperation

There is an economic incentive to cooperate in terms of an active regional fishery management. Joint efforts are lowest and joint profits are maximised if the countries cooperate regionally and act as a Sole Owner (33), and the steady state stock is lower than MSY levels. This can be seen from the distance between costs and revenues in Figure 2, which is the largest in the case of a Sole Owner. If the countries cooperate and act as a Sole Owner, their joint profits would be higher than if they are not cooperating, and if they are only cooperating in terms of shared stock assessments. Moving from Cournot to Sole Owner would increase profits by 12. 5 % and the gain of cooperation is 61 million dollars at FAO-prices.

Moving from the Current scenario to regional cooperation would roughly double profits at FAO-prices. Potential gains of moving from Cournot to Regional Cooperation at different prices, and when costs or catchability differ, are presented below.

5. 4. 2 Equilibrium Effects at Different Prices

The steady state solutions at low and high prices are presented in Table 5 below. As before, efforts are expressed in thousand hours, harvest is expressed in thousand tonnes, stock is presented in million tonnes and profits are shown in million US-dollars.

Table 5: Steady State Solutions at P_{LOW} and $P_{HIGH.}$

Steady State at P_{LOW}						
	SO	**Cournot**	**MSY**	**Stackelberg**	**OA**	**Current**
Effort	160’	213’	229’	240’	320’	324’
Stock	2. 93 M	2. 41 M	2. 25 M	2. 14 M	1. 36 M	1. 31 M
Harvest	216’	236’	238’	237’	200’	196’
Profit	222 M	198 M	181 M	167 M	-	-13 M
Steady State at P_{HIGH}						
	SO	**MSY**	**Cournot**	**Stackelberg**	**Current**	**OA**
Effort	203’	229’	270’	304’	324’	405’
Stock	2. 51 M	2. 25 M	1. 85 M	1. 52 M	1. 31 M	0. 52 M
Harvest	234’	238’	230’	212’	196’	97’
Profit	929 M	914 M	826 M	697 M	593 M	-

At high prices, the order of the steady state equilibriums is the same as at FAO-prices. The Cournot, Current Scenario and Open access are characterized by higher efforts and lower stock than the MSY and Sole Owner. The effect of the price increase on the direction of efforts, stock and harvest in the case of the Sole Owner, and stock and efforts in Open Access is according to theory. The direction of Open Access harvest is theoretically ambiguous; in this scenario harvest is reduced (Perman 2011). Total revenue increases more than total costs at a price change when costs and catchability are unchanged.

At low prices, the order of the Open Access and Current scenario changes. There are negative profits of the fishery in the current scenario. The reason for this may be that the price is unrealistic, or that that the numerical model is based on unrealistic parameters.

In comparison, the value of the combined species fishery is today considered to be worth USD 570 million (Strømme, Lipinski et al. 2016).

5. 4. 2. 1 The Value of Cooperation at Different Prices

A summary of the steady state profits in million US-dollars at FAO-prices, P_{LOW} and P_{HIGH} for the economic equilibriums of a Sole Owner, at MSY, in Cournot, Stackelberg and the current scenario are summarized in Table 6.

Table 6: Steady State Profits at P_{FAO}, P_{LOW} and P_{HIGH}.

Profits in million USD					
	Sole Owner	MSY	Cournot	Stackelberg	Current
P_{FAO}	544 M	521 M	483 M	408 M	268 M
P_{LOW}	222 M	181 M	198 M	167 M	-13 M
P_{HIGH}	929 M	914 M	826 M	697 M	593 M

There are potential gains by moving from the current stock management regime to a Cournot duopoly and to regional cooperation at all prices, other things constant.
The gain of moving from the current scenario to Cournot is higher at high prices than at FAO-prices. The gain of moving from the current scenario to Cournot is 215 million USD at FAO-prices (80%), and 233 million USD at high prices (40%). Thus the price increase implies a benefit of 18 million USD in terms of increased potential gains.

Moving from a Cournot-steady state to regional cooperation yields a gain of 61 million dollars at FAO-prices (12. 5 %), and at a higher 103 million US-dollars at high prices (12. 5 %). At high prices, the value of regional cooperation increases by 42 million USD compared with FAO-prices.

At high prices and FAO-prices, an overall maximum sustainable yield target would yield larger profits than the currents stock management and Cournot. In recent years, the MSY has served a reference point in Namibian and South African stock assessments. (BCC 2011, Kirchner, Kainge et al. 2012).

5. 4. 3 Equilibrium Effects of Increases in Costs and Catchability

In the following section, we will investigate the effects of an increase in costs and catchability on steady state efforts, stock and profits. All equilibrium effects are measured at FAO-prices. Both countries are still assumed to be symmetric, thus both countries experience the same increase in w or *e.*

5. 4. 3. 1 A 50 % Increase in Costs

Imagine that costs are increased. Reasons for an increase in costs can be higher wages or higher fuel prices. An increase in costs by 50 % implies hourly costs of 1799 USD. The inequality and condition for an interior solution (positive efforts) $PeS_{max} > w$ still holds at all prices. The effects on the steady state solutions are presented in Table 7. The values of efforts are expressed in thousand hours, stock in million tonnes, harvest in thousand tonnes and profits in million dollars. Graphically, an increase in costs can be showed as a rotation of the linear cost curve towards the left (Figure 1).

Table 7: Steady State Solutions after a 50 % Cost Increase

	New Steady State Solutions ($w \uparrow$)				
	Sole Owner	**Cournot**	**MSY**	**Stackelberg**	**OA**
Effort	170’	226’	229’	254’	339’
Stock	2. 84 M	2. 28 M	2. 25 M	2. 00 M	1 .17 M
Harvest	222’	238’	238’	235’	183’
Profit	436 M	387 M	383 M	327 M	-

Notably, Cournot is now located between the Sole Owner and the MSY, and has lower effort levels than the efforts that would yield maximum sustainable growth. Harvest levels are below the MSY by only 327 tonnes. When there is an increase in costs, overall efforts are reduced and steady state stock will increase.[a] In Open Access, efforts are reduced by 40 000 hours and stock is increased by 390 000 tonnes (50 %), Stackelberg efforts are reduced by 30 000 hours and the stock is increased by 290 000 tonnes (17 %), Cournot the effort reduction of 27 000 hours increases stock by 260 000 tonnes (15 %), while efforts in regional cooperation is reduced by 19 000 hours and stock is increased by 200 000 tonnes (7 %). In percentage, overall efforts are reduced by one tenth.

Overall harvest increases in Cournot, Stackelberg and Open Access. Theoretically, the direction of harvest in Cournot is ambiguous and depends on which side of the MSY equilibrium the Cournot is located. However, we found that harvest by an increase in costs if the inequality $1 > \frac{4w}{PeS_{max}}$ holds, which is the case in our model. On the other side, overall harvest in the case of a Sole Owner is reduced.

In terms of profits, a change in costs has a larger negative effect on the Sole Owner (-108 million USD), followed by the effect on the Cournot profits (-96 million USD), and then the Stackelberg profits (-81 million USD). This order was theoretically discussed[a]. The profits are reduced by around one fifth in all scenarios.

Note that the value of cooperation is reduced when costs are increased. The value of moving from Cournot to Regional Cooperation is reduced to 49 million USD from the previous 61 million USD. An increase in costs thus reduces the value of cooperation, and in this numerical model the value of regional cooperation is reduced by 12 million USD.

5. 4. 3. 2 A 50 % Increase in Catchability

Now let's assume an increase of 50 % in the catchability coefficient. The catchability coefficient is now e = 6,91175E-07. An increase in efficiency may be due to more successful fishing strategies (ex. fishing at a different time of day), new knowledge of biological patterns or in an improvement in vessel's technology. The numerical results of the change are presented in Table 8. As before, the values of efforts are presented in thousand hours, stock in million tonnes, harvest in thousand tonnes and profits in million USD.

