Management Issues in the Fisheries Commons

by

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Abstract

This dissertation addresses three issues in managing the fisheries commons: international sharing; international agreements; and property rights management. The overall purpose is to move towards providing consistent and broadly applicable analysis of fisheries management issues by conducting studies at an internationally comparable level.

The first issue examined is whether fish stocks that are internationally shared are systematically more exploited than solely owned stocks. With the use of a newly compiled database that includes economic and biological characteristics along with the exploitation status of nearly two hundred fish stocks from around the globe, it is found that sharing is indeed a detrimental force in determining stock status.

The second issue is the natural next question of what effect international agreements have on shared fish stocks. Incorporating information on international cooperative and access agreements into the exploitation status database allows a first-pass analysis of the average effect of cooperative and access agreements on fish stocks.

The final issue considered is the impact on productivity of the introduction of property rights management regimes. A parallel analysis of a traditional productivity approach and an index number decomposition to establish the source of productivity changes is conducted on a unique vessel-level dataset of the Norwegian coastal cod fishery and finds that the introduction of individual vessel quotas raised productivity.

Contents

List of Tables

List of Figures

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Dedication

For my Mother, my Father, and my Brother.

All of whom gave me their love, encouragement, and belief in me

throughout this thesis process, and always.

The waves of the oceans will always connect us when land and life cannot.

Chapter 1

Introduction

Historically, all capture fisheries have proven hard to manage due to their common property nature. Until recently, studies of fisheries management have been hampered by lack of data but this is becoming less of a problem as international organizations, research institutes, and national governments are recognising that "If you can't measure it, you can't manage it." (Trevor Manuel, South Africa's minister of finance, World Bank (2004)). As wider data becomes available, a consistent and more generally applicable body of evidence can be developed on key fisheries management questions. This thesis takes advantage of new data sources to examine fisheries issues at both the international and domestic levels from an empirical perspective.

The international common property problem in fisheries has been examined in terms of the gains from cooperation for particular species or locations, but evidence is lacking on the wider effect that international sharing has in relation to other variables that affect stock status. The second chapter of this thesis is an attempt to shed a broader light on the effect of sharing by identifying whether shared fish stocks are systematically more exploited. Predictions from the Clark-Munro dynamic, single species fisheries model form the theoretical structure for my empirical analysis. I compile exploitation status, and biological and economic data into a unique two-period panel of more than two-hundred fish stocks from around the globe with which I test the theoretical implications of sharing. The empirical results from ordered category estimation suggest that shared stocks do indeed suffer from overexploitation.

This detrimental impact of international sharing on exploitation status leads to the natural next question of what effect international agreements have on shared fish stocks. The third chapter analyses two main types of agreements: those that entail cooperative management of the fisheries; and those that permit access to fish stocks. The former are of particular interest with respect to whether they alleviate the sharing problem, the latter are of interest in their impact on host country resources. The empirical analysis is conducted on the same data as chapter two but with the addition of international agreement information. The results from this broad, first-pass analysis indicate that on average cooperative management is correlated with poor, and declining, stock status whilst access agreements tend to be associated with better stock status highlighting the need for future research into what characteristics of the international cooperative agreements are or are not performing.

An increasingly recommended solution to the common property problem in fisheries management is the use of property rights regimes. While theoretical examination and anecdotal evidence suggest that these regimes are successful at increasing productivity, the empirical evidence on their effects is limited. The fourth chapter provides an empirical examination of the effect of a move to a property rights system on productivity in the Norwegian coastal cod fishery. Using a unique vessel-level dataset I conduct a parallel analysis using a traditional productivity approach and an index number decomposition. The strength of the parallel analysis is to be comparable with previous studies while exploiting the power of the decomposition to identify the component effects of the policy. Determining the important components allows for the refinement of management to mimic the effect of property rights systems even when their full implementation may not be possible. Results suggest that introducing individual vessel quotas in the coastal cod fishery increased productivity.

The overall purpose of this thesis is to move towards providing consistent and broadly applicable analysis of fisheries management issues. The second and third chapters do this by undertaking international scale empirical studies of sharing and agreements. The fourth chapter returns to the more traditional national scale but uses a parallel methodology to allow comparison with other domestic level studies. In the fifth chapter I give some concluding remarks and ideas for future work that will further the notions of internationally comparable and useful fisheries research.

Chapter 2

The Tragedy of the Commons in International Fisheries: An Empirical Examination

2.1 Introduction

The Tragedy of the Commons has long been recognized with respect to fisheries.[1] This problem of the common pool is pervasive amongst both international and domestic fisheries and managers are trying to cope, with limited success. The United Nations Convention on the Law of the Sea (United Nations (U.N.) 1982) was intended to alleviate the pressure on the international commons by extending from a usual three to a 200 nautical mile exclusive economic zone (EEZ) around a nation. Unfortunately, the Food and Agriculture Organization has reported that the percentage of stocks exploited beyond the maximum sustainable yield (MSY) has increased from 10 percent in the early 1970s to 30 percent by the late 1990s, with another 40 percent of stocks fished at MSY (FAO 2000). This evidence suggests that limiting international entry into the fishery is not satisfactory as we observe "Tragedy of the Commons" outcomes in both domestic and internationally shared

[1]Gordon (1954) was the first to analyse fisheries common property, and was popularised in a different context by Hardin (1968).

fisheries.[2]

This chapter analyzes international sharing by using a unique two-period panel of species from around the globe to identify whether shared fish stocks are systematically more exploited. As this is the first time global variation has been used in fisheries, I compile data on exploitation status along with economic and biological characteristics. The data comes from a variety of sources and includes newly available catch and price information on more than two-hundred fish stocks. The use of biological and economic data together allows me to test standard predictions from fisheries theory to determine how important international sharing is in relation to other determinants of stock status.

The results of my ordered category estimation indicate that the probability of a fish stock being depleted, or over- or fully-utilised rises as the number of countries that share the stock rises, while the probability of being moderately or under-utilised falls. This negative effect of sharing is apparent both when stocks are harvested from large or small portions of nations' waters suggesting that access is all that is required to have an affect on stock status.

The theory of shared fisheries is considerable and various. It studies optimal management strategies (Munro 1979), the noncooperative effects on harvests and stock levels (Clark 1980, Levhari and Mirman 1980), mechanisms to attain cooperation for specific fisheries (Lindroos 2004), and the interaction between coastal states and distant water fishing nations (McKelvey, Sandal, and Steinshamn 2002). While the focus, techniques and applications of these papers may differ, the consensus is that a prisoner's dilemma outcome may result due to both static and dynamic incentives to overharvest even when the countries involved have good management otherwise. This chapter explicitly tests this hypothesis across species and countries.

To date, the empirical fisheries literature has considered the potential gains of

[2]The FAO uses the term "shared" generically to refer to transboundary, straddling and highly migratory stocks. Transboundary stocks are shared by two or more nations' EEZs and straddling and highly migratory stocks cross into international waters.

cooperation rather than testing the degree to which sharing exacerbates the problem of the common pool. Authors such as Kennedy (1999), Arnason, Magnusson, and Agnarsson (2000) and Armstrong and Sumaila (2000, 2001) use computational case studies to examine the specific gains from cooperation for particular stocks. While these papers are important in encouraging specific countries to cooperate they do not address the overarching question of how important sharing is in relation to other variables that affect stock status. Understanding the relative contributions of international sharing, domestic management, and economic and biologic characteristics will facilitate appropriate policy advice for fisheries management, particularly amongst countries that must choose where to focus their management resources and in regions where shared stocks are the rule rather than the exception.

Empirical analysis of international sharing has been carried out within other contexts. The success of international pollution reduction agreements has been found to depend on the ability to reduce international externalities (Murdoch and Sandler 1997a, 1997b) and studies have shown that international and interstate river pollution and toxic releases from border counties are higher than domestic pollution (Sigman 2002a, 2002b, Helland and Whitford 2003). In this chapter I am able to see if the externalities found in the international pollution studies are consistent with the overuse of internationally shared fisheries.

Section 2.2 outlines the theoretical predictions from the Clark-Munro dynamic, single species fisheries model that give the framework for the empirical analysis. The distinctive dataset with which these predictions are tested is detailed in Section 2.3. The empirical analysis and results of ordered category estimation are given in Section 2.4. Finally, the conclusion that international sharing is indeed a driving force in determining stock status is discussed in Section 2.5.

2.2 Theoretical Foundations

Before moving to the empirical analysis I develop the theoretical foundations needed to determine the necessary control variables and provide predictions for the effects of said controls. A model that analyzes the interaction of multiple players is the dynamic case of a single species fisheries model as developed by Clark and Munro (1975). This gives a Cournot-Nash solution with a modified golden rule to define the equilibrium stock level. This simple Markov perfect equilibrium can be used to find implications for the variables important in determining fisheries status that are consistent with other theoretical work in fisheries. Of particular importance here, it is easy to interpret the number of players as the number of countries that own the fish stock in question.

The competitive problem for n symmetric players is to choose individual effort levels (L_{it}) to maximise their own sequence of profits, taking others' effort levels (L_{jt}, $j \neq i$) and the natural growth of the fish stock as given.

$$\max_{L_{it}} \int_{0}^{\infty} e^{-\delta t} \left[pqL_{it}x_t - cL_{it} \right] dt \tag{2.2.1}$$

$$\text{s.t.} \quad \dot{x}_t = rx_t \left(1 - \frac{x_t}{K}\right) - qL_{it}x_t - \sum_{j \neq i} qL_{jt}x_t \tag{2.2.2}$$

Where profit depends on the price (p), technical capability (q), effort level (L_{it}), stock size (x_t), and average cost of effort (c). The fish stock grows dependent on the logistic natural growth function, with an intrinsic growth rate (r), natural maximum stock size (K), and stock size (x_t), less the amount of harvesting done by all players.

Taking first-order conditions of the associated Hamiltonian, Equation 2.2.3, the steady-state solution with identical agents is defined by the modified golden rule of Equation 2.2.4. The incentive to overharvest today, or underinvest in the fish stock for tomorrow, is due to the possibility that other countries may harvest the invested fish in the meantime.

$$H = e^{-\delta t} \left[pqL_{it}x_t - cL_{it} \right] + \lambda_t \left[rx_t \left(1 - \frac{x_t}{K}\right) - qL_{it}x_t - \sum_{j \neq i} qL_{jt}x_t \right] \tag{2.2.3}$$

$$\delta = r\left(1-\frac{2\tilde{x}}{K}\right)-\frac{r}{n}\left(1-\frac{\tilde{x}}{K}\right)\left[(n-1)-\frac{c}{pq\tilde{x}-c}\right] \tag{2.2.4}$$

From this equilibrium condition it is easy to identify the effects of each variable by considering the comparative statics. The total derivative of Equation 2.2.4 is:

$$\begin{aligned}\left[(n+1)\tilde{\pi}^2+\hat{\pi}c\right]\frac{d\tilde{x}}{\tilde{x}} &= -(\hat{\pi}-\tilde{\pi})\tilde{\pi}\frac{dn}{n}+\frac{\delta nK\tilde{\pi}^2}{r\tilde{x}}\frac{d\delta}{\delta}+\tilde{\pi}\left[\hat{\pi}-(n+1)\tilde{\pi}\right]\frac{dr}{r}\\ &+ \tilde{\pi}\left[(n+1)\tilde{\pi}+c\right]\frac{dK}{K}-(\hat{\pi}-\tilde{\pi})c\left[\frac{dq}{q}+\frac{dp}{p}-\frac{dc}{c}\right]\end{aligned} \tag{2.2.5}$$

where $\tilde{\pi} = pq\tilde{x} - c$ and $\hat{\pi} = pqK - c$ are the profit per unit effort when stock is at equilibrium harvest and carrying capacity respectively.

An increase in the number of players (n), the price (p), the catchability coefficient (q), and the discount rate (δ) reduce the equilibrium stock level whereas higher carrying capacity (K) and cost (c) increase it. The intrinsic rate of growth of the stock (r) has a positive effect on the stock level if $\hat{\pi} > (n+1)\tilde{\pi}$, which is true for the relevant range of $\tilde{x}$.[3] These results are intuitively appealing, more competition and factors that increase profitability increase the pressure on the stock, while a higher natural preponderance of the stock and an increased ability to rejuvenate improve stock status.

In the data used for the empirical analysis, exploitation status of fish stocks is defined relative to the stock that gives the biological maximum sustainable yield (MSY). This stock is where the natural growth rate is maximised. From the first term in Equation 2.2.2 the maximum sustainable yield stock is derived as $x_{MSY} = \frac{K}{2}$. To apply the theoretical predictions above, they must be converted to give the impact on exploitation status rather than stock level. Let exploitation (X) be defined as the relative difference from the MSY stock level:

$$X = \frac{x_{MSY}-\tilde{x}}{x_{MSY}} = 1-\frac{2}{K}\tilde{x} \tag{2.2.6}$$

[3]For the *bionomic* stock level, $x_{n\to\infty} = \frac{c}{pq}$, the right-hand-side is zero, so the condition is always true. For the static level of $\tilde{x}$ the condition holds with equality. From Equation 2.2.5 we can see that $\frac{\partial x}{\partial \delta} < 0$ thus any dynamic level of $\tilde{x}$ will be less than the static level and hence the condition will hold for any relevant $\tilde{x}$.

All the comparative statics from above, except one, are then just multiplied by $-\frac{2}{K}$, reversing their signs. The intuition remains the same, factors that harm stock level increase the degree of exploitation and vice versa. For carrying capacity (K), however, the conversion is not so simple.

$$\frac{\partial X}{\partial K} = -\frac{2}{K}\frac{\partial \tilde{x}}{\partial K} + \frac{2\tilde{x}}{K^2} = \frac{2\tilde{x}c(\hat{\pi} - \tilde{\pi})}{K^2\left[(n+1)\tilde{\pi}^2 + \tilde{\pi}c\right]} \geq 0 \tag{2.2.7}$$

This means that a higher carrying capacity is more likely to increase the degree of exploitation relative to the biological maximum.[4]

By choosing to interpret the number of players given by the theory as the number of countries, the implicit assumption is that the countries are choosing the overall catch optimally and are perfectly able to manage their domestic fleets to only take this catch level. Of course, reality is quite different. The empirical strategy will account for this by including a measure of management ability. If a nation sticks to an optimally chosen catch, no matter with what efficiency it is distributed amongst the domestic fleet, then the theory will represent reality. If a nation is unable to enforce optimal effort it will be manifested similarly to an increase in the number of players. Another twist on international sharing is harvesting in the high seas. The high seas are essentially "unowned" and open to all nations. A variable for being caught in the high seas is included in the analysis.

This theory provides the following reduced form structure for the empirical tests:

$$X = f(n, M, HS, K, r, p, q, c, \delta) \tag{2.2.8}$$

where X is exploitation of the fish stock, n is how many countries' waters the stock is fished in, M is the domestic management ability within those countries, HS is whether the stock is caught in the high seas or not, and the remaining variables are as defined earlier this section.

[4]The economic maximum is a preferable baseline that future work would like to consider but the currently available data only allows comparison to the biological maximum. The static theoretical predictions about the signs on the effect of explanatory variables remain the same using the economic maximum as a baseline.

2.3 The Data

The data for this chapter has been drawn together from a variety of sources and has been collated to be useful in an economic rather than biological analysis. The dependent variable, exploitation of the fish stock (X), comes from the Food and Agriculture Organization's "Review of the state of world fishery resources: marine fisheries" (1997) and "Review of the state of world marine fishery resources" (2005). These FAO reports use data through to 1994 and 2002 respectively to assign each fish stock in each of seventeen regions,[5] as shown in Figure 2.1, one of the following categories:

- U = Underexploited, undeveloped or new fishery. Believed to have a significant potential for expansion in total production;
- M = Moderately exploited, exploited with a low level of fishing effort. Believed to have some limited potential for expansion in total production;
- F = Fully exploited. The fishery is operating at or close to an optimal yield level, with no expected room for further expansion;
- O = Overexploited. The fishery is being exploited above a level which is believed to be sustainable in the long term, with no potential room for further expansion and a higher risk of stock depletion/collapse;
- D = Depleted. Catches are well below historical levels, irrespective of the amount of fishing effort exerted;
- R = Recovering. Catches are increasing after a collapse from a previous high;
- Blank or ? = Not known or uncertain. Not much information is available to make a judgement.

[5] I use no observations from Areas 18 or 88.