Table 8: Steady State Solutions after a 50 % Catchability Increase

Steady State Solutions ($\boldsymbol{e} \uparrow$)					
	Sole Owner	**MSY**	**Cournot**	**Stackelberg**	**OA**
Effort	135’	153’	180’	203’	270’
Stock	2. 51 M	2. 25 M	1. 85 M	1. 52 M	0. 52 M
Harvest	234’	238’	230’	212’	97’
Profit	622 M	612M	553 M	467 M	-

The steady state stock is reduced and profits increased when there is an increase in the catchability coefficient[b.] Due to profitability, the Sole Owner takes the stock into account more than other management regimes. (31)

Steady state stock is reduced by 259 000 tonnes in the Open Access scenario (-35 %), followed by the reduction of 194 000 tonnes in Stackelberg (-12 %), 172 000 tonnes in Cournot (10%) and lastly by the reduction of 130 000 tonnes in the Sole Owner scenario (-5%). This order is in line with the theoretical discussion of the effects of a change in the catchability coefficient.

The effort levels are reduced [b] by around 109 000 hours in Open Access, 82 000 hours in Stackelberg, 72 000 hours in Cournot and 54 000 hours in regional cooperation. The order of the effort levels remains the same as before the increase (48). In Cournot, the Sole Owner and Open Access are reduced by almost one third. The direction of harvest and effort was theoretically ambiguous, but when the inequality $1 > \frac{4w}{PeS_{max}}$ holds, harvest and effort will decrease [b]. This inequality holds in the numerical model, and we can read from the table that efforts and harvest are decreased. Harvest is reduced by 39 000 tonnes in Open Access (- 29 %), followed by 12 000 tonnes in Stackelberg, 5 000 tonnes in Cournot (-2 %), and increased by 4 000 tonnes in Sole Owner (2%).

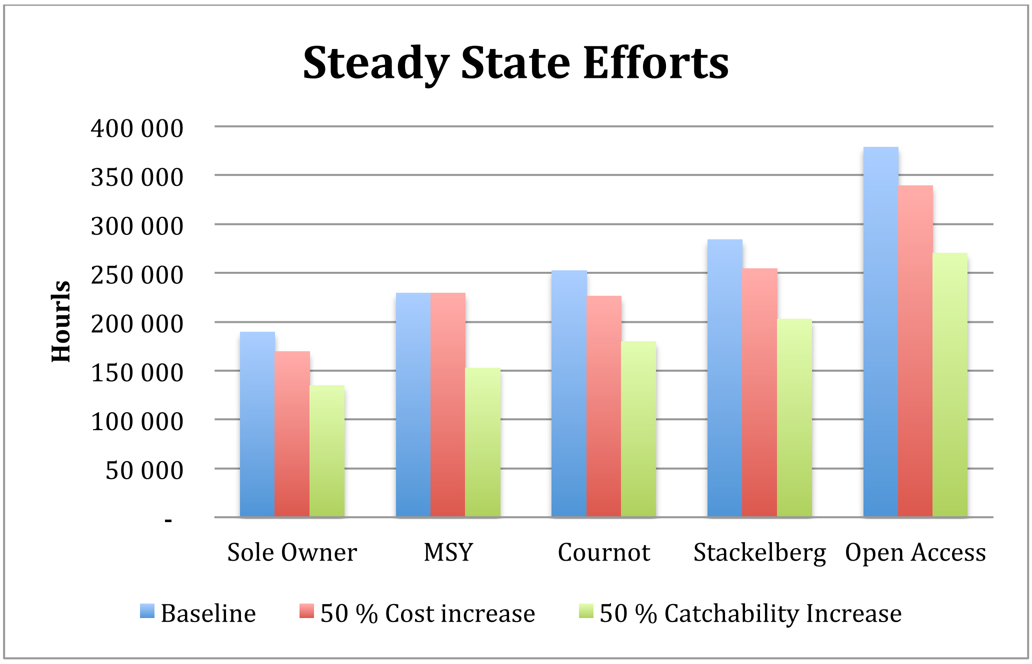
Profits are increased by 14% in the case of Cournot, Sole Owner and Stackelberg. The change of 78 million USD in the case of regional cooperation is the largest [b], followed an increase of almost 70 million USD in Cournot and almost 59 million USD in Stackelberg.
It is worth noting that the value of cooperation is increased by an increase in the catchability coefficient. The value of moving from Cournot to Regional Cooperation is now 69 million USD. An increase in catchability thus increases the value of a regional management regime by 8 million USD (from 61 million USD to 69 million USD).

5. 4. 3 The Effects of Increases in Costs and Catchability Summarised

Effects on Steady State Efforts

As illustrated in Figure 3, overall efforts are reduced when costs and catchability increases. However, efforts respond more to the change in the catchability coefficient. In the case of the Sole Owner, Cournot, Stackelberg and Open Access, an increase in costs reduces efforts by one tenth while the increase in the catchabiliy increases efforts by one third.

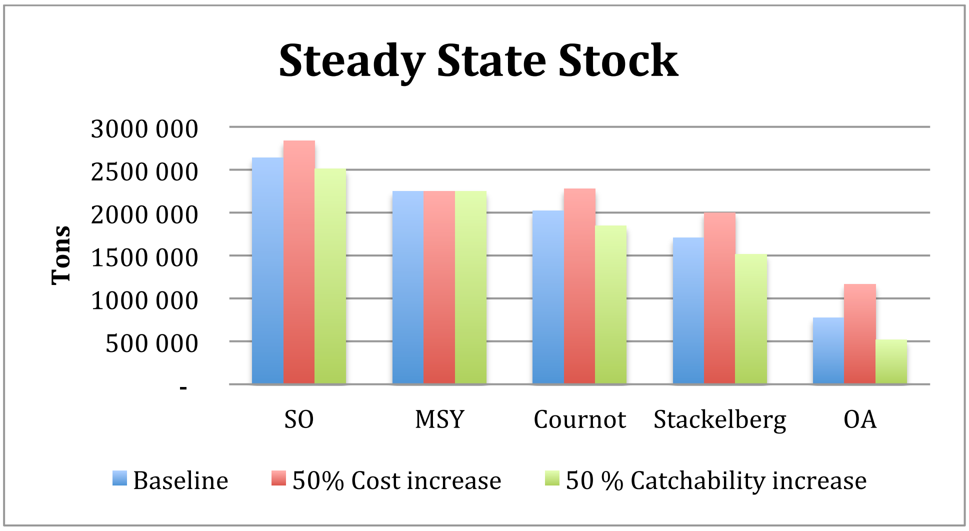
Figure 3: Effects on Steady State Efforts



Effects on Steady State Stock

The stock is increased when costs increases, and reduced when catchability increases, as illustrated in Figure 4. The change in stock differs across the equilibriums, and the stock increase due to higher costs is larger than the stock decrease due to higher catchability for the Sole Owner, Cournot, Stackelberg and Open Access. The steady state stock is more sensitive to a change in costs than to a change in catchability.

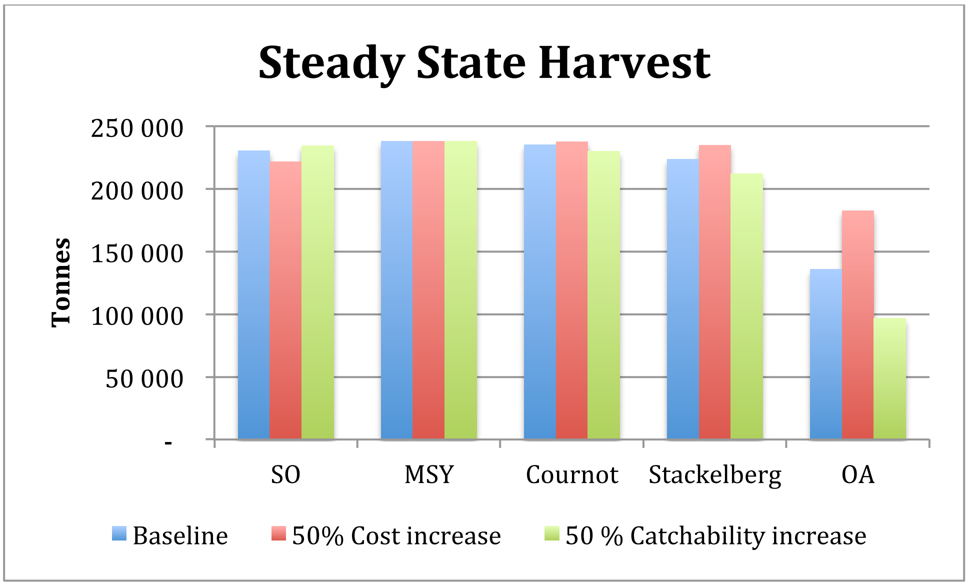
Figure 4: Effects on Steady State Stock



Effects on Steady State Harvest

Overall harvest increases in Cournot, Stackelberg and Open Access as these equilibriums were located at higher effort levels than the effort level yielding MSY. Theoretically, the direction of harvest in Cournot is ambiguous and depends on which side of the MSY equilibrium the Cournot is located on. In the numerical model, the inequality $1 > \frac{4w}{PeS_{max}}$ holds, and it follows that Cournot, Stackelberg and Open Access harvest will increase by an increase in costs [a], but harvest and efforts will decrease by an increase in catchability[b]. The findings on overall harvest are presented in Figure 5 below.

Figure 5: Effects on Steady State Harvest

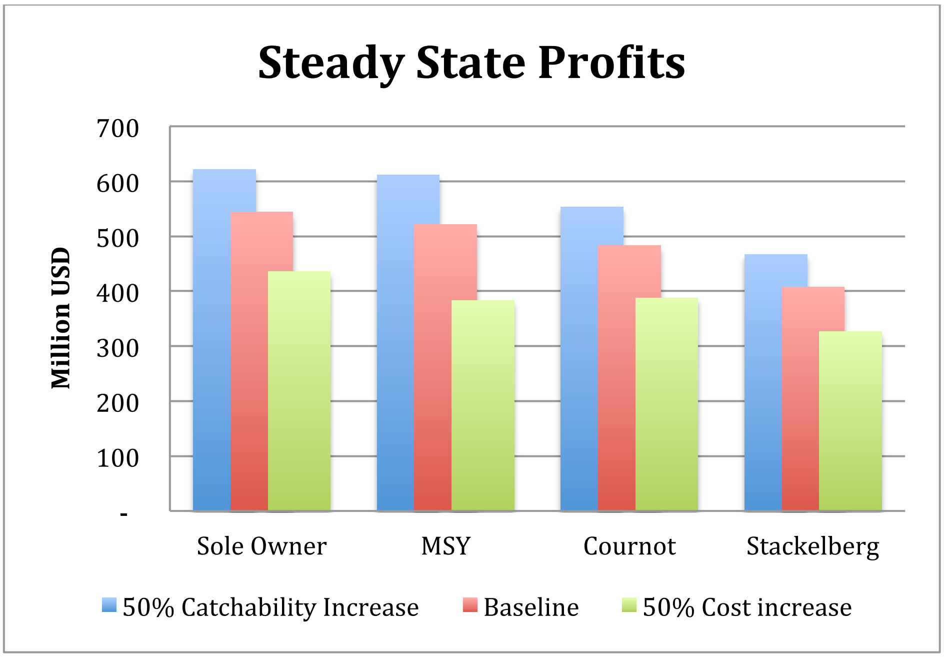


Effects on Potential Gains of Cooperation

Notably, the value of cooperation was reduced when costs increased, and increased when catchability increased. The effects are demonstrated in Figure 6 below. The value of regional cooperation changed from 61 million USD in the baseline model, to a lower 49 million USD post cost increase, and a higher 69 million USD post catchability increase.

Profits are more sensitive to a change in costs. Profits in regional cooperation, Cournot and Stackelberg were reduced by one fifth when costs are increased, and profits were increased by 14 % when the catchability is increased.

Figure 6: Effects on Steady State Profits



A summary of the changes in steady states of moving from the current scenario to Cournot and from Cournot to regional cooperation, and the change expressed in percentages, is presented in Table 9.

The value of regional cooperation is 12. 5 % at all prices and when catchability or cost is increased. The potential gain of regional cooperation is largest after the increase in the catchability coefficient, followed by the baseline gain and the gain after a cost increase. Joint management reduces efforts by a quarter, and the loss in hours is largest in the baseline model, and smallest when the catchability is increased. Stock increases the most after a catchability coefficient, and the least after a cost change, and while the harvest is increased when the catchability is increased, it is reduced by 7 % after a cost increase, and by 2 % in the baseline model.

It follows that the value of regional cooperation is highest at a higher catchability coefficient than the baseline model. This high potential gain of profits is associated with the lowest reduction in efforts (compared with reduction in efforts when moving from Cournot to Sole Owner the baseline model and after a cost increase). Moreover, an increase in the catchability increases the stock more than in the other scenarios and in contrast, it yields an increase in harvest.

Table 9: Potential gains at Higher Costs and Catchability

	Current to Cournot	Cournot to Regional		
	Baseline	Baseline	Cost↑	Catchability↑
Effort	-72 000 (-22%)	-63 000 (-25 %)	-57 000 (-25 %)	-45 000 (-25 %)
Stock	706 000 (54 %)	621 000 (31 %)	556 000 (24 %)	664 000 (36 %)
Harvest	39 000 (20 %)	-5 000 (-2 %)	-16 000 (-7 %)	4 500 (2 %)
Profit	216 M (81 %)	60 M (12. 5 %)	49 M (12. 5 %)	69 M (12. 5 %)

5. 4. 4 Cournot vs Stackelberg.

In the case of a Stackelberg-duopoly, a leader may be a country with a natural advantage in factors that are independent of the parameters in the model. Moreover, the commitment to a leader-strategy must be credible.

There is no asymmetric information, and the assumption of symmetric catchabilities and costs still hold. One could think that a natural leader is a country that invests in new vessels, but in order for the costs and catchabilities to be unchanged, such vessels must not be associated to technological improvement that may affect marginal costs or the catchability of the fleet. Another example of a Stackleberg-leader is that one country increases quotas and can credibly commit to the new quota level. Furthermore, there is a biological constraint on how much fish each country can catch within her economic zone. The credibility of the strategy is associated with historic behaviour (Watson 2013) as well being related to the constraint on exploitable stock; if higher quotas cannot be landed in terms of the catch, the commitment to the new strategy loses credibility.

An example follows. Although Namibia increased quotas above the scientific advice, Namibian vessels fish less fish than their quotas allow. There is also a trend in fewer active vessels over time. Although the high quota could be an attempt for Namibia to increase profits by increasing efforts and acting as a Stackelberg-leader, their commitment is not credible as South Africa 1) knows that there is extensive fishing but still quotas are unreached 2) recent studies show that Namibia has a smaller share of exploitable fish than South Africa, thus even higher quotas or more vessels would imply that they would struggle to commit as a leader.

On the other hand, let's assume that South Africa is the natural leader. They have a record of setting quotas equal to scientific recommendations and have landed the announced TAC. Their commitment to a strategy of higher efforts as a result of an announced level of higher quotas is thus more credible.

In the theoretical discussion of the four symmetric equilibrium, it was proved that in the case of a Stackelberg-duopoly, total efforts will be higher and the steady state stock and overall profits will be lower than in the Cournot-duopoly. However, overall profits and stock will be higher in Stackelberg than in an unregulated Open Access scenario. This is confirmed in our numerical model.

The overall catch is lower than in Cournot, as the the Cournot equilibrium solution of efforts is on the right side of MSY.

Imagine we start in the Cournot-equilibrium. Assume that Country 1 can act as a Stackelberg-leader and commits to her strategic choice. Let's say this is South Africa, and that it is credible that they can commit to move first and harvest more than Namibia. Credibility can rely on historic behaviour (Watson 2013), such as South Africa's former fishery behaviour and record of catching their official quotas. Moreover, let's assume that it is realistic that a higher quota can be catched. Country 2 acts as a follower. Even though the countries have equal catchability coefficients and costs, the countries will no longer be symmetric per se since their levels of harvest and effort will differ.

The individual Stackelberg solutions are presented in Table 10. Effort is expressed in thousand hours, harvest in thousand tonnes, stock in million tonnes and profits are expressed in million USD. The individual solutions in the Stackelberg duopoly are found using the parametric equilibriums solutions in the theoretical discussion. The individual efforts, harvest and profits in Sole Owner, MSY, Cournot and Open Access are found by dividing the numerical results of the baseline model of the overall fishery in Table 4 by two.