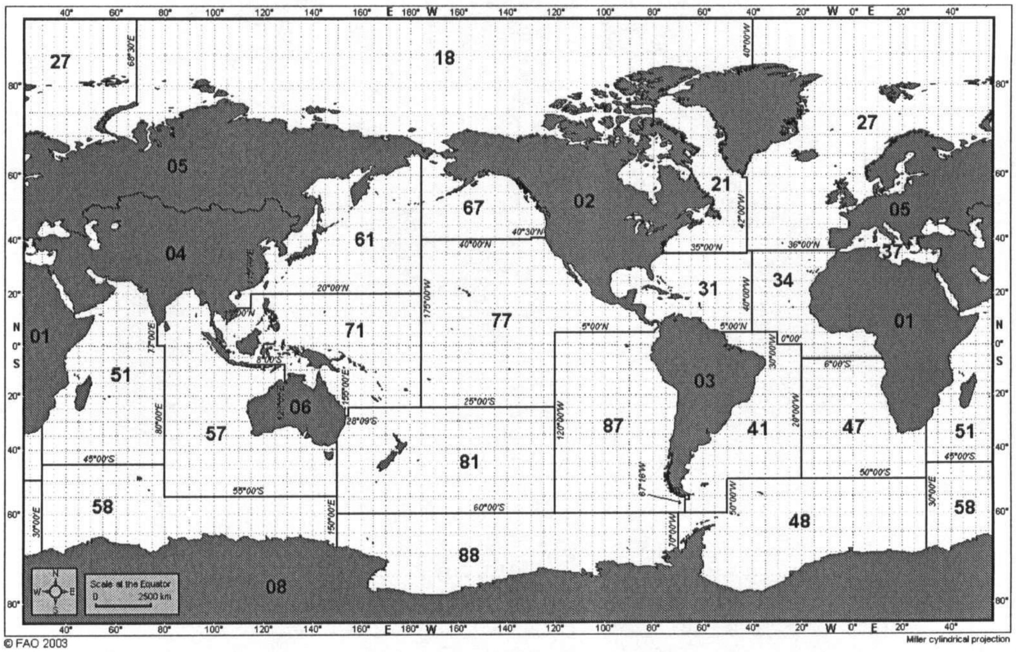

Figure 2.1: Map of FAO Areas

Thus, an observation is the exploitation level of a stock in an FAO area in a time period. It should be noted that some species will be observed in more than one area and may have different levels of exploitation in each. After removing shellfish and cephalopods for lack of physical data, recovering as there is no natural ordering, and blank or ? for obvious reasons, the total number of usable observations is 373. Of these 373: 165 are categorised in both periods; 23 are only categorised in 1994; and 20 are only categorised in 2002, giving 208 species-FAO area combinations, which together account for almost 40% of the volume and 50% of the value of marine fisheries globally. Table 2.1 shows the proportions in each of the exploitation

Table 2.1: Number and Percentage of Exploitation Status Data

	Depleted	Over	Fully	Moderate	Under	All
Exploitation	15	39	78	48	8	188
Status - 1994	8%	21%	41%	26%	4%	
Exploitation	12	46	78	45	4	185
Status - 2002	6%	25%	42%	24%	2%	

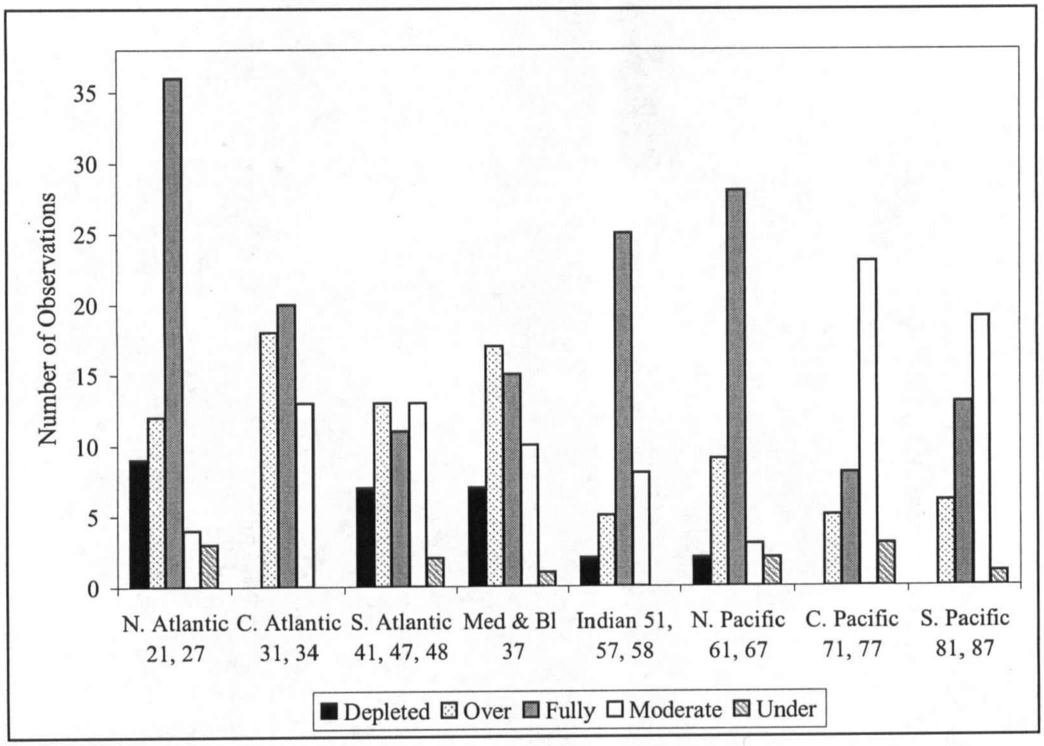

Figure 2.2: Frequency of Exploitation Status by Groups of FAO Areas

categories, Figure 2.2 plots the frequency of exploitation status by groups of FAO areas, and a list of species is given in Table 2.8 at the end of the chapter.[6,7]

From the theory of Section 2.2 we can see that data on the number of countries, management, and economic and physical characteristics are required. A discussion of each follows and summary statistics are presented in Table 2.2.

The number of players (n) variable was developed from catch data from the Sea Around Us project database (2005). This data has incredible detail with catch of a fish species in a FAO area broken down across the globe into half degree by half degree cells (approximately 55km by 55km at the equator) by the nation that caught

[6]The ocean areas are grouped in this figure for presentational clarity, the analysis is run at the FAO area level.

[7]There is a potential issue that shared fisheries may be better scrutinised than fisheries that fall under a single jurisdiction. However, information gathering and processing is also subject to free-riding in shared fisheries so the effect could easily go either way.

Table 2.2: Means of Explanatory Variables by Exploitation Status and Year

	Depleted		Over		Fully		Moderate		Under		All
	1994	2002	1994	2002	1994	2002	1994	2002	1994	2002	
Observations	15	12	39	46	78	78	48	45	8	4	373
Number of Countries, n	7.60 (7.95)	9.42 (8.24)	12.03 (7.77)	11.80 (8.72)	8.50 (7.76)	8.15 (7.08)	11.56 (8.73)	11.18 (8.95)	2.88 (1.46)	3.00 (.00)	9.73 (8.13)
Avg Real Int. Rate, δ	8.2 (9.6)	6.5 (5.2)	7.3 (9.6)	5.5 (6.4)	8.6 (10.9)	5.2 (7.1)	8.3 (7.4)	6.4 (4.8)	12.8 (11.9)	10.8 (14.4)	7.1 (8.4)
Dbl. Time >14yr, r	0.07	0.00	0.00	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.01
Subtropical or Trop., K	0.13	0.17	0.69	0.65	0.62	0.59	0.79	0.89	0.63	0.50	0.64
AvgAgVA/wkr (\$10000US), c	1.70 (.87)	2.12 (1.35)	1.04 (.66)	1.40 (.98)	1.35 (.91)	1.90 (1.47)	0.95 (.59)	1.25 (.80)	1.53 (1.10)	2.66 (1.48)	1.43 (1.07)
AvgGDP/cap (\$10000US), q	1.53 (.58)	1.71 (.80)	1.07 (.51)	1.24 (.61)	1.29 (.69)	1.56 (.88)	0.99 (.42)	1.15 (.51)	1.46 (.76)	2.02 (.78)	1.30 (.69)
Price (\$1000US US/tonne), p	2.82 (3.80)	2.93 (3.75)	3.63 (3.68)	2.77 (3.52)	2.08 (2.18)	1.36 (1.35)	1.28 (1.32)	1.88 (3.16)	0.43 (.27)	0.62 (.56)	2.06 (2.69)
High Seas, HS	0.47	0.58	0.33	0.41	0.55	0.59	0.54	0.47	0.63	0.75	0.51
Avg Risk Rating, M	73.6 (7.99)	75.1 (8.35)	68.7 (7.79)	71.9 (5.69)	71.3 (8.99)	73.4 (8.04)	69.9 (8.36)	72.1 (5.06)	74.3 (8.20)	76.5 (5.45)	71.8 (7.81)

Observations 373. 188 for 1994, 185 for 2002, 165 in both.
Standard deviations in parentheses for continuous variables.

it. This data can then be aggregated to EEZ and FAO area.[8] From this data, n was calculated as the number of EEZs in a given FAO area that a species was caught in. Therefore, different species in the same area may have different status and number of countries than another species in the same area, or be different from the same species in a different area. The choice to analyze sharing in this way is to capture the idea of ownership rights to access. As is evident from the "fish wars" that involved only small areas of high seas, just some right of access is all that is required to disrupt fish stocks; it is not necessarily the geographic share that matters.[9] Note that counting based on where harvesting occurs does not distinguish between who is doing the harvesting. This is done to reflect the fact that location determines ownership and any decision of any country to allow other nations vessels to harvest

[8]For the Mediterranean 'hypothetical' EEZs are used to delimit the relevant marine areas.

[9]For example on the Grand Banks of Newfoundland (Bjørndal and Munro 2003) and in the Herring loophole in the Norwegian Sea (Arnason, Magnusson, and Agnarsson 2000).

there is a separate consideration.[10] The number of countries owning a stock ranges from one to 28, with almost half of the stocks being fished in five or less country's waters and one quarter fished in sixteen or more. A dummy variable was created if the fish was harvested in the high seas to capture the effects of "unowned" areas.

For clarity of how the number of countries is counted, consider the following example. Pink salmon is observed in both the NW and NE Pacific. In the NW Pacific, it is harvested in Japanese, North and South Korean, Russian, and American waters plus the high seas so it is classified as being shared by five countries and the high seas dummy equals one. In the NE Pacific, pink salmon is harvested in Canadian, Russian and American waters but not the high seas so it is classified a being shared by three countries and the high seas dummy equals zero. In contrast, Pacific halibut in the NE Pacific is harvested in Canadian, Russian and American waters and the high seas so is classified as being shared by three countries and the high seas dummy equals one.

Counting the number of countries this way may give rise to a potential endogeneity problem that as stocks get worse countries no longer find it so profitable to harvest them. However, there are two reasons to allay any concern. Firstly, countries are counted if the catch of that species from their waters is positive so if the catch rises or falls with changes in exploitation status but remains positive it does not matter. Secondly, any affect of this type will work against finding a negative effect of the number of countries, that is, countries exiting when stocks fall means a higher number of countries will be associated with better stocks rather than vice versa. The following management and economic characteristics are assigned by a simple average of the countries that are identified as sharing each stock, again to reflect the access criteria.[11]

[10] I do, however, consider some alternate definitions that are dependent on geographic size or include distant water fishing nations' involvement that are discussed in Section 2.4.

[11] I also tried weighting the economic variables by proportion of catch and found that it altered little. As I was concerned about weighting by a choice variable I report only the equal weighted results. In addition, a version is reported that includes standard deviations of the country charac-

Capturing the domestic management ability is difficult. Initially I considered using a set of categories that summarised information from the FAO's Fishery Country Profiles (2003). The advantage is that these capture specific fisheries management measures such as quota use, and size, gear and season restrictions. Unfortunately, they are not consistently reported nor available for many countries. Another problem is that measures based on fisheries management specifically are most likely endogenous as "good " management is frequently only implemented in a restorative fashion after overfishing has occurred rather than in a preventative fashion. Hence, we would observe a positive relationship between "good" management and "bad" outcomes. To avoid this problem I use a more general measure of the enforcement of property rights: the PRS Group's "International Country Risk Guide" rating, accessed via the World Development Indicators (2004), which rates political, financial, and economic risk (the higher the rating, the lower the risk). This measure captures a country's ability to manage, whether or not it chooses to use that ability.

The economic variables contributing to exploitation are also difficult to measure and hence why case studies have been used in the past. This chapter uses a new price database developed as part of the Sea Around Us project (2005). This database is a collection of fisheries prices from around the globe and across time, all in US dollars per tonne. I use the mean observed price for each species in each year; if the exact species was unavailable I used the closest species, determined by taxonomy and location. This provides me with a measure of the world price of each species, albeit imperfectly. The advantage of using one world price for each species is that avoids potential local endogeneity of price; note also that prices are relatively constant in this time period, if anything, prices have fallen as depletion has risen.

Costs are measured imperfectly by agricultural value added per worker, from the World Development Indicators (2004), as an average across owner countries. This data includes fisheries value added and is used like an opportunity cost to represent

teristics.

wages because a consistent and comparable wage data source has proven elusive.[12]

Ideally, technical capability would be country and fishery specific. I explored using the number of vessels and ports from the Fishery Country Profiles (2003) but inconsistent reporting, in distinguishing between industrial and artisanal fleets for example, or no reporting at all, meant that I could not use this measure in this global analysis. Instead, I use gross domestic product (GDP) per capita, from the Penn World Tables (2002), to reflect richer, more capital intensive countries who could therefore choose higher technical capability, once again as an average across owner countries.

As a measure of the discount rate, I use the real annual interest rate, also from the World Development Indicators (2004). The interest rate is potentially a conservative estimate of the discount rate as it does not include default or fisheries-specific risk. Note that just one year of each explanatory variable is used; the results are almost identical for different years so I use data from 1992 and 2000 for my explanatory variables to allow for a small lag in the effect on exploitation status.

Finally, physical characteristics need to be accounted for. Data on fish stock doubling time (greater than 14 years, 4.5-14 years, 1.4-4.4 years and less than 15 months) and climate (deep-water, polar, temperate, subtropical and tropical), amongst various other biological information under separate entries for each species, is available from Fishbase (2005). These were converted into sets of dummy variables and are used to capture the growth rate of the stock and the carrying capacity (or productivity) of the environment.

2.4 Empirical Analysis and Results

As the dependent variable is categorically ordered, an ordered probit analysis is called for. This takes the explanatory variables and estimates the probability of

[12] I do conduct a version in Section 2.4 using a measure of wages from the Occupational Wages from Around the World Database (2005), unfortunately, the coverage is limited so I lose more than half my sample.

being in each exploitation category (depleted, overexploited, fully exploited, moderately exploited and underexploited). The following regression is estimated for fish stock i in FAO area l at time period t.[13]

$$\begin{aligned} Pr(Exploitation_{ilt}) = {} & f(Number\ of\ Countries_{ilt},\ Price_{it},\ Climate_i, \\ & Doubling\ Time_i,\ Average\ Real\ Interest\ Rate_{ilt}, \\ & Average\ GDP/Capita_{ilt},\ Average\ Agriculture \\ & Value\ Added/Worker_{ilt},\ Average\ Risk\ Rating_{ilt}, \\ & High\ Seas\ Dummy_{ilt},\ Year\ Dummy) \end{aligned}$$

With the data as an unbalanced two-period panel I also include a dummy variable for the later period to capture any global trend in stock status and use the GLLAMM programme (Skrondal and Rabe-Hesketh 2003) for Stata 8 (2003) to estimate a random-effects panel ordered probit. My exploitation status categories are coded such that Depleted is a "1", Overexploited is a "2", and so forth, thus a negative coefficient on the explanatory variables indicates a worsening of stock status.

The coefficients of the ordered probit model only indicate whether the variables generally improve the exploitation status or not, so we should generally examine the marginal effects. Marginal effects tell us how much the probability of being in each exploitation category changes for a one unit change in a particular variable, or for a discrete jump in a dummy variable. However, after presenting the marginal effects for the base specification I shall only present coefficients of remaining specifications to save space. The coefficients and marginal effects for each exploitation category for the initial regression are reported in Table 2.3.

The number of countries is statistically significant at the 5% level and works in the anticipated direction; the more countries a fish stock is shared between, the more likely it is to be overexploited or depleted. The positive coefficient on the squared term reduces this impact but is not statistically significant. This result can

[13] All standard errors are clustered at the species-FAO area level.

Table 2.3: Base Ordered Probit: Coefficients and Marginal Effects

Dependant Var. Exploitation	Coefficients	dD/dx	dO/dx	dF/dx	dM/dx	dU/dx
Number of Countries	-.1282 ** (.058)	.0039	.0076	-.0008	-.0094	-.0014
Number Sq.	.0032 (.002)					
High Seas	.6012 ** (.279)	-.0293	-.0667	-.0070	.0855	.0175
(Sub)Tropical	1.871 *** (.667)	-.1908	-.1414	.1326	.1834	.0162
Dbl.Time>14yr	-2.113 *** (.619)	.2321	.1423	-.1628	-.1953	-.0164
Price ($000 US/tonne)	-.1479 *** (.050)	.0087	.0168	-.0017	-.0207	-.0031
Avg Real Interest Rate	.0064 (.010)	-.0004	-.0007	.0001	.0009	.0001
Avg GDP/cap ($10 000 US)	-1.472 * (.819)	.0876	.1576	-.0160	-.1960	-.0332
Avg Ag VA/wkr ($10 000 US)	.6837 (.440)	-.0403	-.0766	.0077	.0946	.0145
Avg Risk Rating	.0324 (.025)	-.0019	-.0037	.0004	.0045	.0007
Year 2002	-.4281 ** (.191)	.0221	.0482	.0022	-.0611	-.0114

Obs: 373. Log likelihood -420.868
Significance levels: *10% **5% ***1%. Clustered standard errors of coefficients in parentheses.
The marginal effects for Number of Countries includes the effect via the squared term.

be more clearly seen in Figure 2.3 where the predicted probability of being in each exploitation category is given, evaluating all other variables at their means and only allowing the number of countries fished in to change.

These predicted proportions mean that if a fish stock is shared between two countries it is 7% more likely to be overfished and 14% more likely to be depleted than a stock fished by one country. If the stock is shared by five countries it is 28% more likely to be overfished and 60% more likely to be depleted. When the stock is shared by ten countries it is 56% more likely to be overfished and 136% more likely to be depleted than a stock fished by just one country.