Table 10: Individual Equilibrium Solutions

Individual Equilibriums at Steady State						
	Sole Owner	**Leader**	**Cournot**	**MSY**	**Follower**	**OA**
Effort	95’	189 ’	126’	115’	95’	189’
Stock	2.64 M	1. 71 M	2. 02 M	2. 25 M	1. 71 M	0. 78 M
Harvest	115’	149’	118’	119’	75’	68 ’
Profit	272 M	272 M	242 M	260 M	136 M	-

The Stackelberg leader chooses to increase effort, in order to earn profits equal to the individual Sole Owner profits. Country 2 will follow by reducing her efforts, but not with as much as the leader increases her efforts. Hence, overall efforts are increased and larger than Cournot, and the overall catch is lower than the steady state Cournot-solution, but still higher than Open Access.

In the new steady state, overall profits are reduced. The leader’s profits are higher than the individual Cournot profits, while the follower’s rent is the smallest. This reflects the first mover advantage. However, the Stackelberg leader uses as much efforts as the individual efforts in Open Access[9]. These findings are in line with the theoretical discussion on the Stackelberg equilibrium.

Moving from Cournot to Stackelberg implies that the stock will be reduced in the long run, and overall profits will be reduced.

[9] Found by dividing overall efforts in Open Access by two.

6 The Asymmetric Cournot

The following analysis concerns changes in steady state solutions of Cournot when one country's costs or catchability is increased. It will be assumed that countries were symmetric to begin with and that we were initially in the steady state Cournot equilibrium as described in the baseline numerical model. The biological and economic parametric values of the steady state Cournot were summarized in Table 3.
We would be in a Cournot scenario if countries act interdependently when exploiting the fish stock, and chose their efforts simultaneously.

6. 1 Country 1's Costs Increases by 50 %

As before, an increase in costs can be due to increased wages or fuel prices. Country 1's new costs are 1799 USD and the effect on efforts, harvests, stock and profits in steady state are presented in Table 11. The baseline overall values are the same as the Cournot values in Table 4, and the individual values are found by the parametric solutions in the theoretical discussion and are equal to half of the overall values. The values of effort are expressed in thousand hours, harvest in thousand tonnes, stock in million tons, and profits in million US-dollars.

Table 11: Equilibrium Effects when Country 1's Costs are Increased

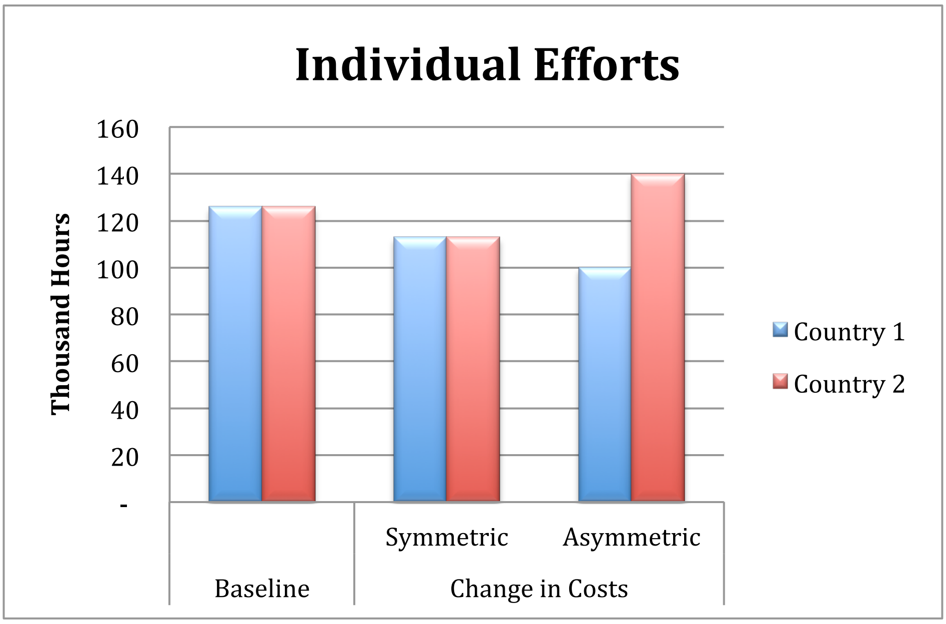
	Equilibrium Effects of a Cost Increase				
	Baseline		Cost Increase in Country 1		
	Overall	Individual	Overall	Country 1	Country 2
Effort	253'	126'	239'	100'	140'
Stock	2. 02 M		2. 15 M		
Harvest	235'	118'	237'	99'	138'
Profits	483 M	242 M	446 M	151 M	295 M

Overall stock increases [a] by 130 000 tonnes (6%). This increase is lower than when both countries faced a cost increase, and stock increased by 260 000 tonnes (13 %).

Overall efforts are reduced by around 13 000 hours, of which Country 1 reduces efforts by 26 000 hours and Country 2's efforts are increased by 13 000 hours. The effort reduction is larger than the increase. This is in accordance with the theoretical discussion on the effects of changes in a country's costs on individual efforts, which proved that Country 1 would reduce her efforts more than Country 2 will increase her efforts when the catchability coefficients were equal. Thus, overall efforts are reduced for $e_1 = e_2$.

The changes in efforts as a result of a 50 % increase in costs of one country or both countries are presented in Figure 6 below. Overall efforts are reduced in both scenarios, but the effect is largest when both countries experience an increase in costs (27 000 hours) than when only one country's costs are increased (14 000 hours).

Figure 6: The effect of an increase in costs on individual efforts.

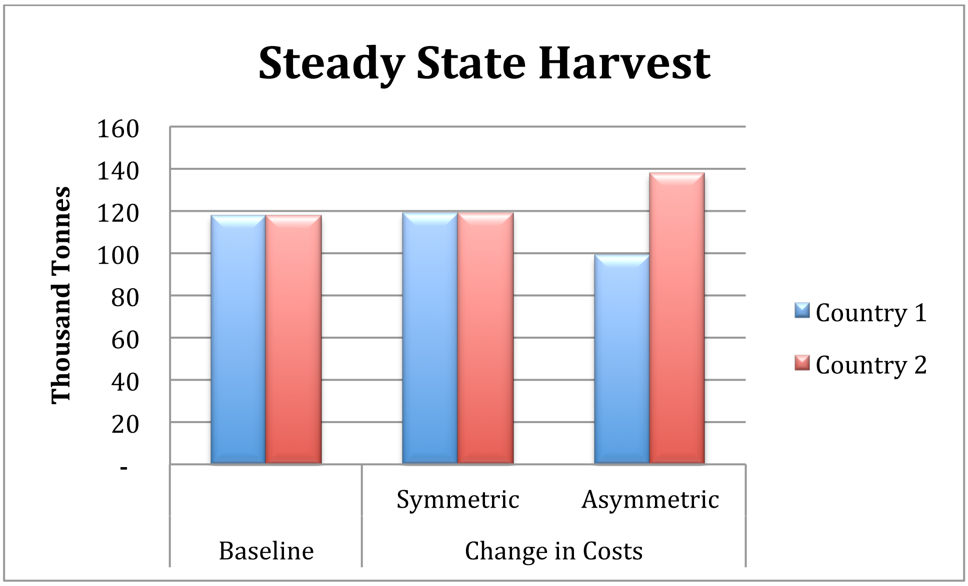


Overall harvest is increased by 2 000 tonnes. In the theoretical model, the direction of the overall harvest was ambiguous. However, we found [a] that the Cournot solution is equal to MSY if the condition $1 = \frac{2w_1}{Pe_1 S_{max}} + \frac{2w_2}{Pe_2 S_{max}}$ holds, and overall harvest increases by increased marginal costs if the inequality $1 > \frac{2w_1}{Pe_1 S_{max}} + \frac{2w_2}{Pe_2 S_{max}}$ holds. If overall efforts are reduced, and harvest increases, which is the case in our numerical model, then Cournot is located above MSY.

Individual harvests move in opposite direction. While Country 1's harvest is reduced [a] by 19 000 tonnes, Country 2's harvest is increased by 21 000 tonnes. As effort is more expensive for Country 1, she cuts back on effort levels and reduces less. Since efforts are pure strategic substitutes, Country 2 can increase efforts and harvest (harvest is proportional with efforts) in order to increase profits.