Moving to the biological variables, a more productive (subtropical or tropical) climate works consistently with the raw stock effect, a better climate increases the

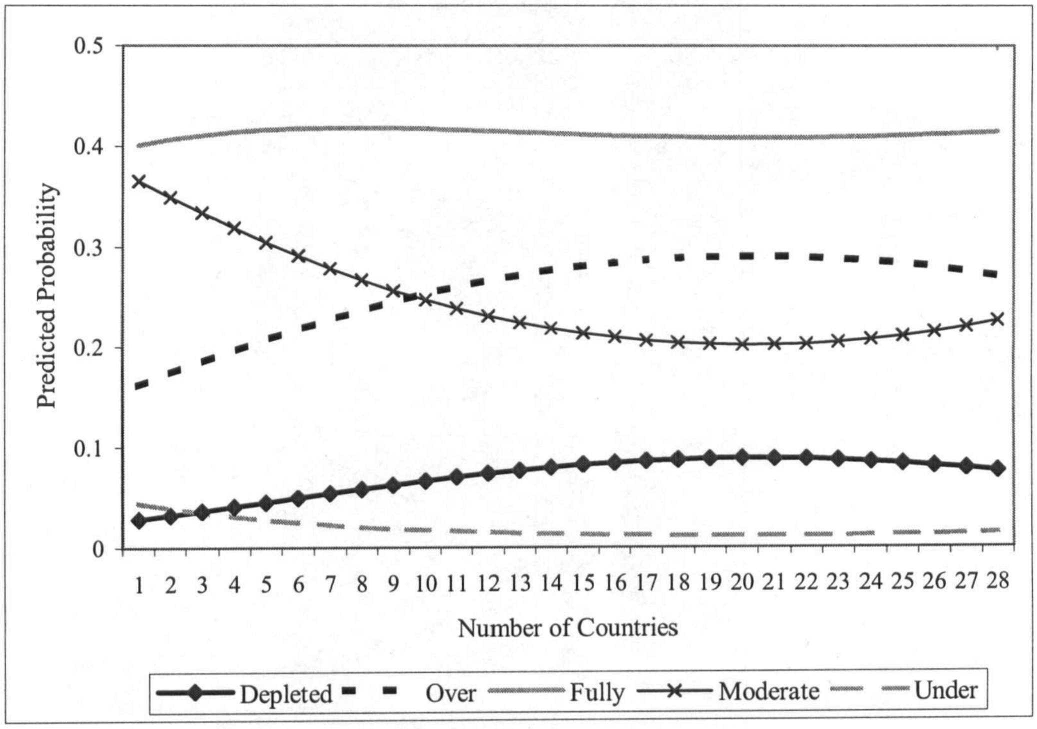

Figure 2.3: Predicted Probabilities of Exploitation Status using Base Ordered Probit

stock. However, from the form of Equation 2.2.7, a better climate should, somewhat counterintuitively, increase exploitation relative to the biological maximum level, which does not hold up in the data. Having a very slow doubling time (greater than 14 years) has statistically significant negative impact.[14] A higher price works in the anticipated direction by increasing the chance of a stock being overexploited or depleted; higher GDP per capita works in the same direction. Neither Agricultural Value Added per worker nor Risk have statistically significant impacts but the signs are consistent with the theory. A curious result is the positive effect that being harvested in the high seas has on exploitation status. It is puzzling in that the high seas are the last remaining true commons and should therefore be "unowned"

[14]For expositional ease I report results for groups of climate and doubling time variables throughout. The groups were chosen as results from the complete specification indicate that subtropical and tropical climates have very similar coefficients, as do all the doubling time categories other than very slow.

and more likely to be exploited. However, the distance from shore combined with the high seas stocks being generally more migratory may be providing some degree of natural protection. Finally, the negative coefficient on the Year 2002 dummy indicates that globally, stock status has declined on average since 1994.

The next step in the examination of international sharing is to examine a variety of different specifications of the explanatory variables. Table 2.4 shows the coefficients for these specifications with the base version in the first column. The second column shows the results of including the standard deviations of the owner-countries' variables.[15] These were included as a way to allow for the empirically observed heterogeneity of countries that is not present in the theoretical model. Including the standard deviations along with the means reinforces the results of the basic model and only the standard deviation of the risk rating has a statistically significant impact suggesting the heterogeneity is not such an important factor. This is perhaps not surprising as the countries are already being grouped by FAO area where neighbours have more similar characteristics than is observed on global scale.

The third column of Table 2.4 gives the results of one of three alternate measures of management ability, the average Polity rating. The Polity rating comes from the "Integrated Network for Societal Conflict Research Program" and is a measure of political regime characteristics including democratic process, stability, executive power and so forth. Like the Risk rating, it does not have a statistically significant impact but its sign follows the theory. Two other measures were also used with similar results: the Heritage Foundation's "Index of Economic Freedom"; and the index of property rights, one of the ten components of the Economic Freedom index.

Finding a consistent measure of wages proved almost impossible but the Occupational Wages from Around the World Database (2005) gives average monthly wage rates for male workers in US dollars. Unfortunately, the coverage is limited so only 156 of my 373 observations are included in this version, presented in the

[15]Recall that the coefficients just indicate the direction of the effect rather than specific effects on each category. A negative sign means more of that variable worsens the status of the stocks.

Table 2.4: Coefficients of Alternative Specifications

Dependant Var. Exploitation	Base Version	with Std Deviations	with Polity Alternative	with Wages (156 obs)	with Real Disc. Rate (358 obs)
Number of Countries	-.1282 ** (.058)	-.1365 * (.078)	-.1240 ** (.060)	-.0887 (.081)	-.1662 *** (.063)
Number Sq.	.0032 (.002)	.0033 (.003)	.0031 (.003)	.0032 (.003)	.0046 * (.003)
High Seas	.6012 ** (.279)	.8045 *** (.303)	.5998 ** (.299)	.0211 (.288)	.6103 ** (.281)
(Sub)Tropical	1.8706 *** (.667)	1.1966 * (.668)	1.9247 *** (.675)	.9596 *** (.349)	1.5588 *** (.598)
Dbl.Time>14yr	-2.1131 *** (.619)	-3.0310 *** (.687)	-1.9535 *** (.635)	-.1976 (.400)	-2.3169 *** (.732)
Price ($000 US/tonne)	-.1479 *** (.050)	-.1142 ** (.050)	-.1501 *** (.051)	-.1205 (.076)	-.1382 *** (.051)
Avg Real Interest Rate	.0064 (.010)	.0183 (.018)	.0050 (.010)	.0215 (.039)	
Avg GDP/cap ($10 000 US)	-1.4722 * (.819)	-1.9164 * (1.083)	-.9987 (.698)	-1.0956 * (.565)	-1.5504 * (.822)
Avg Ag VA/wkr ($10 000 US)	.6837 (.440)	.9057 * (.513)	.5225 (.424)		.7029 (.433)
Avg Risk Rating	.0324 (.025)	-.0230 (.031)		.0860 ** (.039)	.0359 (.025)
Year 2002	-.4281 ** (.191)	-.0246 ** (.010)	-.4107 ** (.190)	-.0606 (.252)	-.4540 ** (.185)
SD Money Market Rate		1.1066 (.855)			
SD GDP/cap ($10 000 US)		.0458 (.566)			
SD Ag VA/wkr ($10 000 US)		-.0464 (.033)			
SD Risk Rating		-.7486 *** (.220)			
Avg Polity Rating			.0300 (.041)		
Wages ($10 000 US)				-.0009 (.001)	
Avg Real Discount Rate					.0004 (.001)
Log likelihood:	-420.868	-399.098	-421.281	-171.265	-399.165

Obs: 373. Significance levels: *10% **5% ***1%. Clustered standard errors in parentheses.

fourth column. Consequently, the power of the regression falls but the coefficients are generally similar and wages are still not significant. Finally, instead of using the real interest rate I use the real discount rate of the central bank. As can be seen in column five, the results are robust to this alternate measure.

Table 2.5: Coefficients of Examining Geographic Size

Dependant Var. Exploitation	Base Version	≥ 1% of Catch	≥ 1% of Own EEZ Cells	≥ 1% of All FAO Cells	≥ 1 tonne of Catch
Number of Countries	-.1282 ** (.058)	-.2150 (.137)	-.1293 * (.069)	-.2314 ** (.096)	-.1281 ** (.063)
Number Sq.	.0032 (.002)	.0125 (.010)	.0032 (.003)	.0078 (.006)	.0033 (.003)
High Seas	.6012 ** (.279)	.3440 (.332)	.5961 * (.362)	1.0676 ** (.530)	.7236 ** (.298)
(Sub)Tropical	1.8706 *** (.667)	1.7164 *** (.654)	1.7809 *** (.672)	1.6547 *** (.463)	1.7406 *** (.660)
Dbl.Time>14yr	-2.1131 *** (.619)	-2.1170 *** (.674)	-2.2840 *** (.709)	-2.7983 *** (.864)	-2.1776 *** (.665)
Price ($000 US/tonne)	-.1479 *** (.050)	-.1443 *** (.048)	-.1485 *** (.051)	-.1644 *** (.053)	-.1446 *** (.052)
Avg Real Interest Rate	.0064 (.010)	.0074 (.012)	.0081 (.011)	.0078 (.012)	.0058 (.011)
Avg GDP/cap ($10 000 US)	-1.4722 * (.819)	-1.0428 (.821)	-1.3108 (.820)	-1.1889 (.801)	-1.5462 * (.837)
Avg Ag VA/wkr ($10 000 US)	.6837 (.440)	.4727 (.460)	.6361 (.451)	.6031 (.450)	.7120 (.441)
Avg Risk Rating	.0324 (.025)	.0384 (.024)	.0337 (.025)	.0328 (.025)	.0334 (.024)
Year 2002	-.4281 ** (.191)	-.4346 ** (.194)	-.4316 ** (.186)	-.4488 ** (.190)	-.4110 ** (.187)
Log likelihood:	-420.868	-423.415	-421.496	-418.211	-419.926

Obs: 373. Significance levels: *10% **5% ***1%. Clustered standard errors in parentheses.

Of further interest is the effect of the degree of sharing. Until now, a country has been counted as an owner of the stock if any of the species is harvested in that country's waters. Table 2.5 presents a variety of different specifications that restrict ownership in a variety of ways. The second column only counts countries that harvest more than one percent of the catch of that species in that FAO area. While the coefficient on the Number of Countries increases in magnitude it reduces in power. This is not surprising as a restriction based on percent catch will necessarily be more binding for stocks with many countries thus the maximum number of countries is now only seventeen compared to the previous high of 28. The remaining columns use geographic measures to restrict the counts to reduce this problem.

The third column of Table 2.5 only counts countries for which the stock is harvested in more than one percent of that country's waters. The results are almost identical to the base version and continue to be very similar as the percentage is increased. The fourth column continues along this line and only counts countries for which the stock is harvested in more than one percent of all the cells in the FAO area. All results in this specification strengthen the results of the base version. These two sets of results suggest that access is what matters supporting my original specification. Lastly, column five only counts countries that harvest more than one tonne of that stock in that area; this version essentially eliminates any catch data anomalies and the base results are robust to this.

The penultimate table examines the effect of location and time in more detail. The second column of Table 2.6 allows different time effects for different ocean areas; the Central and South Atlantic fare worse than the 1994 average while the Central Pacific fares relatively better. Various specifications of this type were tried, including both 1994 and 2002 area specific effects and trends and including FAO area specific effects and trends, and the qualitative results were similar but the power falls. The last two columns together present a specification where all variables are included and are also interacted with a dummy for the year 2002 allowing for variable specific time effects. Once again, the qualitative results are similar even though the power falls. Generally the interaction terms are not interesting nor significant suggesting the additional impact of 2002 is not variable specific. However, the high seas interaction term is a large negative and is significant at the 10% level indicating that there has perhaps been a move to harvesting from the high seas as national waters become more depleted and regulated.

In addition, for econometric thoroughness, I considered three different econometric models and report the results in Table 2.7. I first ignored the panel structure of the data and ran an ordered probit with errors clustered at the species-FAO area level with similar qualitative results but with magnitudes of generally half the size. I next returned to the panel formation but ignored the purely categorical interpretation of the exploitation status categories and treated exploitation as a linear variable

Table 2.6: Coefficients of Examining Place and Time

Dependant Var. *Exploitation*	Base Version	with Oceans	with Time Interactions	Interaction
Number of Countries	-.1282 ** (.058)	-.1375 ** (.058)	-.1205 (.075)	-.0123 (.085)
Number Sq.	.0032 (.002)	.0037 (.002)	.0035 (.003)	-.0004 (.003)
High Seas	.6012 ** (.279)	.7050 ** (.285)	.8969 *** (.337)	-.5298 * (.319)
(Sub)Tropical	1.8706 *** (.667)	1.5825 *** (.584)	1.6620 ** (.718)	.3976 (.360)
Dbl.Time>14yr	-2.1131 *** (.619)	-2.3733 *** (.748)	-1.8133 * (.958)	-.8554 (.802)
Price ($000 US/tonne)	-.1479 *** (.050)	-.1519 *** (.045)	-.1860 *** (.048)	.0532 (.056)
Avg Real Interest Rate	.0064 (.010)	.0170 (.016)	.0056 (.011)	-.0052 (.016)
Avg GDP/cap ($10 000 US)	-1.4722 * (.819)	-2.2334 * (1.140)	-.7720 (1.357)	-.5769 (1.732)
Avg Ag VA/wkr ($10 000 US)	.6837 (.440)	1.0469 (.675)	-.2122 (.953)	.8477 (1.109)
Avg Risk Rating	.0324 (.025)	.0371 (.029)	.0541 ** (.026)	-.0097 (.015)
Year 2002	-.4281 ** (.191)			
North Atlantic*2002		-.6532 (.582)		
Central Atlantic*2002		-.8048 ** (.322)		
South Atlantic*2002		-.7624 ** (.315)		
Indian*2002		-.4187 (.327)		
North Pacific*2002		.1981 (.395)		
Central Pacific*2002		.7139 ** (.361)		
South Pacific*2002		-.3640 (.468)		
Log likelihood:	-420.868	-413.306	-416.605	

Obs: 373. Significance levels: *10% **5% ***1%. Clustered standard errors in parentheses.

(that is, being depleted is five times worse than being underexploited). The last two columns of Table 2.7 show the random and fixed effects versions of this linear panel regression. Once more the qualitative results are similar supporting the results of the earlier econometric specification. A Hausman test rejects the hypothesis that

Table 2.7: Coefficients of Alternative Econometric Models

Dependant Var. Exploitation	Base Version Random Effects Ordered Probit	Ordered Probit without Random Effects	Linear in Exploitation Fixed Effects	Linear in Exploitation Random Effects
Number of Countries	-.1282 ** (.058)	-.0686 * (.037)	-.1203 (.120)	-.0449 (.030)
Number Sq.	.0032 (.002)	.0021 * (.001)	.0029 (.003)	.0012 (.001)
High Seas	.6012 ** (.279)	.3330 ** (.152)	.5820 (.516)	.3297 *** (.121)
(Sub)Tropical	1.871 *** (.667)	.7586 *** (.193)		.6383 *** (.150)
Dbl.Time>14yr	-2.113 *** (.619)	-1.029 * (.552)		-.9232 (.598)
Price ($000 US/tonne)	-.1479 *** (.050)	-.1061 *** (.032)	.0078 (.030)	-.0591 *** (.018)
Avg Real Interest Rate	.0064 (.010)	.0004 (.008)	.0029 (.008)	.0025 (.006)
Avg GDP/cap ($10 000 US)	-1.472 * (.819)	-.5520 (.486)	-.9915 (.657)	-.5298 (.379)
Avg Ag VA/wkr ($10 000 US)	.6837 (.440)	.1915 (.255)	.4208 (.254)	.2569 (.194)
Avg Risk Rating	.0324 (.025)	.0254 (.016)	-.0053 (.022)	.0108 (.012)
Year 2002	-.4281 ** (.191)	-.1525 (.093)	-.1000 (.123)	-.1604 ** (.066)
Constant			4.423 ** (1.77)	2.337 *** (.777)
Log likelihood:	-420.868	-467.455		
Overall R^2:			0.0245	0.1661
			Hausman Test $\chi^2(9) = 42.84$	

Obs: 373. Significance levels: *10% **5% ***1%. Clustered standard errors in parentheses.

the difference in coefficients between the random and fixed effects specifications is not systematic but did not reject the same hypothesis for different specifications of this linear version.

Finally, I also investigated a variety of other specifications, a few of which I will briefly discuss here. Using ordered logit rather than probit gave almost identical results while two bivariate versions, where Depleted and Over (and Fully) were compared to (Fully and) Moderately and Under, support the base version. No observations has clearly outlying characteristics, but excluding those that had characteristics more than three standard deviations from the mean reduced the number of observations to 347 without significantly changing the results. Whether a stock was harvested in two, three, four, or five-plus FAO areas did not seem to help nor hinder stock status. A few countries are of interest, for their fisheries management or from curiosity, so I use a set of dummies for Australia, Canada, Iceland, New Zealand or the United States being amongst the owners but none were notable after controlling for ocean area.

2.5 Conclusion

This chapter uses a unique dataset on a panel of species from around the globe to identify the effect of international sharing on the status of the fish stock. I find that international sharing is indeed a detrimental force in determining stock status and that stocks harvested from large or small portions of nations' waters are equally susceptible. This result is robust to a variety of specifications. Hence, it may be concluded that policy advice that ignores the role of international sharing does a disservice to the countries and fish stocks involved. Further, while direct consideration of the effects of international cooperation is not considered here, the poor performance of shared stocks compared to their solely owned counterparts does suggest that regional fisheries management organizations should be useful as forums for cooperatively managing shared fish stocks. Finally, this international tragedy of the commons in fisheries is consistent with free-riding results found in international pollution studies.

Given the time period limitations of this study, an extension of the panel of data would be desirable. A longer panel would allow a comparison of the differences in international property rights from the 1980s to 1990s and would also enable further consideration of cooperative efforts at an international level.

Table 2.8: Fish Species by Ocean Area

N. Atlantic	Dusky grouper	**N. Pacific**
American angler	European anchovy	Alaska pollock
American plaice	European hake	Chinook salmon
Atlantic cod	European pilchard	Chub mackerel
Atlantic herring	European sprat	Chum salmon
Atlantic horse mackerel	Flathead grey mullet	Coho salmon
Atlantic mackerel	Flounders/Halibuts/Soles	Japanese anchovy
Atlantic menhaden	Gilthead seabream	Japanese jack mackerel
Atlantic salmon	Jack and horse mackerels	Japanese pilchard
Blue whiting	Mullets	Largehead hairtail
Capelin	Picarels	Pacific cod
European pilchard	Plain bonito	Pacific halibut
European plaice	Pontic shad	Pacific herring
European sprat	Porgies/Seabreams	Pacific ocean perch
Greenland halibut	Red mullet	Pacific saury
Haddock	Red mullet	Pink salmon
Norway pout	Sardinellas	Sablefish
Saithe/Pollock	Swordfish	Sockeye salmon
Sandeels nei	Whiting	Yellow croaker
Silver hake		Yellowfin sole
Summer flounder	**S. Atlantic**	
Tusk/Cusk	Albacore	**C. Pacific**
White hake	Antarctic rockcods/Noties	Anchovies
Whiting	Argentine anchovy	Bali sardinella
Winter flounder	Argentine croaker	California pilchard
Witch flounder	Argentine hake	Californian anchovy
Yellowtail flounder	Bigeye tuna	Chub mackerel
	Blackfin icefish	Flyingfishes
C. Atlantic	Brazilian sardinella	Indian mackerels
Albacore	Cape horse mackerel	Kawakawa
Atlantic horse mackerel	Kingklip	Largehead hairtail
Atlantic menhaden	Mackerel icefish	Lizardfishes
Atlantic Spanish mackerel	Panga seabream	Mullets
Atlantic thread herring	Patagonian grenadier	Pacific anchoveta
Bigeye grunt	Patagonian toothfish	Pacific jack mackerel
Bigeye tuna	Pink cusk-eel	Pacific thread herring
Bobo croaker	Snoek	Ponyfishes/Slipmouths
Carangidae	Southern African anchovy	Sardinellas
Chub mackerel	Southern African pilchard	Scads
Common dentex	Southern blue whiting	Sea catfishes
Common sole	Southern bluefin tuna	Skipjack tuna
Croakers/Drums	Southern hake	Threadfin breams
European hake	Striped weakfish	Toli shad
European pilchard	Whitehead's round herring	Yellowfin tuna
Flyingfishes	Whitemouth croaker	
Grouper		**S. Pacific**
Grunts	**Indian**	Barracudas
Gulf menhaden	Anchovies	Blue grenadier
Jack and horse mackerels	Bigeye tuna	Blue mackerel
King mackerel	Bombay-duck	Butterfishes/Pomfrets
Round sardinella	Chacunda gizzard shad	Chub mackerel
Sciaenids	Croakers/Drums	Greenback horse mackerel
Senegalese hake	Indian mackerel	Jack and horse mackerels
Skipjack tuna	Indian oil sardine	Misc demersal fishes
Snapper	Kawakawa	Mullets
Yellowfin tuna	Largehead hairtail	Orange roughy
	Mackerel icefish	Oreo dories
Med & Black	Narrow-barred Spanish mackerel	Pacific thread herring
Albacore	Patagonian toothfish	Patagonian grenadier
Atlantic bluefin tuna	Ponyfishes/Slipmouths	Patagonian toothfish
Atlantic bonito	Sardinellas	Red codling
Azov sea sprat	Scads	Silver gemfish
Bogue	Sea catfishes	Snoek
Chub mackerel	Skipjack tuna	South Pacific breams
Common dentex	Threadfin breams	Southern blue whiting
Common pandora	Toli shad	Southern hake
Common sole	Yellowfin tuna	White trevally

Chapter 3

The Effect of International Agreements on Internationally Shared Fisheries

3.1 Introduction

The second chapter of this thesis examined the Tragedy of the Commons in international fisheries and found that shared fish stocks are systematically more exploited. This chapter takes a first step in exploring the natural next question of what effect international agreements have on shared fish stocks at an overall level. Two main types of agreements are considered: those that entail cooperative management of the fisheries; and those that permit access to fish stocks. The former are of particular interest with respect to whether they alleviate the sharing problem, the latter are of interest in their impact on host country resources.

International agreements are increasingly implemented to manage fisheries around the globe; they are, however, not a new phenomenon. Halibut and salmon in the northeast Pacific have been managed sporadically with agreements between the United States and Canada since the 1920s and 1930s respectively (IPHC 2005, PSC 2005), and regional cooperation has helped Norwegian spring-spawning herring in the North Atlantic since the 1970s (Bjørndal *et al.*, 2004). In Articles 63 and 64 of the 1982 United Nations Convention on the Law of the Sea, nations were encouraged to cooperate through appropriate regional or international organizations to conserve, develop, and utilise shared fish stocks.

It was not, however, until the 1995 United Nations Fish Stocks Agreement that regional fisheries management organisations (RFMOs) were actively developed in response to concern for stocks that crossed into international waters. RFMOs include the 1994 agreement covering Alaskan pollock in the Bering Sea Donut Hole, and the 2000 signing of the Western and Central Pacific Ocean Fish Stocks Convention. The RFMOs are generally meant to enact full cooperative management including setting total catch and dividing it amongst members, undertaking scientific analysis of stock behaviour and wellbeing, coordinating monitoring and enforcement, and sometimes providing product market coordination and support. In addition to RFMOs that undertake full management responsibility, there are numerous international agreements that carry out research and development, and promote coordination and harmonisation, but with few specific management objectives, for example, the Latin American Organization for Fisheries Development, 1984, the Sub-Regional Commission on Fisheries off west Africa, 1989, and the Caribbean Regional Fisheries Mechanism, 2002.

International cooperation that undertakes specific fisheries management is the focus of this analysis but the largest set of international agreements is the multitude of access agreements. These are generally bilateral agreements (exceptions are those that have the European Union acting as a single entity and the agreement between the United States and the Pacific Islands Forum Fisheries Agency) that establish the rules for one nation to fish in another nation's waters. These agreements come in a variety of forms; some set exact limits on specific species, others allow access to vessels that traditionally harvested in areas prior to the extension of exclusive economic zones, and others grant blanket access rights. In return for access rights, the harvesting countries may reciprocate with access to their own waters, provide fisheries science and development funds, build ports or undertake fisheries joint ventures, or simply pay cash.

What makes access agreements different from the fully cooperative management agreements is that there is a clear hierarchy of parties, the host country retains the management authority of the stocks involved while the other countries are essentially hired harvesters. This means that while the contracts are binding they generally have a short (one- to five-year) timeframe and allow the host country to manage optimally, if they so desire. Where the access agreements have become of concern is that the harvesting nation may be able to exert undue pressure on the host nations to increase catches, for example, agreements between powerful distant water fishing nations such as Japan, the United States, and the European Union, and small host countries in the South Pacific or West Africa.

To analyse the effect of the cooperative management and access agreements I compile data from two sources, OceanLaw (2005) and Sea Around Us project (2005), on the countries, timing, agreement type, and species groups involved in fisheries agreements from 1984 to 2002.[1] This information is then merged with the exploitation status, economic, and biological data used in Chapter 2 to extend that analysis to include the effects of international fisheries agreements. The two main hypotheses are: that fully cooperative management leads to better stock status; and that access agreements lead to poorer stock status.

The results, in fact, indicate on average the opposite: cooperative management is correlated with poorer stock status whilst access agreements tend to be associated with better stock status. There are two reasons I may be finding these puzzling effects. The first is that by finding the average effect I am offsetting cases, such as Canada-USA salmon (Miller, 2003)[2] and halibut (Hilborn *et al.*, 2005), and Norway-

[1]The data go back to at least the 1950s but I only report here the statistics for agreements in force during the period I have other data on.

[2]The Pacific Salmon Treaty has had a chequered history and in its current form is far from perfect. However, the consensus is that, given the experience under both cooperation and lack thereof, the Treaty is far better than the non-cooperative alternative. (Munro *et al.*, 1998; Miller *et al.*, 2001)

Russia in the Barents Sea (Stokke, 2003), where agreements have helped stocks to improve or stabilise with those that have not worked so conclusions will not be universal. What I can learn from this average effect is which type of agreements to focus on in further analysis to examine the characteristics that contribute to an agreement working or not. The second reason is one that may arise from using just two periods of data to identify the impact of agreements in that some degree of reverse causality is likely in fisheries management. That is, while we hope that cooperative management improves stock status it may be that cooperative management only arises for stocks that suffer from poor status. I attempt to address this potential endogeneity issue by controlling for agreement length; using lagged agreement status as an alternative variable and as an instrument; and using the difference in status across my two time periods instead of the status level in a given period, but the effect remains. Given that the cooperative agreements in the dataset have been in place for upwards of twenty years on average, and that the two periods of exploitation status data are eight years apart, this chapter is a first pass to see what we can learn thus far.

The remainder of this chapter is organised as follows. A summary of the international agreements dataset is given in Section 3.2. The empirical analysis and results of ordered category estimation are given in Section 3.3 with extensions to consider the potential endogeneity issue that agreements only occur when stock status justifies them. Finally, the conclusion that international agreements matter is given in Section 3.4.

3.2 The Data

The analysis in this chapter is conducted using the same base data on exploitation status, and economic and biological characteristics as previously, with the addition of information on international agreements. As the base data is discussed in detail in the second chapter I will only elaborate on the agreements information here.

The first set of agreements, those that establish cooperation for fisheries management, was sourced from the multilateral and bilateral treaties compendia of OceanLaw (2005). Each agreement was coded by countries included, years in force, agreement type, and species groups. The type of agreement depends on the degree of management or access (full, specific cooperation; some, broad cooperation; simple access; or unknown) and the geographic orientation (unilateral; reciprocal; or multilateral). The species that each agreement is applied to ranges from being very specific (Alaskan pollock or Pacific halibut) to being very broad (all living marine resources) so to be consistent with the access agreements data (discussed below) I categorise by thirty "target groups": nine of pelagics, six of demersal, three of reef-associated, two each of flatfish, sharks, and rays, one for each of cephalopods, shrimps, lobsters and crabs, jellyfish, mollusc, and krill; and a category for all inclusive.[3]

The second set of agreements are the access agreements, a database of these came from the Sea Around Us project (2005). Each of these agreements was also coded by countries included, years in force, agreement type, and species groups. Where an access agreement was noted in both databases, the record from the Sea Around Us project was used. Summary statistics of all agreement types are presented in Table 3.1.

There are a total of 186,956 target group-year-country-pair-agreement-type combinations from 1984 to 2002.[4] Of those, about 8% are of unknown management type, 39% have fully cooperative management, 28% involve some cooperation, and 25% are access agreements. Note that by construction there will be more country-pairs in the multilateral categories as each pair counts once, for example, a five country agreement will have ten country-pairs. In terms of the species involved, 37%

[3]Only the pelagic, demersal, reef-associated, flatfish, and all inclusive categories are used in the final analysis.

[4]Agreement types are not mutually exclusive; target group-year-country-pairs are assigned all types of agreements they are covered by.

Table 3.1: Number, Type and Length of International Agreements 1984 - 2002

Agreement Type	Number of Agreements	Average Length (yrs)	Agreement Type	Number of Agreements	Average Length (yrs)
Unilateral, access	25,358	8.05 (4.65)	Multilateral, full coop.	72,577	23.70 (15.65)
Reciprocal, full coop.	98	25.60 (18.79)	Multilateral, some coop.	52,338	23.04 (12.39)
Reciprocal, some coop.	165	8.50 (5.79)	Multilateral, access	6,208	4.64 (3.40)
Reciprocal, access	15,164	5.94 (4.37)			
Multilateral, unknown	15,048	25.00 (5.49)	*Total*	*186,956*	*11.84* *(11.44)*

Standard deviations in parentheses.

of agreements relate to pelagics, 15% to demersals, 3% to reef-associated, 1% to flatfish, and 31% are all inclusive. In anticipation of being curious in the empirical analysis I make note of the length of time that target group-country combination has had an that type of agreement in force, agreements that involve full cooperation are the longest on average.

International agreements are negotiated at the country level but my exploitation status data is at the ocean area level. To merge the two datasets together I have to aggregate the international agreements data to the ocean area level, hence I count the number of each type of agreement in each ocean area for each target group in every year. This aggregation means I now have the average length of time the target group-country combination has been covered. Counting the number of country-pairs involved in each agreement type will give rise to a problem in the empirical analysis due to the fact that where there are more countries, the number of potential country-pairs is higher and multilateral agreements are more common meaning that the number of countries and number of agreements will be correlated. For example, for any species group in an FAO area in any given year, if there are three countries there are three possible pairings within a multilateral agreement, and a further three possible reciprocal agreements within the same FAO area. If, however, there are six countries, there are fifteen possible multilateral pairings and fifteen possible reciprocal pairs within the same FAO area and more beyond. To address the counting issue, I instead create a dummy variable for whether that species group, FAO area, year combination has at least one of a particular type of agreement; after showing the results using the count, I use the dummy variable measure for the rest of the following analysis.

3.3 Empirical Analysis and Results

The issue I am addressing in this chapter is the effect of international agreements on fisheries exploitation status. In the empirical analysis that follows the two main hypotheses are: that fully cooperative management leads to better stock status; and that access agreements lead to poorer stock status.

We expect cooperative management to do better because an agreement should internalise the effect each country has on the others' harvest. There are, however, confounding effects about how to define a "good" or "bad" outcome. Here an agreement is considered bad if it is associated with stocks that are overexploited or depleted or, in the later analysis, if the stock status falls a category or more between the two periods. An agreement is good if it is associated with better, or improving, stock status. There are three concerns with these definitions in the empirical analysis.

First, the results we might expect from theory depend on the ability to negotiate or sustain an agreement, and threat points and relative bargaining power of members will matter, thus an agreement may only lead to a slightly better stock outcome than without cooperation. The five categories of exploitation status used here may not be fine enough to pick up small improvements in status.

Second, at the broad two-period, five-category level of data used here we can only observe whether agreements are associated with good or poor stock status, not what the status would have been for these stocks without an agreement. I cannot distinguish between an agreement that prevents an overexploited stock from further decline and an agreement that continues to overexploit a stock at a slower rate, in both cases the stock is overexploited in both periods and hence both agreements are classified as bad. This is in comparison to examining individual cases where periods with and without agreements have been observed and provide support for cooperation. These first two issues are a matter of data availability, thus will not be addressed in this analysis. They are mentioned to keep in mind in interpretation and to give guidance as to what future studies should examine.

Third, fisheries management tends to be reactive, the stocks that are most in trouble from overexploitation are the ones that are most likely to be the focus of international agreements. I will attempt to address this issue of reverse causation here in a series of ways: controlling for agreement length; using lagged agreement status as an alternative variable and as an instrument; and using the difference in status across my two time periods instead of the status level in a given period.

The second hypothesis assumes that the country doing the fishing both wants to overharvest the resource and has the ability to pressure the host country, it may in fact be the case that countries with favourable stocks have the desire and ability to manage the resource optimally for the future. We can only wait for the empirical results on this one. Of additional interest here is who makes access agreements with whom? I examine this question by considering the fraction of agreements that are between countries in the same FAO area and the relative status of fish stocks in the contracting countries areas.

I conduct the analysis on the two-period panel of data used in the earlier chapter. That is, I have an unbalanced panel of 373 observations on stock status across two periods, 1994 and 2002, with associated data on the number of countries sharing the stock, and economic and biological characteristics. Exploitation status is in five categories (Depleted, Overfished, Fully Fished, Moderately Fished and Underexploited) and the number of countries ranges from one to 28. Bringing in the data on agreements, I use the number of each type of agreement in each ocean area for each target group in 1994 or 2002 as appropriate and the associated average agreement lengths, fraction within the FAO area, and average relative stock status. I also bring in the characteristics of broad agreements, ones that cover all fish stocks generally, in that FAO area in 1994 or 2002.

The empirical methodology is similar to that used in examining whether shared stocks are more exploited, with the addition of the measures of international agreements. That is, an ordered probit estimation is undertaken to estimate the probability of being in each exploitation category (depleted, overexploited, fully exploited, moderately exploited and underexploited) using use the GLLAMM programme (Skrondal and Rabe-Hesketh 2003) for Stata 8 (2003). The regression equation for fish stock i in FAO area l at time period t is:

$$\begin{aligned} Pr(Exploitation_{ilt}) \;=\; & f(Number\ of\ Countries_{ilt},\ Price_{it},\ Climate_i, \\ & Doubling\ Time_i,\ Average\ Real\ Interest\ Rate_{ilt}, \\ & Average\ GDP/Capita_{ilt},\ Average\ Agriculture \\ & Value\ Added/Worker_{ilt},\ Average\ Risk\ Rating_{ilt}, \\ & High\ Seas\ Dummy_{ilt},\ Year\ Dummy, \\ & International\ Agreements_{jlt}) \end{aligned}$$

The j subscript on the International Agreements denotes the target group the agreement relates to. Every species i has an associated target group j, the agreements mapping is at this broader level. Broad, all inclusive, agreements are assigned by FAO area and time.