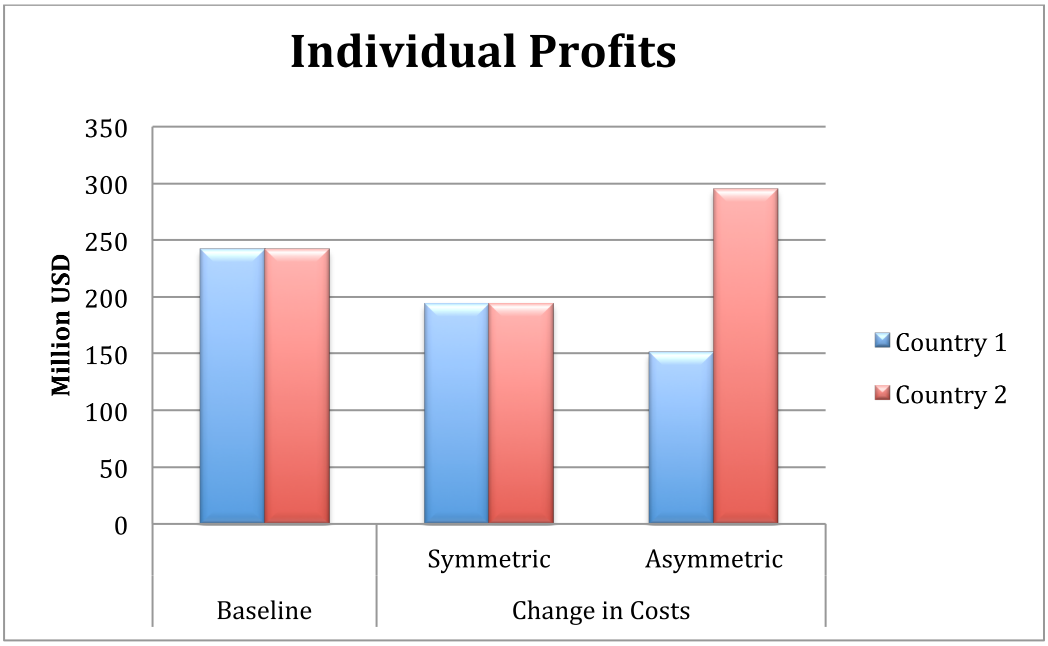
The changes in the steady state harvest as a result of an increase in one or both countries costs are presented in Figure 7 Overall harvest is increased more if both countries get higher costs. The overall harvest is around 400 tonnes larger when both countries experience a cost increase, and individual harvests are close to 119 000 tonnes for each country. When Country 1 is the only country to face higher costs, her harvest will be reduced by 19 000 tonnes and Country 2's harvest will be increased by 20 000 tonnes. Overall harvest is increased more when both countries face higher costs. This is because overall efforts are reduced more when both countries get higher costs: Less effort implies more harvest when the Cournot yield-effort is located to the right of the MSY.

Figure 7: The Effect of a Change in Costs on Steady State Harvest



The effects of a change in costs on profits are illustrated in Figure 8 on the next page. Individual profits go in opposite directions: While the more costly fleet yields lower profits, Country 2's profits are increased.. Country 1's profits are reduced by 21 million USD, and Country 2's profits are increased by 53 million USD. The behaviour of individual profits is in line with the theoretical discussion on the effects of a change in costs.

Figure 8: The effect of a change in costs on profits



From the theoretical discussion on the effects of a change in costs on overall profits, we know that overall profits must go down if they countries were symmetric before the increase. Overall profits are reduced in both scenarios, however the reduction is larger when both countries increase their costs (-96 million USD) than if one country increases their costs (-37 million USD). From the figure it is clear that Country 1's profits are reduced more (- 91 million USD) if only her costs are increased and Country 2's profits are increased (by 53 million USD), than if both countries' costs are reduced. If both countries face increased costs, they each face an individual loss in profits of 48. 5 million USD.

6. 2 Country 1's Catchability Increases by 50 %

An increase in the catchability coefficient may be due to improved fishing strategies or better technology. Country 1's new catchability coefficient is 6,91175E-07, and the effect on efforts, harvests, stock and profits in steady state are presented in Table 12. The value of effort is in thousand hours, profits in million USD and harvest and stock in thousand and million tons respectively. The findings below are in line with the theoretical discussion of the effect of a change in a country's catchability coefficient on steady states [b]. As before, the overall values in the baseline model are the same as those presented of the Cournot solution in Table 4. The individual values is a split of these values, and can also be found by using equations of symmetric Cournot efforts in the theoretical discussion.

Table 12: Equilibrium effects when Country 1's catchability is increased

	Equilibrium Effects of a Change in Catchability				
	Baseline		Country 1's catchability is increased		
	Overall	Individual	Overall	Country 1	Country 2
Effort	253'	126'	213'	96'	117'
Stock	2. 02 M		1. 93 M		
Harvest	235'	118'	233'	128'	105'
Profits	483 M	242 M	523 M	314 M	209 M

We can read from the table that the shared stock is reduced (by 90 000 tonnes) when one country's individual catchability is increased. When the catchability increased for both countries, the stock was reduced by 170 000 tonnes.

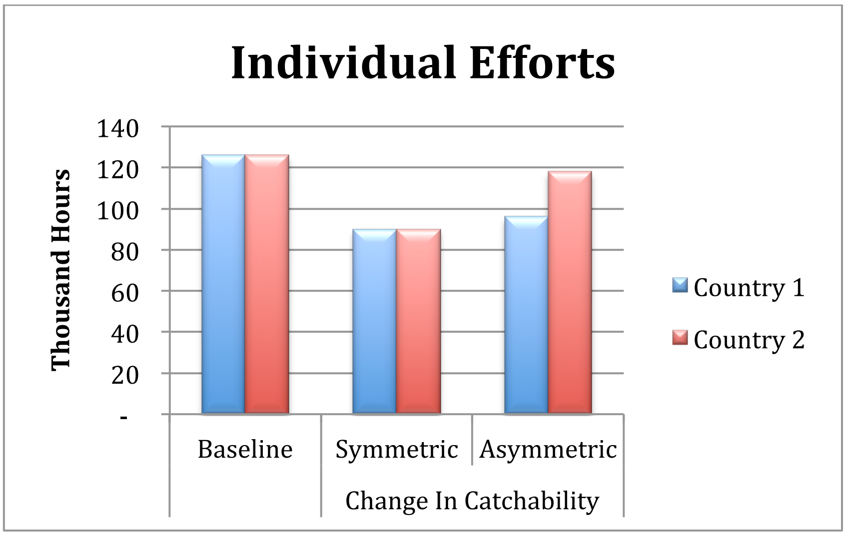
The changes in stock are larger when costs are increased, then stock is increased by 6% and while when catchability is increased, stock is reduced by 4 %.

Efforts are no longer pure strategic substitutes. When one country's catchability increases, she gets more productive and can use less effort to harvest at least the same as before. The productivity of Country 2 however is unchanged. Since she knows that Country 1 is more productive, she reduces efforts (by 9 000 hours) which is relatively less than Country 1's (- 30 000 hours). Country 2 uses more efforts than Country 1, but catches less fish due to the difference in the productivity of efforts.

The more productive Country 1 reduces efforts by 30 000 hours, thus overall efforts are reduced by around 40 000 hours. Country 1 reduces her efforts, but can harvest more and reaches a higher level of profits in steady state. In the theoretical discussion on a change in the catchability coefficient, we found that the direction of Country 2 was clear, while Country 1's efforts and overall efforts was ambiguous. However, Country 1's efforts and overall efforts would decrease if the inequality $1 > \frac{4w_1}{Pe_1S_{max}}$ holds, which is the case in the numerical model.

The changes in individual efforts are presented in Figure 9 below. Although efforts are reduced in both scenarios, the overall effect is larger when catchability increases in both countries (-73 000 hours) than when only Country 1's catchability increases (-40 000 hours). The individual efforts of country 1 are reduced more when both countries catchability increases (-36 000 hours), than when only her catchability increases (-30 000 hours). Thus, when both countries become more efficient, overall efforts are reduced in the long run, as this increases profits, and the long run stock is at a lower level.