Table 3.2 presents the results of three specifications including measures of international agreements and the base version from the earlier chapter for comparison. Accounting for the number of international agreements for that species group, location, and year, reduces the magnitude and power of the coefficient on the number of countries. At first glance this is bad news for the earlier chapter as it indicates that what is important (in a negative fashion) is the number of multilateral, fully

Table 3.2: Coefficients of Ordered Probit with International Agreements

Dependant Var. *Expln. Status*	Base Version	With Number of Agreements	Dummies of Positive Agreements	Dummies for Positive and Broad Agreements	***Broad Agts.***
Number of Countries	-.1282 ** (.058)	-.0897 * (.054)	-.1325 ** (.068)	-.1658 * (.093)	
Number Sq.	.0032 (.002)	.0026 (.002)	.0033 (.002)	.0054 (.004)	
High Seas	.6012 ** (.279)	.4699 (.313)	.7074 ** (.309)	.6250 * (.339)	
(Sub)Tropical	1.871 *** (.667)	1.864 *** (.700)	1.762 ** (.821)	1.013 ** (.421)	
Dbl.Time >14yr	-2.113 *** (.619)	-2.208 ** (.924)	-2.182 (1.348)	-2.791 *** (.912)	
Price ($000 US/tonne)	-.1479 *** (.050)	-.1354 *** (.045)	-.1397 *** (.044)	-.1275 *** (.045)	
Avg. Real Interest Rate	.0064 (.010)	.0055 (.013)	.0021 (.014)	-.0039 (.016)	
Avg.GDP/cap ($10000US)	-1.472 * (.819)	-1.172 (.846)	-.991 (.940)	-1.256 (.909)	
Avg.AgVA/wkr ($10000US)	.6837 (.440)	.6002 (.452)	.5779 (.537)	.6789 (.544)	
Avg Risk Rating	.0324 (.025)	.0271 (.029)	.0012 (.030)	.0184 (.033)	
Year 2002	-.4281 ** (.191)	-.3695 (.228)	-.5115 ** (.213)	-.3342 * (.201)	
Unilateral, access		.0035 (.004)	-.1867 (.201)	-.0894 (.216)	-.3251 (.709)
Reciprocal, full coop.		.0001 (.850)	-.4572 (1.889)	-.5905 (.822)	.5808 (.381)
Reciprocal, some coop.					-.2013 (.334)
Reciprocal, access		.0034 (.009)	.5370 ** (.246)	.4033 * (.236)	.1268 (.292)
Multilateral, unknown		-.0103 (.013)	-.1988 (.465)	.0619 (.626)	
Multilateral, full coop.		-.0067 *** (.002)	-.6262 * (.331)	-.3496 (.309)	-.9138 * (.541)
Multilateral, some coop.		.0043 (.005)	.7025 ** (.350)	.1904 (.392)	3.762 ** (1.572)
Multilateral, access		.0849 (.061)	.5917 (.384)	.4163 (.353)	.2190 (.303)
Log likelihood:	-420.868	-412.580	-414.030	-404.740	

Obs: 373. Significance levels: *10% **5% ***1%. Clustered standard errors in parentheses.

cooperative agreements rather than the number of countries. However, as discussed at the end of the previous section, there is a problem with the number of countries and number of agreements being correlated.[5]

To address the counting issue, the third column of Table 3.2 presents a formulation with a dummy variable for whether that species group, FAO area, year combination has at least one of a particular type of agreement. The coefficient on the number of countries returns to a similar magnitude as the base version while the coefficients on other base variables are similar in all three versions. The version with dummies for the existence of agreements also allows the comparison of different types of agreements to not be hampered by the counting problem. We see that reciprocal and multilateral access agreements and multilateral agreements involving some cooperation are associated with better stock status while multilateral fully cooperative agreements are associated with poor stock status.

In the fourth column I add a set of dummy variables for whether there is a broad agreement of each type in that area and time period. The results for the original variables are quite similar to previous specifications but the impact of agreements change. Only the reciprocal access type of species group agreements are significant while general multilateral fully cooperative ones are associated with worse stock status and general multilateral agreements with some cooperation are associated with better status.

Recall that the coefficients of the ordered probit model only indicate whether the variables generally improve the exploitation status or not, so we should generally examine the marginal effects. Marginal effects tell us how much the probability of being in each exploitation category changes for a one unit change in a particular variable, or for a discrete jump in a dummy variable. However, to save space, I shall only present marginal effects for the main specification and just coefficients for the remaining specifications. The coefficients and marginal effects for the version

[5]All standard errors are clustered at the species-FAO area level.

Table 3.3: Ordered Probit with Dummies if Positive Agreements: Coefficients and Marginal Effects

Dependant Var. *Expln. Status*	Dummies if Positive Agreements	dD/dx	dO/dx	dF/dx	dM/dx	dU/dx
Number of Countries	-.1325 ** (.069)	.0043	.0078	-.0019	-.0090	-.0011
Number Sq.	.0033 (.002)					
High Seas	.7074 ** (.309)	-.0357	-.0805	-.0008	.0999	.0171
(Sub)Tropical	1.762 ** (.821)	-.1867	-.1290	.1464	.1575	.0118
Dbl.Time>14yr	-2.182 (1.348)	.1791	.2014	-.1119	-.2405	-.0282
Price ($000 US/tonne)	-.1397 *** (.044)	.0087	.0159	-.0040	-.0185	-.0022
Avg Real Interest Rate	.0021 (.014)	-.0001	-.0002	.0001	.0003	.0000
Avg GDP/cap ($10 000 US)	-.991 (.940)	.0624	.1101	-.0272	-.1289	-.0165
Avg Ag VA/wkr ($10 000 US)	.5779 (.537)	-.0362	-.0653	.0162	.0760	.0093
Avg Risk Rating	.0012 (.030)	-.0001	-.0001	.0000	.0002	.0000
Year 2002	-.5115 ** (.213)	.0225	.0571	.0087	-.0734	-.0149
Unilateral, access	-.1867 (.201)	.0061	.0189	.0085	-.0259	-.0075
Reciprocal, full coop.	-.4572 (1.889)	.0196	.0507	.0091	-.0656	-.0138
Reciprocal, access	.5370 ** (.246)	-.0148	-.0508	-.0308	.0716	.0247
Multilateral, unknown	-.1988 (.465)	.0077	.0214	.0061	-.0284	-.0068
Multilateral, full coop.	-.6262 * (.331)	.0286	.0703	.0081	-.0895	-.0175
Multilateral, some coop.	.7025 ** (.350)	-.0179	-.0642	-.0440	.0917	.0343
Multilateral, access	.5917 (.384)	-.0267	-.0663	-.0085	.0847	.0168
Log likelihood:	-414.030		Observations:	373		

Significance levels: *10% **5% ***1%. Clustered standard errors of coefficients in parentheses. The marginal effects for Number of Countries includes the effect via the squared term.

including the dummies for the existence of each agreement type are reported in Table 3.3. The marginal effects are generally close to those from the base specification, for example, an increase in the number of countries by one increases the probability of being depleted by .43 of a percentage point. Having a multilateral, fully cooperative agreement is associated with an increase in the probability of being depleted by 2.86 of a percentage point, so it increases the likelihood of being depleted as much as being harvested by 6.7 more countries.

In Table 3.4, I begin to examine whether the average length of the agreements matters and whether the relative location matters. Once again, the general results are quite robust, but including average agreement length does alter some of the agreement effects. Reciprocal and broad multilateral access agreements, and broad multilateral with some cooperation retain their positive effect while the coefficient on broad multilateral fully cooperative agreements remains negative. Broad, unilateral agreements are associated with poorer status although shorter agreements of this type are worse. Broad reciprocal agreements with some cooperation are correlated with poorer stocks the longer these agreements are.

Accounting for the fraction of pairs in a agreement where both countries are in the same FAO area is done in the right-hand half of Table 3.4. Now only general multilateral fully cooperative agreements affect stock status negatively, while some cooperation at the general multilateral level is good. Only for multilateral access agreements is there an effect of within-FAO area pairs, and more neighbourly pairs are good.

I now pursue a further examination of the potential reverse causality problem that poor stocks are the ones countries are most concerned about and hence the ones more likely to be governed by internationally cooperative agreements. The first of two ways of considering the problem uses lagged information on agreements, as an alternative measure and as an instrument. The first two columns of Table 3.5 show the ordered probit results of using dummies for whether there was an agreement

Table 3.4: Coefficients Using Dummies and Including Length of Agreements

Dependant Var. *Expln. Status*	Dummies for Positive, Broad and Lengths of Agreements		Dummies for Positive, Broad and Fraction of Agts in Same Area	
		Length of Agts.		***Fraction Agts. in Same Area***
Number of Countries	-.1757 * (.094)		-.3105 *** (.120)	
Number Sq.	.0064 ** (.003)		.0126 ** (.005)	
High Seas	.6567 * (.357)		.4816 (.506)	
(Sub)Tropical	1.300 (.893)		.397 (.771)	
Dbl. Time >14yr	-3.644 *** (.979)		-1.431 ** (.675)	
Price ($000 US/tonne)	-.1442 *** (.049)		-.1712 * (.096)	
Avg. Real Interest Rate	.0183 (.019)		-.0074 (.015)	
Avg.GDP/cap ($10000US)	-2.821 * (1.46)		-1.399 (1.13)	
Avg.AgVA/wkr ($10000US)	1.473 * (.786)		.5922 (.422)	
Avg Risk Rating	.0398 (.053)		.0348 (.066)	
Year 2002	.4362 (.474)		-.4169 * (.251)	
Unilateral, access	.0536 (.472)	-.0573 (.041)	-.0714 (.326)	.2422 (.791)
Reciprocal, full coop.	-1.388 (1.14)	.0495 (.038)	.1475 (.354)	.5966 (1.51)
Reciprocal, access	.7505 ** (.346)	-.0461 (.037)	.6465 (.395)	-1.879 (1.18)
Multilateral, unknown	4.660 ** (2.32)	-.1576 ** (.077)	-.5347 (.862)	11.38 (25.7)
Multilateral, full coop.	.2509 (.671)	-.0227 (.024)	.3017 (.723)	-1.413 (1.57)
Multilateral, some coop.	.3644 (.912)	.0197 (.067)	.2217 (.607)	-.4139 (1.21)
Multilateral, access	1.015 (.729)	.0363 (.087)	-.0136 (.329)	3.354 ** (1.56)
Brd. Unilateral, access	-2.620 ** (1.27)	.1148 ** (.052)	-.3857 (.813)	-.1803 (.868)
Brd. Reciprocal, full coop.	-1.489 (1.58)	.2442 (.305)	.4912 (.708)	1.019 (1.21)
Brd. Reciprocal, some coop.	1.141 (.720)	-.1642 ** (.075)	-.0847 (.551)	.7090 (1.13)
Brd. Reciprocal, access	-.3354 (.501)	-.0329 (.040)	.0524 (.676)	1.344 (1.07)
Brd. Multilateral, full coop.	-.7895 * (.458)	-.0247 (.058)	-2.440 * (1.45)	.2705 (1.16)
Brd. Multilateral, some coop.	6.198 *** (2.02)	-.0002 (.024)	5.864 *** (1.12)	-3.873 (2.42)
Brd. Multilateral, access	1.407 * (.779)	-.0685 (.065)	.4423 (.428)	.1078 (1.58)
Log likelihood:	-392.725		-410.443	

Obs: 373. Significance levels: *10% **5% ***1%. Clustered standard errors in parentheses.

Table 3.5: Examining Effect of Lags of Agreements

Dependant Var. *Expln. Status*	O. Probit 1 Pd Lag	O. Probit 5 Pd Lag	Linear 1 Pd Lag	Linear 5 Pd Lag	IV 1 Pd Lag	IV 5 Pd Lag
Number of Countries	-.1857 ** (.093)	-.1571 ** (.079)	-.0780 ** (.032)	-.0610 ** (.030)	-.0831 ** (.036)	-.1520 (.105)
Number Sq.	.0050 (.005)	.0047 * (.003)	.0024 ** (.001)	.0020 * (.001)	.0026 ** (.001)	.0054 (.004)
High Seas	.6721 ** (.312)	.6216 ** (.282)	.3143 ** (.129)	.2727 ** (.127)	.3340 ** (.170)	.3413 (.365)
(Sub)Tropical	1.244 (.921)	.9421 * (.506)	.4252 *** (.159)	.3420 ** (.164)	.4790 * (.276)	-.0912 (.589)
Dbl. Time >14yr	-2.678 ** (1.11)	-3.116 *** (.771)	-1.109 * (.597)	-1.258 ** (.579)	-.9419 (.618)	-1.198 (1.02)
Price ($000 US/tonne)	-.1276 *** (.047)	-.1281 *** (.047)	-.0510 *** (.017)	-.0538 *** (.018)	-.0486 *** (.018)	-.0436 (.028)
Avg. Real Interest Rate	-.0069 (.014)	.0012 (.015)	-.0015 (.007)	.0001 (.006)	-.0008 (.008)	-.0068 (.022)
Avg.GDP/cap ($10000US)	-2.392 (1.50)	-.6806 (1.15)	-.7461 (.484)	-.1990 (.497)	-.5308 (.441)	-1.755 (1.79)
Avg.AgVA/wkr ($10000US)	1.3432 (.931)	.4937 (.639)	.4186 (.268)	.1746 (.277)	.2558 (.251)	.6347 (.625)
Avg Risk Rating	.0195 (.032)	-.0172 (.031)	.0066 (.014)	-.0076 (.014)	.0072 (.015)	.0622 (.076)
Year 2002	-.1538 (.257)	-.5088 ** (.244)	-.0712 (.110)	-.2072 ** (.100)	-.1180 (.140)	.4136 (.660)
Unilateral, access	-.0177 (.247)	-.0097 (.235)	-.0044 (.109)	-.0028 (.135)	-.0946 (.166)	.5583 (.85)
Reciprocal, full coop.	-.1405 (1.30)	-.4268 (11.9)	-.1173 (.419)	-.1263 (.791)	-.2907 (.467)	1.030 (1.74)
Reciprocal, access	.4151 (.309)	-.2686 (.318)	.1731 (.114)	-.1075 (.103)	.2345 (.342)	.1589 (.429)
Multilateral, unknown	-.3565 (.473)	-.0122 (.462)	-.1264 (.201)	.0331 (.207)	.0447 (.228)	.6153 (.683)
Multilateral, full coop.	-.5934 * (.309)	-.2876 (.294)	-.2343 * (.124)	-.1257 (.131)	-.2004 (.297)	.2361 (.440)
Multilateral, some coop.	.6672 (.483)	-.4719 (.427)	.2884 (.210)	-.1447 (.279)	.2746 (.275)	-.6289 (.851)
Multilateral, access	.5360 (.495)	1.444 ** (.577)	.1773 (.166)	.5446 * (.319)	.3395 * (.181)	-.617 (1.20)
Brd. Unilateral, access	-.1496 (1.14)	.0441 (.416)	.0980 (.302)	.0474 (.183)	.0137 (.386)	-1.123 (2.42)
Brd. Reciprocal, full coop.	.7802 * (.406)	-.0389 (.466)	.2911 * (.167)	.0104 (.215)	.1219 (.198)	1.402 (1.53)
Brd. Reciprocal, some coop.	.0719 (.320)	-.1985 (.281)	-.0148 (.094)	-.0864 (.136)	-.0612 (.177)	-.6259 (.645)
Brd. Reciprocal, access	.3243 (.481)	-.2850 (.307)	.1008 (.132)	-.1280 (.140)	.2113 (.193)	1.395 (1.85)
Brd. Multilateral, full coop.	-.5801 (.441)	-.3308 (.360)	-.1948 (.153)	-.1280 (.169)	-.1489 (.625)	-1.929 (1.70)
Brd. Multilateral, some coop.	3.050 ** (1.48)	3.339 ** (1.38)	1.140 ** (.447)	1.315 *** (.424)	1.164 ** (.521)	2.563 (1.91)
Brd. Multilateral, access	-.1004 (.289)	.6865 * (.360)	-.0640 (.118)	.2854 * (.159)	.0088 (.148)	.211 (.579)
Constant			1.758 * (.949)	2.412 ** (.962)	1.631 (1.09)	-1.709 (4.46)
Log lik./Wald χ^2:	-405.382	-406.284	89.65	89.36	87.20	38.62

Obs: 373. Significance levels: *10% **5% ***1%. Clustered standard errors in parentheses.

covering that species group in that FAO area of each type one or five years prior to 1994 or 2002, as appropriate. Using the one-period lag of agreements alters the importance of species group versus broad multilateral fully cooperative agreements; species group agreements revert to having a negative effect as in the early version that did not include broad agreements. While this result does not hold up in the five-period lag case, it does remain using alternative lag lengths. Broad agreements involving some cooperation are consistently associated with good stock status.

The middle columns treat exploitation status as a linear variable, for example, being depleted is three times worse than being fully fished and five times worse than being underfished. This linear treatment is to set up running an instrumental variable regression instead. While the coefficients are not comparable across the ordered probit and linear specifications, the qualitative results are very similar.

The last two columns use the one- and five-period lags of agreements, respectively, as instrumental variables that predict whether agreements exist in 1994 or 2002 without being affected by the stock status in 1994 or 2002. While the negative effect of the multilateral fully cooperative agreements disappears, the overall power falls dramatically when using anything beyond three-year lags as instruments so the results are not entirely convincing. Part of this could be due to the fact that while the lagged agreements are a very good predictor of agreements in place in 1994 and 2002, neither agreements nor stock status are fully independent of their past values.