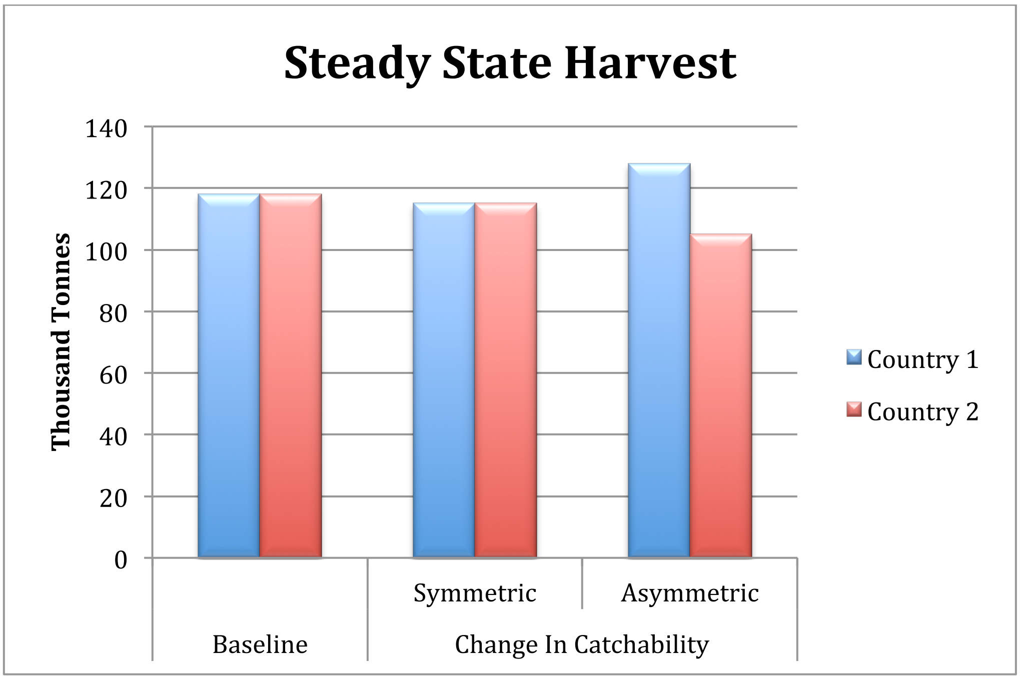
Figure 9: The effect of a change in catchability on steady state efforts



Individual harvests go in opposite directions. [b] While Country 1's harvest is increased by 10 000 tonnes, Country 2's harvest is reduced by 13 000 tonnes. Overall harvest is reduced by around 2 000 tonnes. While the theoretical direction of the overall harvest is ambiguous, we found that overall harvest decreases if $1 > \frac{2w_1}{Pe_1 S_{max}} + \frac{2w_2}{Pe_2 S_{max}}$. This holds in our numerical model. The effects of a change in the catchability coefficient on harvest is illustrated in Figure 10.

The overall catch is reduced more when both countries' catchability coefficients are increased. When both countries face increased catchability coefficients, overall harvest is reduced by 5 000 tonnes (to 230 000 tonnes) their individual harvest is reduced by 3 000 tonnes (to 115 000 tonnes). On the other side, overall harvest is reduced by around 2 000 tonnes when only Country 1's catchability is increased, of which Country 1's harvest is increased by 10 000 tonnes while Country 2's harvest is reduced by 13 000 tonnes.

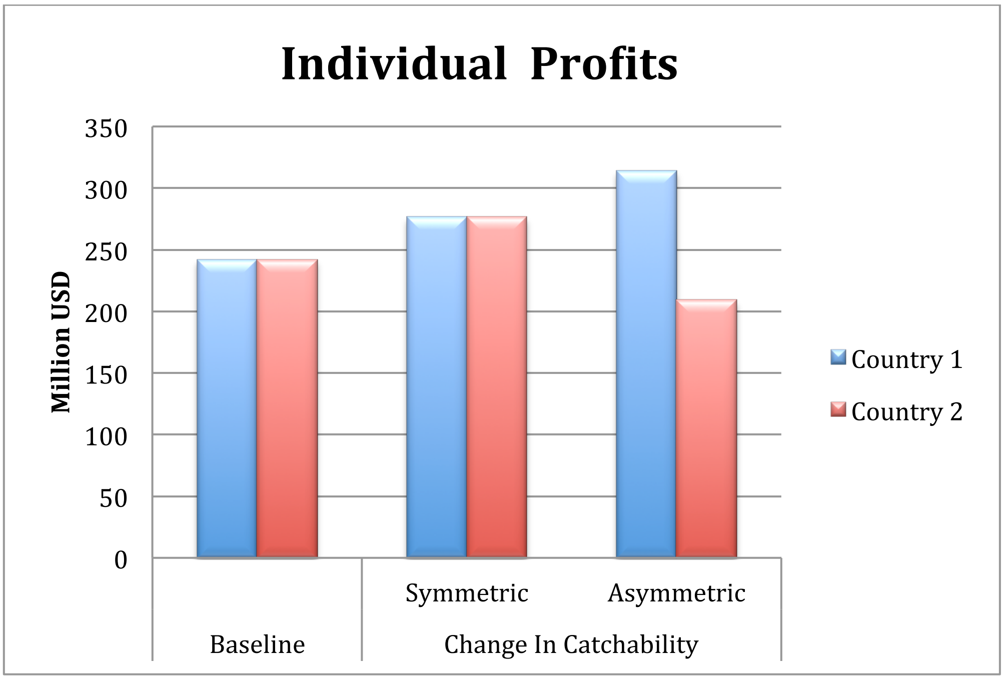
Figure 10: The effect of a change in catchability on Steady State Harvest



The effects of a change in catchability on profits are illustrated in Figure 11 below. A country's individual profits are increased when there is an increase in the catchability coefficient, and it is clear that Country 1 earns more profits if she is the only country to experience an increase in catchability.

In the asymmetric Cournot, Country 1's profits are increased while Country 2's profits decreases[b]. While the theoretical direction of total profits was unclear, the numerical finding is that overall profits are increased. The more efficient a country is relative to the other, the higher her individual profits will be. Country 1's profits are increased more when only her catchability coefficient increases (72 000 million USD) than when both countries catchability coefficient increases (34 500 million USD). Overall profits are increased (since the increase in profits for Country 1 is higher than the reduction in profits for Country 2). Overall profits increases by 40 million USD when only Country 1's catchability is increased, and by 70 million USD when the catchability increases for both countries. Overall profits are higher when both countries face higher catchability coefficients.

Figure 11: The Effect of a Change in Catchability on Steady State Profits



6. 3 A Cost Increase when $e_1 > 2e_2$

In general, efforts are reduced by a marginal increase in costs if the inequality $e_1 < 2e_2$ holds. The following numerical analysis is an example increase when the inequality breaks and the countries differ such that $e_1 > 2e_2$. In contrast to the previous scenario in which $e_1 = e_2$, stock and effort is expected to increase when costs increases [a].

Country 1's catchability coefficient is set at 1E-06 such that $e_1 > 2e_2$ and the effect on the equilibrium solutions by a 50 % increase in Country 1's costs is presented in Table 13. The values of profits are in million USD, harvest in thousand tonnes, stock in million tonnes and efforts in thousand hours.

Table 13: Equilibrium Solutions when w_1 is increased by 50 % and $e_1 > 2e_2$

	Baseline $e_1 > 2e_2$			Cost Increase		
	Overall	Country 1	Country 2	Overall	Country 1	Country 2
Effort	183'	71'	112'	184'	66'	118'
Stock	1. 88			1. 94 M		
Harvest	231'	134'	97'	233'	127'	106'
Profits	553 M	363 M	190 M	520 M	308 M	212 M

In contrast to the reduction in efforts when costs increased and $e_1 = e_2$, efforts are increased by an increase in costs when $e_1 > 2e_2$.
While we previously found that a reduction in efforts was associated with an increase in stock, we can read from Table 13 that stock and efforts move in the same direction for a cost increase when $e_1 > 2e_2$. Efforts and stock is increased. This has to do with the relative efficiency of the countries efforts. In this scenario, Country 1 is very efficient, and we see that her baseline profits are higher than her individual profits when the catchability coefficients were equal. When her costs increases, as before, Country 1 will reduce her efforts and Country 2 will increase her efforts. However, due to her high level of productivity, and the lower relative level of Country 2's efficiency, these changes are not sufficiently high for overall efforts to be reduced.