In the second attempt to disentangle whether fully cooperative agreements just unfortunately occur where stocks are bad or whether these agreements are not achieving the goals of conservation I work off a different type of variation. Taking the 165 stocks that I observe in both 1994 and 2002 I create a variable that measures the improvement in status across time. Theoretically, this measure could range from negative four, if a stock goes from being underfished to depleted, to positive four, if vice versa. In practice, seven stocks move two categories worse, 31 fall one category, 113 do not change, nine improve one category, and five improve by two.

Table 3.6 presents the results of the affect on improving status and includes which types of agreements are in force for these stocks in 1994. The first column does not condition on exploitation status in 1994 while the second column does. Before considering the agreements, it is interesting that not only does the number of countries have a detrimental effect on the status level (from all the previous analysis) but that the more countries there are, the more likely a stock is to become worse off across time. The biological characteristics are also important in this regard, better climate and faster natural growth improve both the status itself and the ability to recover. In contrast, a higher price seems only to have a level effect.

Turning to the agreements, the effects are qualitatively similar for all but two agreement types. Multilateral access and unilateral broad access agreements are associated with poor status whereas broad reciprocal access occurs where stocks are good. Reciprocal fully cooperative agreements are correlated with bad stocks, as are multilateral agreements of the same type once initial status is included. Broad multilateral agreements have a slightly positive effect on changing status, less of an impact than occurred in levels.

What is puzzling in this analysis is that, despite the ways fully cooperative multilateral agreements were given the benefit of the doubt, the results tend in the same direction: fully cooperative multilateral agreements are on average associated with poor and declining stock status. Similarly, while fully cooperative reciprocal agreements did not have a significant level effect, they are associated with declining stock status. While these results are subject to the caveats discussed earlier, interesting future work is to examine whether we observe the average poor outcome because agreements do not have much of an effect or that data limitations have thus far prevented fully addressing unobserved heterogeneity or endogeneity. Issues in practical implementation that may restrict gains from agreements include gathering knowledge, deciding on regulation, and ensuring compliance. Currently unobserved

Table 3.6: Ordered Probit on Whether or Not Status Improves from 1994 to 2002

Dependant Var. Improvement in Status	Ordered Probit without '94 Status	Ordered Probit with '94 Status
Number of Countries	-.1032 * (.061)	-.1457 ** (.065)
Number Sq.	.0030 (.002)	.0048 ** (.002)
High Seas	.1750 (.249)	.3691 (.261)
(Sub)Tropical	.5605 * (.293)	.8727 *** (.315)
Dbl. Time >14yr	-.7774 * (.419)	-1.313 ** (.511)
Price ($000 US/tonne)	.0303 (.028)	-.0219 (.041)
Avg. Real Interest Rate	-.0376 * (.022)	-.0348 (.023)
Avg.GDP/cap ($10000US)	-.5375 (1.31)	-.2358 (1.34)
Avg.AgVA/wkr ($10000US)	.7663 (.655)	.6433 (.685)
Avg Risk Rating	-.0684 (.045)	-.0630 (.040)
Exploitation Status 1994		-.8507 *** (.139)
Unilateral, access '94	.2422 (.274)	.0018 (.278)
Reciprocal, full coop. '94	-1.030 ** (.466)	-1.411 *** (.538)
Reciprocal, access '94	.1846 (.288)	.2295 (.322)
Multilateral, unknown '94	-1.117 *** (.420)	-1.203 *** (.362)
Multilateral, full coop.'94	-.2406 (.284)	-.6258 ** (.307)
Multilateral, some coop.'94	.6701 (.426)	.7720 (.520)
Multilateral, access '94	-.6632 ** (.287)	-.7529 ** (.312)
Brd. Unilateral, access '94	-1.586 ** (.804)	-2.005 ** (.866)
Brd. Reciprocal, full coop. '94	-.2053 (.630)	-1.012 (.669)
Brd. Reciprocal, some coop. '94	.0734 (.431)	.1890 (.396)
Brd. Reciprocal, access '94	.7979 ** (.332)	1.058 *** (.374)
Brd. Multilateral, full coop. '94	.0393 (.424)	-.1585 (.419)
Brd. Multilateral, some coop. '94	.6167 (1.00)	1.884 * (1.03)
Brd. Multilateral, access '94	.1707 (.278)	.0680 (.312)
Log likelihood:	-144.561	-121.849

Obs: 165. Significance levels: *10% **5% ***1%. Clustered standard errors in parentheses.

characteristics that may be important include external climate or ecosystem changes, behavior of parties and stocks prior to agreements, or having the decision to be part of a fisheries agreement intertwined with decisions to be part of broader governing bodies such as the European Union or the South Pacific Forum. A more complete characterisation of agreements to account for this heterogeneity and more complete stock assessment should shed light on these questions.

Finally, returning to the question of who makes access agreements with whom, I use a probit model to see whether the relative stock status of the FAO areas of signatory states affects the probability of an access agreement occurring. I created three measures of relative status, depending on whether the data exists. The first measure is the most specific, it is the difference in the exploitation status of the species group being harvested and the status of the same species group in the harvesting country's home FAO area and is positive if stocks in the area being harvested are better. The second measure is positive if the accessed species group is better than the overall average status at home, and the third is positive if the overall average status of the area being accessed is better than the species status at home.

Table 3.7 shows the change in the probability of each type of agreement occurring depending on the status of the stock and the different measures of relative stock status. Stocks with worse status are less likely to have unilateral or reciprocal access agreements. Difference in status at the species group level reduces the probability of an access agreement, although this is only statistically significant for reciprocal agreements. Differences in species versus overall, in both directions, makes agreements more likely indicating that agreements occur if the outside harvesters are not in direct competition with locals for the same species. In further analysis of who makes agreements with whom it would be interesting to consider factors other than stock status, for example, distance, country similarities, whether countries are trading partners, and so forth, along the lines of the who trades with whom studies such as Rose (2004) and Sigman (2002c).

Table 3.7: Probit for Whether Stock Status Determines Where Access Agreements are Made

Dependant Var. *Agreement Exists*	Unilateral Access	Reciprocal Access	Multilateral Access
Accessed Species Status	-.2179 *	-.2182 **	.0118
	(.132)	(.094)	(.121)
Accessed Species Group Better Than Home Group	-.8957	-1.270 ***	-1.984
	(.646)	(.445)	(1.23)
Accessed Species Group Better Than Home Overall	.8636 *	1.170 ***	2.496 ***
	(.499)	(.348)	(.839)
Accessed Overall Area Better Than Home Group	.9007 *	.8437 **	2.768 ***
	(.532)	(.346)	(.713)
Constant	.7498 *	.2504	-1.617 ***
	(.405)	(.282)	(.371)
Log likelihood:	-243.731	-237.251	-79.597

Obs: 373. Significance levels: *10% **5% ***1%. Clustered standard errors in parentheses.

3.4 Conclusion

This chapter addresses the effect of international agreements on the exploitation status of fish stocks. International agreements have two main categories, cooperative management and access, which may have different impacts on stock status. The hypotheses were that cooperative management should have a positive impact while pressure from additional harvesters would cause access agreements to have a negative impact. The results from the empirical analysis, however, indicate that on average cooperative management is correlated with poorer stock status whilst access agreements tend to be associated with better stock status.

These results are subject to caution in interpretation. The empirical analysis gives an overall picture of the average effect of agreements within the confines of the data, which masks the positive results noted for international agreements such as Canada-USA salmon and halibut, and Norway-Russia in the Barents Sea. In addition, the largely reactionary nature of fisheries management may imply causation may run in the opposite direction, that is, stocks with poorer status are more likely to require international agreements. The extended analysis with lagged agreement characteristics and examining the effect of agreements on the change in status formed a first pass at addressing this potential endogeneity problem but with limited success.

The purpose of this chapter was to get a broad idea of what effect international agreements seem to have on fish stock status. The finding that multilateral, fully cooperative agreements are on average associated with poor stock status is puzzling, and suggests a need for future work examining the interaction between cooperative agreements and stock status. A deeper analysis that takes into account the heterogeneity across agreements, including differences across agreements in motivation and structure, may shed some light on which types of agreements worked and which did not. This will be of interest to not only better understand these agreements but to provide direction for the newer RFMOs that face the additional trial of including straddling and highly migratory stocks.

With respect to access agreements, they seem to be most common where competition between local and foreign harvesters is limited, which may lead to an overall decline in stocks as time progresses. The determinants of access other than stock status, the interaction between access and management agreements, and the appropriate level of compensation are also questions for future work arising from this preliminary analysis.

Chapter 4

The Impact of Rights-Based Management Regimes on Fishery Productivity

4.1 Introduction

Property rights regimes have been prescribed as the panacea of fisheries management the world over and are increasingly implemented in a variety of forms. While theoretical examination and anecdotal evidence suggest that these regimes are successful, both economically and biologically, there is limited empirical evidence on the effect of property rights regimes on fisheries productivity. Studying these effects is important for appropriate policy development, industry support and political understanding.

The objective of this chapter is to empirically examine the effect of a move to a property rights regime on productivity in the Norwegian coastal cod fishery. I take a parallel approach using a data envelopment analysis to calculate technical efficiency and an index number decomposition to calculate relative productivity. An advantage of the index number decomposition is that it can be used to determine the source of productivity changes. The purpose of the parallel approach is to address the problem that analysis of changes in fisheries management regimes are case studies. The reason behind case studies is that they match the level of management and data. The problem comes not from the case study level per se, but that the methodology tends to differ in each study. For managers and researchers to develop a consistent body of evidence about the effects of different types of management, the case studies need to be comparable. I address that need with a parallel approach using a traditional productivity method alongside a newer decomposition method.

Fisheries productivity analysis is done using a variety of methods including data envelopment analysis, stochastic production frontiers, and, most recently, index number profit decomposition using the method developed in Fox *et al.* (2003). However, only two fisheries have had the introduction of property rights analysed with a regime-switch type of analysis. Fox *et al.* (2003) follow up on the productivity frontier analysis of Grafton *et al.* (2000) using data on the British Columbia halibut fishery to illustrate the profit decomposition. They find that profitability rises after the change to individual quotas in this single-species fishery and that rises in price due to an extended season of high quality, fresh fish is an important factor. Dupont *et al.* (2005) extend the decomposition to the Nova Scotia mobile gear multi-species fishery that had previously been studied using a data envelopment analysis (Dupont *et al.*, 2002) and find, similar to the halibut fishery, profitability rises after the introduction of individual transferable quotas due to a rise in price of species subject to quota.

The limitation of studying these fisheries is that only a small number of vessel-level observations across three years of data are available for each: one year before, the year of, and one year after, the management change for the British Columbia halibut fishery with a total of 105 observations; and two years before, and the year of, the change for the Nova Scotia multi-species fishery for a total of 108 observations. The Norwegian coastal cod fishery, in contrast, has 2865 vessel-level observations from 1985-2000, flanking the change in 1990. The longer and larger panel of data is of particular importance for the Norwegian coastal cod fishery as the individual vessel quotas are non-transferable. This non-transferability restricts the adaptability of the fleet as low-productivity vessel owners that might prefer to sell their quotas separately from their vessels are unable to do so, suggesting that productivity gains will take longer to be realised. The longer panel will allow me to compare the effects of the restricted transferability in the Norwegian case to the earlier fisheries in which increased productivity was identified using just one year of data.

The volume of data is a mixed blessing as it has provided a greater degree of heterogeneity across vessels, necessitating an adaptation of the profit decomposition. Fox *et al.* (2003) implement a profit decomposition under the assumption of constant returns to scale, which means that larger vessels must have larger profits to have the same profits per unit of capital, and positive profits. The assumptions are violated in the Norwegian coastal cod fishery; some large vessels have less profit than small vessels and some negative profits are observed, therefore an index of the share of profits that input i or output j has can explode to very small or large values very quickly, making analysis unworkable. The implementation here uses total revenues or costs, as appropriate, in the denominator of the indexes, which avoids the constant returns and positive profits assumptions whilst retaining the ability to decompose the revenue-cost ratio into the input and output effects of the management change.

The results from both the data envelopment analysis and index number decomposition indicate that the individual vessel quota management regime has had a positive impact on productivity for the coastal cod fishery, although the effects took some time to be felt. The decomposition indicates that the importance of cod in total revenues rose as property rights over cod became more secure and that revenues have risen faster than costs despite rising input prices.

Section 4.2 outlines the parallel data envelopment analysis and index number decomposition framework with which I determine productivity changes. A discussion of the management of and the data on the Norwegian coastal cod fishery follows in Section 4.3. Section 4.4 gives the results of the efficiency and productivity analysis. Finally, the conclusion of how property rights management regimes raise productivity and a comparison to previous studies is given in Section 4.5.

4.2 Methodological Framework

There are a variety of methods with which to analyse changes in productivity. The approach I have chosen is to conduct a traditional data envelopment analysis (DEA) parallel to a new index number decomposition (IND).[1] The DEA is carried out in two stages: the first is a calculation of an efficiency score for each observation; the second stage uses regression analysis to determine the effect of management change on the efficiency scores. Of great interest to managers and industry alike, however, is where the effect is coming through, that is, does the management change lead to lower costs, higher prices or a combination? Fox *et al.* (2003) developed an index number profit decomposition specifically to allow a breakdown of these effects. I implement a modified version of their approach that allows for non-constant returns and negative profits that is also conducted in two stages: the first stage uses an index to decompose the revenue-cost ratio (rather than the profit ratio) and hence find productivity ratios; and similar to the DEA, the second stage uses regression analysis to determine the effect of management change. Of note is that both approaches allow for the analysis of multiple outputs so examination of both a change of input and output mix in the response to regulation change is possible. The strength of conducting a parallel analysis is to be comparable with previous studies while exploiting the power of the IND to tease out the component effects of the policy.

[1]Both data envelopment analysis and stochastic production frontiers are used in fisheries analysis but I chose a DEA as my traditional approach to be consistent with the other multispecies fishery studied using a regime-switch, the Nova Scotia fishery studied by Dupont *et al.* (2005) and Dupont *et al.*, 2002.

4.2.1 Data Envelopment Analysis

Data envelopment analysis can examine efficiency in a variety of forms, such as, technical, allocative, cost, or profit efficiency. I take the case of technical efficiency, that is, determining by how much inputs could be contracted while producing the same amount of outputs. The methodology is described in detail in Coelli, Rao, and Battese (1998), from which I will draw heavily in this brief outline. The idea can most easily be seen in Figure 4.1, which shows a two-input (x_1 and x_2), one-output (y) production function. The ss curve represents the most technically efficient isoquant: the smallest combinations of inputs x_1 and x_2 that can be used to produce a certain level of output y. The technical efficiency of a firm depends upon how close to ss a firm's input combination lies. The technical efficiency of a firm with inputs at point P is the ratio $\theta = OQ/OP$; a firm is more efficient the closer θ is to one.

The N-firms, K-inputs, M-outputs version of the linear programming problem associated with this measure of technical efficiency (θ_b) for firm b with input vector

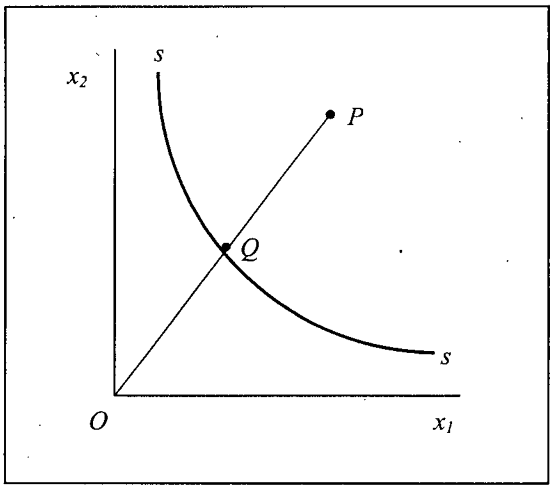

Figure 4.1: Technical Efficiency Theoretical

$\mathbf{x}_b$ and output vector $\mathbf{y}_b$ is:

$$\min_{\theta_b, \lambda_b} \theta_b \quad \text{s.t.} \quad -\mathbf{y}_b + \mathbf{Y}\lambda_b \geq 0$$
$$\theta_b \mathbf{x}_b - \mathbf{X}\lambda_b \geq 0$$
$$\lambda_b \geq 0 \tag{4.2.1}$$

where $\mathbf{X}$ and $\mathbf{Y}$ are $K \times N$ and $M \times N$ matrices with column i of each being $\mathbf{x}_i$ and $\mathbf{y}_i$ for $i = 1, ..., N$, and λ_b is a vector of constants. Equation 4.2.1 essentially calculates technical efficiency in three steps.

First, it takes all the observations and determines the efficient isoquant as a piecewise function of the inner envelope of the data, that is, it finds the most efficient firms. Let us return to the two-input, one-output example but suppose there are three firms in the dataset with input-output combinations illustrated as a, b, and c in Figure 4.2. The most efficient firms are firms a and c so the efficient isoquant is the envelope around them, $s's'$. The vector λ_b gives the weights on the "peers" of firm b. Peers are firms that lie on the efficient isoquant, ones closer to firm b's efficient point have higher weight and firms not on the efficient isoquant have zero weight. Here, firm a will have weight one and firm c will have weight one-half in

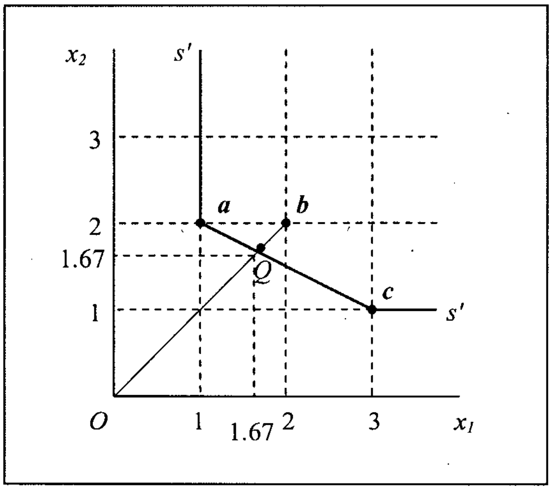

Figure 4.2: Technical Efficiency Example

the λ_b-vector because firm b's efficient point, Q, is half the distance from a as it is from c.