As noted in the theoretical discussion of the equilibrium effects of a cost increase, the direction of overall harvest is ambiguous, but Country 1's harvest will decrease and Country 2's harvest will increase. Harvest increases by around 2000 tonnes. As before, the cost increase implies that overall steady state profits are reduced (USD 33 million) as Country 1's profits are reduced more than Country 2's profits are increased.

7 Concluding remarks

In recent years, transboundary stock research and bilateral resource management have been high on the international fishery agenda. The establishment of Exclusive Economic Zones has been source to the nationalisation of marine resources, leading to possibilities and disputes in resource management. One such possibility is the joint management of a transboundary fish stock.

Although answering questions of potential gains of cooperative behaviour using a simple theoretical model as the one developed in this thesis may be challenging, an analysis of the strategic behaviour and optimal effort yields some insights that are useful for instructing the understanding the strategic issues of the coastal nations. The theoretical and numerical findings in this paper points in the direction of potential gains of cooperation in the Namibian and South African Hake resource. This is in line with literature on the fishery economics of a renewable transboundary resource (Munro 1979, Armstrong and Flaaten 1991).

The value of a shared stock management in which the countries cooperate in stock assessments but maximise the returns of their individual fisheries within their EEZ is exemplified as moving from the current stock management regime to a Cournot duopoly. The potential gain of a shared stock management is found to be 215 million USD at FAO - prices and 233 million USD at high-prices. The study also suggests that a maximum sustainable yield target would yield larger profits than both the current regime and a Cournot – regime. In this study, a low world market price of hake was disregarded as it gave unrealistic results in the numerical findings.

The value of regional cooperation is theoretically defined as Sole Owner harvesting, which is in line with the first economic and empirical literature on transboundary fish stocks (Munro 1979, Armstrong and Flaaten 1991). This simple study suggests that joint profits are highest under joint management, and the potential value of regional cooperation is equal to USD 61 million dollars at FAO – prices and 103 million USD at high prices. In general, moving from the primary to the secondary level of cooperation implies a 12. 5 % increase in overall profits.

The findings in this paper suggest that value of regional cooperation is affected by changes in the costs and the catchability. First, a 50 % increase in costs reduced the value of regional cooperation from 61 million USD to 49 million USD. Moreover, the cost - increase implied that the location of the Cournot duopoly moved from higher to lower effort levels than those giving rise to MSY. The order of the economic equilibrium was unaffected by an increase in the catchability. Second, a 50 % increase in the catchability coefficient increased the value regional cooperation by 8 million USD to 69 million USD. Notably, the value of regional cooperation was highest after the catchability increase and this high potential gain of profits was associated with the lowest reduction in efforts (compared with reduction in efforts when moving from Cournot to Sole Owner in the baseline model and after a cost increase).
For policy makers, these findings suggest that it is beneficial to place emphasis on measures improving fishing strategies or technology; as such policies can yield higher returns from regional cooperation.

Although this paper suggests that there may be potential gains of cooperation, it is worth noting that the lack of transparency in estimates of costs and efforts used in the calibration may bias the numerical findings. This sheds light on the importance of transparency in development research, and moreover on the potential gains of bilateral cooperation in scientific research on transboundary research. Such scientific cooperation could open for the possibility of a closer study of the potential gains of cooperation when countries differ in their characteristics, relaxing the assumption of symmetric countries. Moreover, future studies may want to explore steady states in a dynamic setting, and - if the share of the stock differs to a large extent between the countries then other studies may want to relax the assumption of a uniformly distributed fish.

It can be noted, that although the common property problem in fisheries emphasises the need of regulations to control harvest, the right level of control for the fishery depends on political choices and policy objectives. Recent targets in the Namibian and South African hake fishery includes rebuilding of the stock, nationalisation of the catch and employment.

To conclude, this study was made possible because of a scientific community in South Africa working on hake stock assessments, representatives in the Norwegian fishing industry and Norwegian economists and marine biologists. This may be suggestive of the potential scope for interdisciplinary and international fishery cooperation.

In light of the Fishing For Development dialogues on the international agenda (FAO & OECD 2014), and the Fish For Development initiative recently established by Norwegian authorities (MFA 2015), this paper suggests that fishery assistance and cooperation directed towards the management of coastal nations' industrial fisheries can serve as an important asset in development economics.

References

Armstrong, C. W. and O. Flaaten (1991). The Optimal Management of a Transboundary Fish Resource: The Arcto-Norwegian Cod Stock, Springer Verlag.

Armstrong, C. W. and U. R. Sumaila (2004). The Namibian-South African Hake Fishery: Costs of Non-Cooperative Management. Namibia's Fisheries: Ecological, Economic and Social Aspects. Holland, Eburon Publishers.

Baust, S., et al. (2015). South Africa's Marine Fisheries Catches (1950 - 2010). Le Manach F and P. D. Fisheries Centre, University of British Columbia, 2202 Main Mall, Vancouver V6T 1Z4, Canada**:** 129-150.

BCC (2011). BCC Annual State of Fish Stocks Report. 47 Feld StreetWindhoek, Namibia**:** 3-13.

Belhabib, D., et al. (2015). "A fishery tale: Namibian fisheries between 1950 and 2010." (Working Paper #2015 - 65).

Belleflamme, P. and M. Peitz (2010). Industrial organization : markets and strategies. Cambridge, UK, Cambridge University Press.

Bjørndal, T. and G. R. Munro (2012). The Economics & Management of World Fisheries. United Kingdom, Oxford University Press.

FAO (2016). Fishery and Aquaculture Country Profiles. Namibia (2013). Country Profile Fact Sheets. In : FAO Fisheries and Aquaculture Department. Rome. Updated 2013. from http://www.fao.org/fishery/facp/NAM/en.

FAO and OECD (2014). Fishing for Development, The Development Dimension, FAO, Rome. DOI: 10.1787/9789264232778-en

FAO-Globefish (2010). "Globefish European Fish Price Report." from http://www.fao.org/3/a-bb252e.pdf.

Gulland, J. A. (1980). "Some Problems of the Management of Shared Stocks." FAO Fisheries Technical Paper **206**: 2.

Kirchner, C. and A. Leiman (2014). "Resource rents and resource management policies in Namibia's post-Independence hake fishery." Maritime Studies **13**(1): 1-23.

Kirchner, C. H. (2014). "Estimating present and future profits within the Namibian hake industry: a bio-economic analysis." African Journal of Marine Science **36**(3): 283-292.

Kirchner, C. H., et al. (2012). "Evaluation of the Status of the Namibian Hake Resource (Merluccius spp.) Using Statistical Catch-at-Age Analysis."

Lallemand, P., et al. (2016). "In Press: Estimating the Economic Benefits of MSC Certifications for the South African Hake Trawl Fishery." Fisheries Research.

MFA (2015). "The announcement of a Norwegian Fish for Development programme." Norwegian Ministry of Foreign Affairs. from https://www.regjeringen.no/globalassets/departementene/ud/vedlegg/utvikling/fish_development.pdf.

MFMR (2010). Ministry of Fisheries and Marine Resources. Statistics. from http://209.88.21.36/opencms/opencms/grnnet/MFMR/Fishing_Industry/statistics.html.

MTIF (2016). "Fiskerisamarbeidet med Russland." (Fishery Cooperation with Russia). The Norwegian Ministry of Trade, Industry and Fisheries. from https://www.regjeringen.no/no/tema/mat-fiske-og-landbruk/fiske-og-havbruk/rydde-internasjonalt/fiskerisamarbeidet-med-russland/id376440/.

Munro, G. R. (1979). "The Optimal Management of Transboundary Renewable Resources." The Canadian Journal of Economics / Revue canadienne d'Economique **12**(3): 355-376.

Munro, G. R. (2002). On The Management of Shared Fish Stocks Papers presented at the Norway-FAO Expert Consultation on the Management of Shared Fish Stocks Bergen, Norway.

OECD (2012). "Economics of Rebuilding Fisheries: Case Studies of Fisheries Rebuilding Plans."

OECD (2013). Principles and Practice for Policy Design, OECD.

Paterson, B. and P. Kainge (2014). "Rebuilding the Namibian hake fishery: a case for collaboration between scientists and fishermen." Ecology and Society **19**(2): 49.