The next step takes the input vector $\mathbf{x}_b$ and contracts it until the efficient isoquant is reached at $(\mathbf{X}\lambda_b, \mathbf{Y}\lambda_b)$, point Q in Figure 4.2. The output and input constraints in Equation 4.2.1 ensure that the contraction lies within the technically feasible set, as defined by the peers. In Figure 4.2 firm b should use 1.67 units of each of x_1 and x_2 rather than two of each to produce one unit of y.

Finally, the measure of technical efficiency (θ_b) is calculated as the minimum value that contracts inputs to produce outputs efficiently compared to peers, while remaining technically efficient. Here firm b's technical efficiency score is 0.83.

This linear programming problem is conducted for each firm in the sample. The firms forming the efficient isoquant necessarily remain the same but λ_b and θ_b are chosen to minimise θ_b for each firm b. Firm a, for example, will have only itself as a peer as it is already efficient so the λ_a-vector will be zeroes for all rows other than row a and θ_a will equal one. Each firm's θ is then taken to form the basis for the empirical examination of management change.

4.2.2 Index Number Decomposition

I now move on to tease out the component effects of the policy change on productivity. Productivity of any firm (firm b) is defined in this chapter as the ratio of an index of outputs over an index of inputs:

$$\text{Productivity Index} = \frac{\mathbf{O}^{ab}}{\mathbf{I}^{ab}} \tag{4.2.2}$$

where each index is defined relative to the most profitable firm (firm a). A firm will be considered to be more productive the higher the ratio of outputs to inputs, compared to the most profitable firm. To find the effects of a changing input and output mix, Fox *et al.* (2003) (hereafter denoted FGKS) develop an index number approach to decompose profits. FGKS describe their methodology clearly in their paper but, as I implement a modified version, I briefly present their method here, followed by my adaptation.

FGKS Method

In their profit decomposition, FGKS use the concept of "netputs" and Fisher's weak factor reversal test to construct their indexes. By netputs they mean "net variable outputs", that is, outputs are included with positive quantities and variable inputs are included as negative quantities. Thus the numerator of their version of Equation 4.2.2 will include both outputs (positively) and variable inputs (negatively) while the denominator will include the fixed inputs. Fisher's weak factor reversal test says that a quantity index multiplied by the price index equals the value index or, rearranging the order, a quantity index equals the value index divided by the price index. Here the value index is the value of the netputs, which is the value of all the outputs less the value of the variable inputs, that is, variable profits.

Therefore, FGKS define the netput quantity index to be used in the numerator of Equation 4.2.2 as the ratio of variable profits divided by the netput price index:

$$\mathbf{O}^{ab} = \frac{\pi^b/\pi^a}{T^{ab}} \tag{4.2.3}$$

where π is variable profit and T^{ab} is the netput price index.

Then FGKS define the fixed input index to be used in the denominator of Equation 4.2.2 to include physical capital, k, and fish biomass, f. In this version the index simplifies to the ratios of each.[2]

$$\mathbf{I}^{ab} = \frac{k^b}{k^a} \cdot \frac{f^b}{f^a} \tag{4.2.4}$$

Combining Equations 4.2.2, 4.2.3, and 4.2.4, the FGKS measure of productivity is defined as:

$$\psi^{ab} = \frac{\mathbf{O}^{ab}}{\mathbf{I}^{ab}} = \frac{\frac{\pi^b/\pi^a}{T^{ab}}}{\frac{k^b}{k^a} \cdot \frac{f^b}{f^a}} \tag{4.2.5}$$

[2]More than one capital input can be accommodated by using an index in the denominator; I omit this for simplicity and to match the empirical analysis directly.

Finally, the form of the netput price index, T^{ab}, has to be determined. Any index could be used but the authors recommend a Törnqvist index. The Törnqvist index has the property that it can be derived from profit maximisation of a translog profit function with constant returns to scale in variable inputs and capital together. This is essentially why FGKS define netputs: so they can define the value as profits, and hence derive the Törnqvist form of index from economic grounds.

The Törnqvist price index over n netputs is a weighted geometric average of the prices facing firm b relative to firm a:

$$T^{ab} = \prod_{n=1}^{N} \left[\frac{t_n^b}{t_n^a}\right]^{\frac{\omega_n^b + \omega_n^a}{2}} \tag{4.2.6}$$

$$\omega_n^a = \frac{t_n^a z_n^a}{\pi^a}, \; \omega_n^b = \frac{t_n^b z_n^b}{\pi^b} \tag{4.2.7}$$

where t_n and z_n are the price and quantity of netput n, z_n being negative for an input, and the weights, ω_n^b and ω_n^a, are the shares of netput n's value in variable profits (the sum of all netput values).

The Törnqvist index is usually presented in its log-change form:

$$\ln T^{ab} = \sum_{n=1}^{N} \frac{\omega_n^b + \omega_n^a}{2} \ln\left(t_n^b / t_n^a\right) \tag{4.2.8}$$

or, alternatively:

$$T^{ab} = \prod_{n=1}^{N} \exp\left[\frac{\omega_n^b + \omega_n^a}{2} \ln\left(t_n^b / t_n^a\right)\right] \tag{4.2.9}$$

The disadvantage of using netputs in the index comes in empirical application when there is large heterogeneity of inputs and outputs across firms with possibly non-constant returns to scale or negative profits, both of which are the case in the data I use on Norwegian cod. The problems arise from using profits in the weights on relative prices (ω_n^b and ω_n^a) in Equation 4.2.9: large heterogeneity with non-constant returns means that firms with large revenues and costs may have the same profits as firms with small revenues and costs causing the index to explode to an unmanageable magnitude; similarly, negative profits can make the weights impossible to implement.

Adapted Method

To address the empirical drawbacks of the FGKS measure of productivity I revert to the more usual definition of outputs and inputs in the productivity index of Equation 4.2.2 rather than netputs. I will continue to use Fisher's test to define the quantity index as the value index divided by the price index, however, the value will be total revenues (in the output index) or total costs (in the input index). The advantage of using revenues and costs instead of profits is twofold: the indexes are less susceptible to the non-constant returns problem; and, as profits do not enter, the negative profits problem is eliminated. Thus, the output index is defined as the total revenue (TR) index divided by the output price index (P^{ab}):

$$\mathbf{O}^{ab} = \frac{TR^b/TR^a}{P^{ab}} \tag{4.2.10}$$

and the input index is defined as the total cost (TC) index divided by the input price index (W^{ab}):

$$\mathbf{I}^{ab} = \frac{TC^b/TC^a}{W^{ab}} \cdot \frac{f^b}{f^a} \tag{4.2.11}$$

A further modification is that only the biomass input is included as a fixed input; capital is included as a variable input. This implicitly assigns all remaining profits to the biomass. An advantage of this is that it gives a picture of how well, or poorly, the fishery is performing depending on how much profit remains.[3] Combining Equations 4.2.2, 4.2.10, and 4.2.11, my alternative version of productivity is defined as:

$$\gamma^{ab} = \frac{\mathbf{O}^{ab}}{\mathbf{I}^{ab}} = \frac{\frac{TR^b/TR^a}{P^{ab}}}{\frac{TC^b/TC^a}{W^{ab}} \cdot \frac{f^b}{f^a}} \tag{4.2.12}$$

Once again, the form of the price indexes, P^{ab} and W^{ab}, have to be determined. This is where the disadvantage of using outputs and inputs separately arises. While

[3] In the empirical analysis I also run a specification where capital is treated as a fixed input with little difference in predicted productivity.

I am still able to decompose the component effects on productivity I can no longer justify the use of the Törnqvist index on economic grounds as FGKS were able to do. Fortunately, the Törnqvist index is classified as an almost ideal index so its use is justified on the grounds of its nice properties.[4] As such I use Törnqvist price indexes for $j = 1, ..., J$ outputs and $i = 1, ..., I$ inputs:

$$P^{a,b} = \prod_{j=1}^{J} \exp\left[\frac{1}{2}\left(\frac{p_j^b y_j^b}{TR^b} + \frac{p_j^a y_j^a}{TR^a}\right)\ln\left(p_j^b/p_j^a\right)\right] \tag{4.2.13}$$

$$W^{a,b} = \prod_{i=1}^{I} \exp\left[\frac{1}{2}\left(\frac{w_i^b x_i^b}{TC^b} + \frac{w_i^a x_i^a}{TC^a}\right)\ln\left(w_i^b/w_i^a\right)\right] \tag{4.2.14}$$

where p_j and y_j are the price and quantity of output j with $\sum p_j y_j = TR$, and w_i and x_i are the cost and quantity of input i with $\sum w_i x_i = TC$. Note that the weights are the shares of output j or input i in total revenue or total cost. Equations 4.2.12, 4.2.13, and 4.2.14 together form the basis for the productivity decomposition performed in Section 4.4.

4.3 Data and Management

Individual vessel quotas (IVQs) were introduced into the Norwegian coastal cod fishery in the 1990 season in response to the previous race for fish that in 1989 had exhausted the total allowable catch (TAC) by April. Each year the managers establish the vessel quotas in dialogue with the fishermens' organisation and always include some overregulation (the sum of all IVQs is greater than the TAC) to account for factors such as vessels not taking part. This overregulation is undertaken to avoid having to adjust the quotas throughout the year but frequently it is too high, in which case seasonal closures are introduced. While this method is effective with respect to restricting catch it reduces the effectiveness of the property rights in terms of fishing when prices are highest or costs are lowest. Throughout the period of my study there was no transferability or divisibility of quotas allowed; a vessel

[4] See Coelli, Rao, and Battese (1998) for a discussion of these.

Table 4.1: Summary Statistics by County

County	Obs.	Mean Vessel Length (m)	Mean Profit (NOK)	Cod Share of Total Revenue
Finnmark	291	17.58	56,431	0.53
Troms	538	18.60	134,482	0.44
Nordland	1095	17.74	75,658	0.53
Nord-Trøndelag	90	15.37	94,586	0.43
Sør-Trøndelag	161	15.92	46,910	0.33
Møre og Romsdal	390	18.66	157,530	0.31
Sogn og Fjordane	92	18.95	213,395	0.27
Hordaland	43	19.77	159,182	0.17
Rogaland	21	18.76	39,200	0.20
Vest-Agder	44	19.16	332,426	0.33
Telemark	1	20.12	178,519	0.02
Østfold	5	15.94	176,375	0.17
TOTAL	2771	17.94	105,416	0.44

with quota attached was allowed to be sold but the quota was not saleable separate from the vessel, forming another restriction to taking advantage of property rights.

The Norwegian Directorate of Fisheries provided vessel level data from the Annual Profitability Survey from 1985 to 2000. This dataset is ideal for studying the impact of the introduction of IVQs as it flanks the regime switch. The survey includes data on vessels of length 13-27.9 metres that participate in the fishery for at least 30 weeks. These vessels represent 80-85 percent of the total national catch each year and survey samples approximately 25 percent of this fleet.

The unbalanced panel that results from the survey gives 2865 observations in total, 180 per year on average, with detailed output and input information. I remove 67 observations that have incomplete characteristic information and a further 27 observations that are extreme outliers (indexes for $P_j^{a,b} > 1000$ or < 0.001). This leaves me with 871 vessels observed between one and eighteen times, on average a vessel is observed 3.3 times, to give 2771 observations in all.

As the survey is coast-wide and the mix of outputs varies by county, a geographic snapshot of statistics is given in Table 4.1 with associated map in Figure 4.3. Full summary statistics are presented in Table 4.2. In terms of geographic spread, the

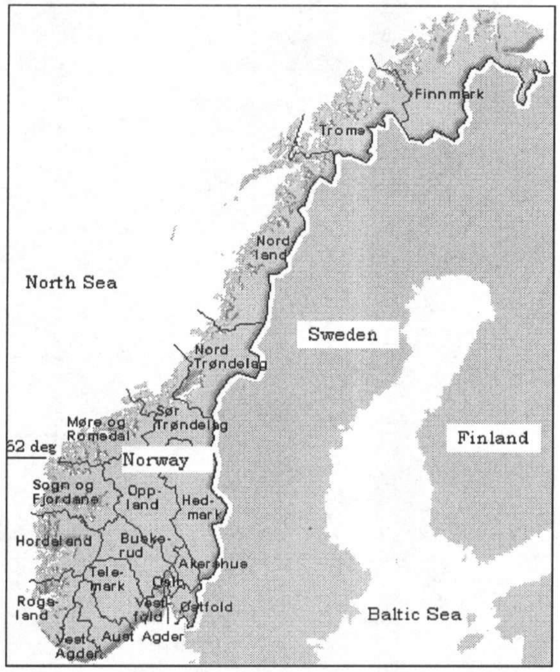

Figure 4.3: Map of Norway with Counties

four northernmost counties, where cod represents more than 40% of total revenue, are 73% of my sample. On average, these vessels are 37cm shorter, harvest 72% more cod, and make only 60% of the profits of their southern counterparts.

The coastal cod fishery is a multi-species fishery where vessels surveyed report quantity and value of four specific species (Northeast Arctic Cod, Northeast Arctic Haddock, Saithe - divided into north or south of 62°, and Greenland Halibut); other species are reported in an "other" category - also divided into north or south of 62°. Due to the diverse nature of the fishery the mix of outputs varies widely, and the vessels from extremely southern, or northern, ports do not generally harvest north, or south, of the 62° reporting division, thus I focus my analysis on the three species that almost all of the fleet catch (Cod, Haddock and Northern Saithe) and group everything else into an "all other" category. Quantities are in kilograms and values

Table 4.2: Summary Statistics of the Coastal Cod Fleet 1985-2000

	Mean	Std. Dev.	Min.	Max.
Cod (kg)	104,055	98,604	7	952,857
Haddock (kg)	19,267	36,054	1	328,784
North Saithe (kg)	66,510	146,870	1	1,701,075
All Other (kg)	254,878	506,354	2	5,477,409
Cod (NOK)	929,609	834,594	29	8,001,647
Haddock (NOK)	119,363	231,601	0	3,259,702
North Saithe (NOK)	232,779	473,307	0	6,721,887
Other Fish (NOK)	802,610	1,280,684	0	13,200,000
Other Income (NOK)	187,421	410,655	-2,539,395	4,712,988
Vessel Length	17.93	4.05	13.00	28.00
Man-Years	4.22	1.80	1.00	12.71
Days in Operation	280.6	43.6	62.0	364.0
Wage Costs (NOK)	994,735	864,697	10,462	8,285,785
Labour Related (NOK)	152,194	135,375	1,514	1,322,988
Fuel Costs (NOK)	160,719	169,939	0	1,852,319
Other Variable (NOK)	294,468	327,950	622	7,275,251
Quasifixed (NOK)	317,458	312,132	14,086	3,326,144
Depreciation (NOK)	248,430	256,999	33	4,110,051
Manuf. Wage(NOK/year)	227,826	16,192	199,368	261,591
Fuel (NOK/litre)	5.18	2.20	2.86	9.25
Revenues (NOK)	2,278,881	2,041,760	68,539	19,400,000
Costs (NOK)	2,173,465	1,804,291	154,258	18,500,000
Profit (NOK)	105,416	486,917	-7,313,557	6,153,804

All values in real Norwegian Kroner (1USD≈7.5NOK)
2771 observations.

are in real Norwegian Kroener.[5] Prices are calculated as Value divided by Quantity and will differ to reflect different ports, time of delivery and so forth. Vessels report operating revenues as well as the value of catch for each species; where the sum of catch value is different from operating revenues I create an additional category of "other income". Recalling that to be in this dataset a vessel must harvest cod, it is not surprising that cod makes up the largest quantity and value of a single species. However, "all other" are together the largest quantity and there is a large degree of variation in quantities and values.

[5]All values are converted to real using the consumer price index with base-year 1998. At that time 1USD≈7.5NOK.

Non-biomass inputs are divided into six categories: labour (wages and salaries including crew-shares); labour-related (social security tax, crew assurances and provisions); fuel (fuel and lubrication oil); other variable (bait, ice, salt and packing, gear maintenance and investment, other operating and administrative); quasi-fixed (vessel insurance and maintenance); and capital (estimated depreciation). As the cost of inputs is reported as expenditure on each category I have to determine prices by Value divided by Quantity, as done with outputs, except for labour and fuel. The labour-related price is value divided by man-years, the other variable price is value divided by days at sea, quasi-fixed price is value divided by vessel length, and the price of capital is depreciation divided by vessel length.

The price of labour cannot be calculated as expenses per man-years because labour is generally paid a crew share rather than a rate per day. That is, each crew member receives a share of the revenues or a mix of a small wage and share of the revenues. This means that the price of labour is in direct proportion to the value of the harvest. Instead, the price of labour is proxied by the annual earnings for a worker in manufacturing (International Labour Office, 2005), representing the likely outside option for fishing labour. These earnings have risen steadily from 199,368 kroner in 1985 to a third higher at 261,591 kroner in 2000. Similarly, the price of fuel cannot be calculated by expenses per day so it is measured by the price per litre of autodiesel (Statistics Norway, 2003 and 2005), rising from around three kroner in the 1980s to around four kroner in the early 1990s before making a leap to more than seven kroner from 1994 onwards.