Perman, R. (2011). Natural resource and environmental economics. Harlow, Pearson.

Rademeyer, R. A. and D. S. Butterworth (2015). "Estimating the Andromeda catchability compared to the Africana for South African hake in an update of the Reference Case assessment." (FISHERIES/2015/AUG/SWG-DEM/16).

SADSTIA (2016). "The South African Deep-Sea Trawling Industry Association" from http://www.sadstia.co.za/

Smith, M. and D. Japp (2014). "2014 Status of South African Hake Resource."

Strømme, T., et al. (2016). "Life cycle of hake and likely management implications." Reviews in Fish Biology and Fisheries **26**(2): 235-248.

Watson, J. (2013). Strategy : an introduction to game theory. New York, Norton.

Wilhelm, M. R., et al. (2015). Biology and fisheries of the shallow-water hake (Merluccius capensis) and the deep-water hake (M. paradoxus) in Namibia. Chichester, UK., John Wiley & Sons, Ltd.

World Development Indicators (2016, updated 2 May 2016). from http://databank.worldbank.org/data/reports.aspx?Code=NE.EXP.GNFS.ZS&id=af3ce82b&report_name=Popular_indicators&populartype=series&ispopular=y.

Appendices

Recalibrating the Numerical Model

A Spawning Stock Steady States

Marine biologists commonly focus on the share of the stock that is capable of reproduction, namely the spawning stock biomass (Bjørndal and Munro 2012). In this analysis, a new numerical model is calibrated using observed values of the spawning biomass at pre-exploitation levels, assuming that countries have equal catchability and costs.. The observed values of spawning deep-water hake in South Africa were presented in the background chapter.

Observed values of costs, MSY, Smax and Smsy

From Table 2, we find the natural carrying capacity (1917-levels) of the spawning biomass to be $S_{max} = 2\ 042\ 000$ tonnes, given the assumption of uniformly distributed fish between South Africa and Namibia. The stock level giving rise to MSY is thus $S_{msy} = 1\ 021\ 000$ tonnes. The observed harvest levels for 2008 will be used in this numerical model, $H_{2008} = 196\ 294$ tonnes. As in the main study, the reasons for choosing the observed harvest level of 2008 are associated with the available data on the Namibian deep-water harvest and the available data from literature on efforts and costs for the period 2007-2009. As before, the hourly costs are USD 1199.

The maximum sustainable yield differs from the observed values used the main study. A recent South African stock assessment presents yearly estimates of the maximum sustainable yields in the period 2013-2015 (Rademeyer and Butterworth 2015). The MSY level closest in time to 2008 is $H = 111\ 000$ tonnes (Rademeyer and Butterworth 2015). The MSY for the entire fishery is thus $H_{MSY} = 222\ 000$ tonnes.

Note on the Observed Carrying Capacity

In this study, the natural level of the spawning stock's carrying capacity (pre-exploitation) is used. Recent estimates on the South African spawning stock, also provides data on the assumed levels of depletion of the spawning stock. In 2015 the spawning stock yielding MSY was found to be 181 000 tonnes, and its assumed depletion is estimated to be 20 %

(Rademeyer and Butterworth 2015). This implies that an estimated carrying capacity equal to $S_{max,spawning} = \frac{181\ 000\ tonnes}{0.20} = 905\ 000$ tonnes . In 2013, the spawning biomass yielding MSY was 153 000 tonnes and the depletion level of the stock was found to be 18 %, hence the spawning stock carrying capacity was 850 000 tonnes. If these levels are multiplied by two, they are below but close to level of 1917 - carrying capacity used in this model.

Calibrated Values of Intrinsic growth, Stock and Catchability

The intrinsic growth rate is now $g = \frac{4H_{msy}}{S_{max}} = 0{,}435$, which means that when the spawning stock is at a low level, it grows by around 44% yearly, indicating a high natural productivity (Bjørndal and Munro 2012). Inserting the observed values of harvest, stock and the polynominal G(S), gives two levels of stock: S_1=673 168 tonnes and S_2=1 368 832 tonnes. Choosing the level closest to the doubled observed spawning stock abundance in 2008 (Table 2), implies S=673 168 tonnes and a catchability coefficient of e=8,98996E-07.

Numerical results

The steady state values in the equilibriums of the Sole Owner, MSY, Cournot, Stackelberg, Current and Open Access are presented in Table 14: Effort values are expressed in hours, stock and harvest in tonnes and profits in US dollars.

Table 14: Steady State Values of the Spawning Deep Water Hake

Steady State Solutions at P_{FAO}						
	Sole Owner	**MSY**	**Cournot**	**Stackelberg**	**Current**	**OA**
Effort	194 696	259 103	259 595	292 045	324 359	389 393
Stock	1 220 359	1 021 000	946 478	809 538	673 168	398 718
Harvest	213 601	237 824	220 884	212 542	196 294	139 576
Profit	481 054 228	484 856 864	427 603 758	360 790 671	267 696 989	-

Potential gains of Cooperation

All economic equilibriums except that of the Sole Owner is located to the right of MSY, and the current scenario is located between the Open Access and Stackelberg. The potential gain of moving from the current scenario to Cournot is now around 160 million USD. The value of regional cooperation is around 54 million USD.

B Steady States at a Lower Carrying Capacity

The numerical model in this study is calibrated using the same observed values of the overall deep water hake stock fishery as in the baseline model of the thesis, but in contrast, it assumes that there is a loss in the potential carrying capacity of the overall stock resource and that the new and lower level of the carrying capacity is equal to an average of the total abundance observed in the period 2000 – 2015. The natural potential of the carrying capacity as used in the main study, may be reduced due to historic over-exploitation and/or other changes affecting the marine habitat.

Using lower levels of Carrying Capacity

From Table 2, we read that the total South African stock abundance is observed to range from 431 000 – 569 000 tonnes in the period 2000-2015. Assuming uniformly distributed fish, the carrying capacity of the overall capacity is set to the double of the average in this period, and equals $S_{max} = 999\ 835$ tonnes. This abundance level is only 22% of the natural carrying capacity used in the main study of the thesis.

Recalibrating the model: Finding g, S and e

The stock level giving rise to the MSY (237 824 tonnes) is $S_{msy} = 499\ 918$ tonnes, and the intrinsic growth rate becomes $g = \frac{4H_{msy}}{S_{max}} = 0.95$ which indicates a very high natural productivity (Bjørndal and Munro 2012). As before, two expressions of the stock follow from the polynominal G(S)=H. Using the observed harvest level in 2008, H=196 294 tonnes, the two levels of stock that follow are S_1=291 768 tonnes and S_2=708 067 tonnes. The highest level of stock is chosen, as this is closest to the double of the observed stock biomass in 2008 presented in Table 2. The catchability coefficient becomes e=8,54686E-07.

Numerical Results

The numerical results of the Sole Owner, Current Scenario, Cournot, Stackelberg, MSY and Open Access is presented in Table 15. Efforts are expressed in hours, stock and harvest in tonnes, and profits in US dollars.

Table 15: Recalibrated Steady State Values of the Deep Water Hake

Steady State Values at P_{FAO}						
	Sole Owner	Current	Cournot	Stackelberg	MSY	Open Access
Effort	322 642	324 359	430 189	483 963	556 610	645 284
Stock	709 612	708 067	612 871	564 500	499 918	419 388
Harvest	195 681	196 294	225 338	233 498	237 824	231 299
Profit	267 704 731	267 696 989	237 959 761	200 778 548	128 146 479	-

Potential gains of Cooperation

The Open Access equilibrium is the only one located to the right of MSY. The Current effort and stock levels are now located between the Sole Owner and Cournot. There is a loss of moving to Cournot, and the gain of moving from Cournot to Regional Cooperation is close to 30 million USD.

Discussion of Results

A collusive equilibrium, or a self-enforced contract, can be sustained in an infinitely repeated version of Cournot, due to the historic reputation that can be achieved (Watson 2013). This could argue for the location of the current scenario (between the Cournot and Sole Owner equilibrium). On the other side, the numerical findings may lack credibility as both Namibian and South African stock assessments report the current deep-water hake stock to be below the stock level corresponding to MSY. Moreover, if there is no other form of cooperative behaviour, effort levels below the Cournot effort levels are not associated with profit maximising behaviour.

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