Wages and labour-related expenses together make up slightly more than half of total costs and while profit is on average positive, 44% of the observations record negative profits. Even excluding vessel depreciation, which could be justified given that overcapitalisation is a problem in fisheries the world over, 14% report negative profits. This means that there is most likely some degree of underreporting of revenues and overreporting of costs.

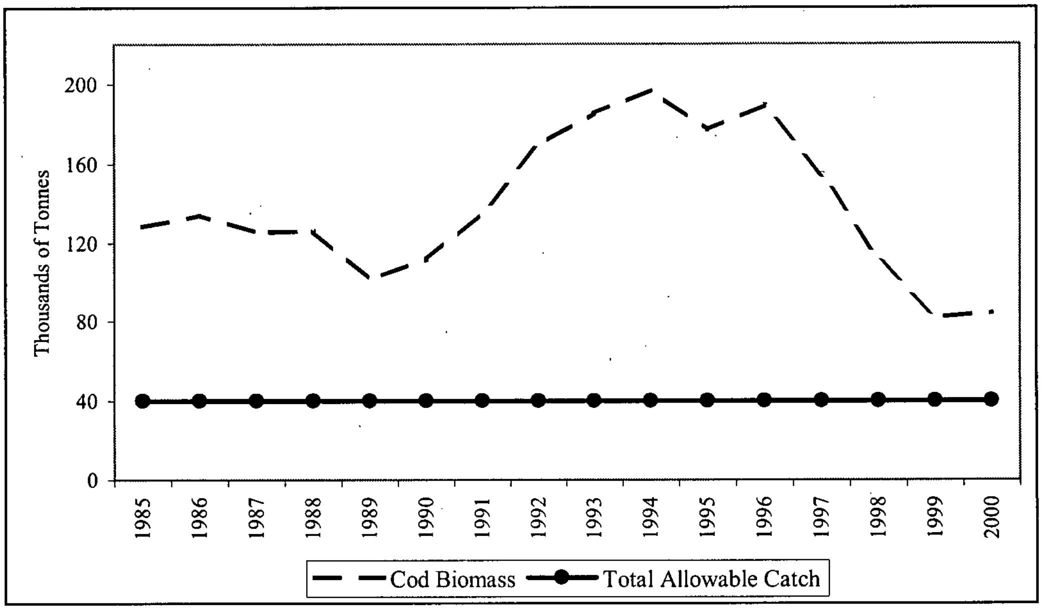

Figure 4.4: Cod Biomass and Total Allowable Catch 1985 - 2000

The final pieces of required information are stock biomass and total allowable catch. These were accessed from the International Council for the Exploration of the Sea (2004) Advisory Report. The total allowable catch is 40,000 tonnes per year for the duration of my study period and is presented with cod biomass in Figure 4.4. Biomass dropped about 20% in 1989 before experiencing a growth to being 50% larger in the mid-1990s than the mid-1980s but a collapse in the late 1990s has continued into this century.

4.4 Productivity Analysis Results

As outlined in Section 4.2 both the data envelopment analysis and the index number decomposition are a matter of computation. For each firm I first calculate the measure of technical efficiency relative to the efficient isoquant (θ_b) using a variable returns to scale DEA. I then use the IND to calculate a measure of productivity for each relative to the most profitable firm (γ^{ab}) and decompose the elements.[6] The variable inputs are labour, labour-related, fuel, other variable, quasi-fixed, and capital; stock biomass is included as a fixed input. The outputs are cod, haddock, northern saithe, other fish, and other income. While I chose my species groups to limit the problem of blanks, for the 217 observations that did not catch haddock, northern saithe or other, the analysis is done with respect to just the species caught.

Before considering the components, I take the calculated measures of technical efficiency and relative productivity and examine the effect of IVQ management using panel least squares analysis with vessel fixed effects and a spline to allow for a structural break at 1990. The simplest specifications, presented in Columns 1 and 3 of Table 4.3 just use a constant and the structural break; the specifications presented in Columns 2 and 4 include controls for vessel length, vessel age, a set of county dummies, and a set of gear type dummies.

Using the DEA approach, the coefficients for the Post-1990 effect on technical efficiency (column 1) indicate that observations after 1990 are 4.9 percentage points closer to the efficient isoquant than observations prior to 1990. This effect is slightly smaller (4.6 percentage points) after controlling for vessel size and age, and county and gear-type (column 2). The IND approach supports this conclusion, in the simple case (column 3) the introduction of IVQs raises productivity 45.2 percentage points compared to the previous licensing scheme, while the additional controls reduce this to 38.0 percentage points. The difference in magnitude is due to the DEA approach restricting the measure of efficiency to a maximum of one. In contrast, the IND approach provides no upper bound as it is relative to the most profitable firm; here 80% of the observations have higher productivity than the most profitable firm.

The positive coefficients on vessel length suggest that there are increasing returns to scale in this fishery, supporting the use of the alternative decomposition of revenues and costs rather than profits. Vessel age has a slightly negative effect,

[6] I use the DEAP software of Coelli (1996) to perform the DEA calculations, and Stata 8 (2003) to perform the IND calculations and regression analysis.

Table 4.3: Panel Regression Results with Vessel Fixed Effects

	DEA-Simple	DEA-Controls	IND-Simple	IND-Controls
Constant	.3149 *** (.011)	.2961 ** (.130)	1.830 *** (.110)	-1.976 (1.26)
Pre-1990	-.0053 * (.003)	-.0011 (.004)	-.1161 *** (.030)	-.0740 ** (.036)
Post-1990	.0492 *** (.004)	.0461 *** (.004)	.4523 *** (.040)	.3796 *** (.039)
Vessel Length		.0128 * (.007)		.3723 *** (.065)
Vessel Age		-.0044 ** (.002)		-.0277 (.021)
Troms		-.1322 ** (.051)		-.6936 (.496)
Nordland		-.1056 ** (.043)		-1.427 *** (.421)
Nord-Trøndelag		-.1126 (.100)		-1.496 (.971)
Sør-Trøndelag		-.1561 ** (.065)		-3.921 *** (.635)
Møre og Romsdal		-.1868 *** (.060)		-2.312 *** (.579)
Sogn og Fjordane		-.1504 ** (.067)		-.6154 (.654)
Hordaland		-.3866 *** (.146)		-3.006 ** (1.424)
Rogaland		-.0011 (.154)		2.994 ** (1.50)
Vest-Agder		-.2082 * (.110)		-4.519 *** (1.07)
Gillnet, handline, Danish seine		-.0057 (.029)		-1.125 *** (.278)
Longline		.0784 ** (.037)		-.7845 ** (.360)
Longline only, offshore		-.0389 (.089)		-.5644 (.863)
Longline, gillnet, trawl, offshore		-.0207 (.027)		-1.943 *** (.262)
Seine		.0016 (.025)		-.1230 (.240)
Shrimp trawl only		-.0945 ** (.039)		-.7931 ** (.376)
Shrimp trawl and other gear		-.0682 ** (.034)		-.7855 ** (.328)
Ocean trawl shrimp		-.1623 *** (.061)		-1.810 *** (.595)
Ocean trawl shrimp, no storage		-.1257 *** (.034)		-1.804 *** (.333)
Purse Seine		-.0172 (.130)		1.848 (1.26)
Cod and saithe trawl		.0925 * (.054)		-3.340 *** (.522)
Gillnet, North Sea		-.0409 (.047)		-.7859 * (.461)
Obs. 2771	$F(2,1918)$: 446.5	$F(26,1894)$: 38.8	$F(2,1918)$: 237.6	$F(26,1894)$: 29.1
Groups 851	Overall R^2: 0.35	Overall R^2: 0.43	Overall R^2: 0.25	Overall R^2: 0.33

Standard errors in parentheses. Significance levels: *10% **5% ***1%.
Left-out county: Finnmark. Left-out gear-type: Miscellaneous

depending on the specification. Despite the lower profits reported for vessels in the north, recall that from Table 4.1 Finnmark's vessels had little over half the profits of the average vessel, the coefficients on the county dummies are all negative in comparison to Finnmark indicating that the more southern vessels are less productive. The results for gear-type are mixed, vessels that use gillnets or trawl seem to perform worse than the seiners. All specifications perform well overall, F-tests that the coefficients are jointly zero fail and the overall R^2 are all relatively high.

To get a better sense of when the productivity effects are coming through, I conduct the same regressions but instead of using a structural break I use a set of year dummies. The coefficients of these are presented in Figure 4.5 and tell us how productivity has changed compared to 1985 so we can examine when the management effects took hold. In all specifications there is an increase in efficiency or productivity after the change to IVQ management in 1990. While there is some indication of a rise as early as 1991 using the DEA it is not statistically significant

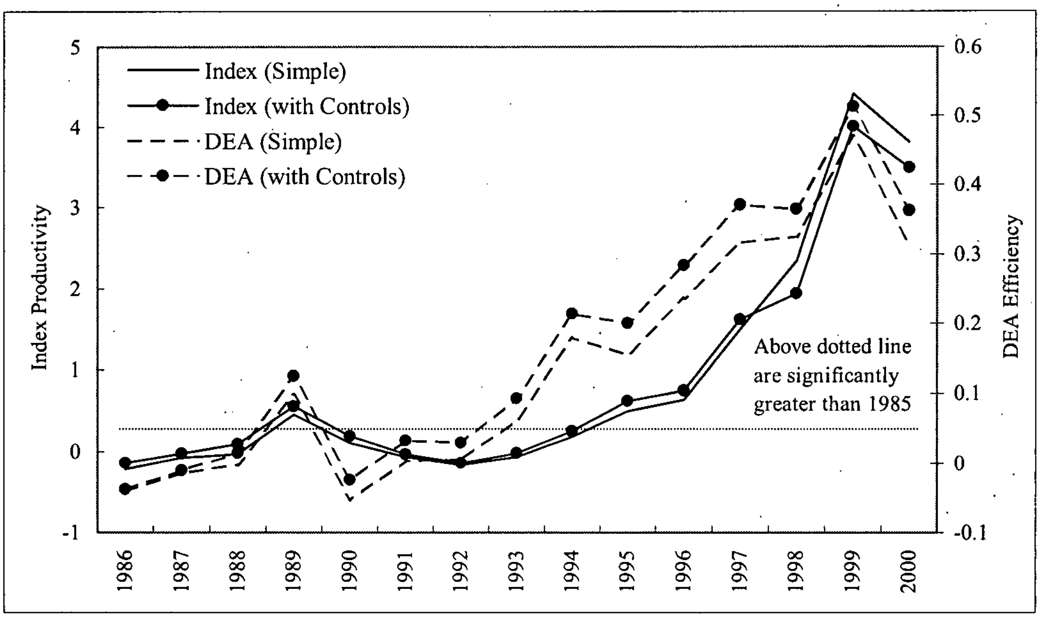

Figure 4.5: Efficiency and Productivity Increases Over 1985

until 1993 for the DEA or 1995 for the IND.

In comparison to the earlier studies that were able to see a rise in productivity using just one year of data after the implementation of property rights management, a delay of three to five years here seems slow. However, there are several confounding factors in the Norwegian coastal cod fishery. Apart from in 1989, the fishing season continued for most of the year, rather than restricting the season to ensure only the TAC was taken the fisheries managers allowed overharvesting. This is in comparison to the Pacific halibut fishery where the season went from six days in the year prior to IQs to 214 days in their first year. For the cod fishery, we can only expect to see an increase in productivity due to the increase in security that quotas give beyond the rights perceived by the owners under the old regime. In addition, the quotas were not transferable meaning that more productive vessels cannot buy out quota from their less productive counterparts. Even in the halibut fishery productivity's contribution to profits only rose after the quotas became transferable in the third year of the program (Fox *et al.*, 2003); the higher profits in the first year came largely from the higher prices received for fresh fish across the longer season.

It is interesting to note that 1989 has statistically higher efficiency and productivity than 1985 when this is the year of collapse that led to the introduction of IVQs. However, this is most likely due to the fact that the fishery was actually closed in April thus restricting the season and thus the use of inputs.

Recall the definition of productivity from Equation 4.2.12 is made up of a deflated revenues component (the numerator), a deflated costs component (most of denominator), and the biomass ratio:

$$\gamma^{ab} = \frac{\mathbf{O}^{ab}}{\mathbf{I}^{ab}} = \frac{\frac{TR^b/TR^a}{P^{ab}}}{\frac{TC^b/TC^a}{W^{ab}} \cdot \frac{f^b}{f^a}}$$

To take advantage of the component analysis allowed by the IND I present the decompositions of productivity in Tables 4.4 and 4.5. I present the geometric means of the indexes for the whole sample, then break the sample based on management pe-

Table 4.4: Profits, Revenues, Costs, Biomass and Productivity Ratios

	Profit Ratio	Total Revenue Ratio	Total Cost Ratio	Biomass Ratio	Productivity Ratio
All Years	0.029	0.090	0.138	1.038	1.787
	(3.58)	(2.36)	(2.13)	(1.29)	(2.03)
Pre-1990	0.021	0.069	0.115	0.925	1.430
913 obs	(3.70)	(2.40)	(2.13)	(1.09)	(1.63)
Small	0.014	0.045	0.079	0.926	1.318
558 obs	(2.92)	(2.06)	(1.81)	(1.09)	(1.62)
Large	0.031	0.135	0.209	0.923	1.625
355 obs	(4.05)	(1.93)	(1.77)	(1.09)	(1.61)
1990-on	0.031	0.102	0.151	1.099	1.995
1858 obs	(3.50)	(2.27)	(2.10)	(1.33)	(2.16)
Small	0.018	0.063	0.095	1.144	1.461
1056 obs	(3.07)	(1.86)	(1.68)	(1.30)	(1.85)
Large	0.058	0.193	0.276	1.043	3.006
802 obs	(2.99)	(1.78)	(1.70)	(1.37)	(2.15)

Geometric means and standard deviations.

t-statistics testing hypotheses that index values are different under IVQ management

All vessels	7.98	11.20	8.99	23.77	13.76
Small vessels	4.75	9.09	6.54	24.07	3.67
Large vessels	7.64	8.92	7.82	10.15	16.65

riod (pre- and post-1990) and vessel size (smaller or larger than the sample average) to perform t-tests on whether the indexes have changed since the implementation of IVQ management.[7] Table 4.4 gives the main components while Table 4.5 breaks down the inputs and outputs.

From Table 4.4 we can see that the profit, total revenue, total cost, biomass, and productivity ratios have all risen since IVQs were introduced. For productivity to have risen, we need the numerator of Equation 4.2.12 to rise faster than the denominator. In fact, the total revenue ratio rose 48% while the total cost ratio rose 31% and biomass ratio rose 19%. Now we need to find out what has happened to the input and output contributions.

Table 4.5 gives the six input and five output indexes. All the input indexes have

[7] The actual t-test that is performed tests the null hypothesis that the natural log of the geometric mean of the index before the management change is the same as after.

Table 4.5: Input and Output Index Decompositions

	Labour	Labour Related	Fuel	Other Variable	Quasi-fixed	Capital	Cod	Haddock	Northern Saithe	Other Fish	Other Income
All Years	1.056	0.898	1.042	1.044	0.865	0.823	1.027	0.995	0.993	0.514	0.494
	(1.04)	(1.04)	(1.04)	(1.09)	(1.08)	(1.09)	(1.06)	(1.02)	(1.03)	(1.62)	(1.31)
Pre-1990	1.014	0.888	1.003	1.033	0.847	0.805	1.023	0.995	0.997	0.573	0.498
913 obs	(1.02)	(1.04)	(1.01)	(1.10)	(1.08)	(1.09)	(1.05)	(1.01)	(1.03)	(1.46)	(1.30)
Small	1.013	0.876	1.003	1.008	0.818	0.779	1.025	0.994	1.002	0.582	0.457
558 obs	(1.02)	(1.03)	(1.01)	(1.09)	(1.07)	(1.09)	(1.06)	(1.01)	(1.02)	(1.41)	(1.30)
Large	1.015	0.906	1.003	1.074	0.893	0.848	1.021	0.997	0.991	0.560	0.570
355 obs	(1.02)	(1.03)	(1.01)	(1.09)	(1.07)	(1.08)	(1.05)	(1.01)	(1.04)	(1.53)	(1.21)
1990-on	1.078	0.903	1.061	1.049	0.875	0.832	1.029	0.995	0.990	0.487	0.493
1858 obs	(1.03)	(1.03)	(1.03)	(1.09)	(1.08)	(1.08)	(1.06)	(1.02)	(1.03)	(1.68)	(1.31)
Small	1.074	0.890	1.061	1.018	0.841	0.802	1.031	0.994	0.997	0.583	0.461
1056 obs	(1.03)	(1.03)	(1.03)	(1.07)	(1.07)	(1.07)	(1.06)	(1.02)	(1.02)	(1.52)	(1.30)
Large	1.082	0.921	1.061	1.091	0.921	0.874	1.027	0.996	0.983	0.384	0.538
802 obs	(1.03)	(1.03)	(1.03)	(1.09)	(1.07)	(1.07)	(1.06)	(1.01)	(1.04)	(1.71)	(1.30)
Geometric means and standard deviations.											
t-statistics testing hypotheses that index values are different under IVQ management											
All vessels	66.52	11.92	75.19	4.12	9.95	9.53	2.66	0.65	6.57	9.43	0.92
Small vessels	50.47	9.33	56.88	2.34	7.82	7.17	1.93	0.16	5.48	0.09	0.74
Large vessels	43.69	7.98	49.14	2.74	6.86	6.56	2.01	1.35	3.91	12.82	4.23

risen and these can be attributed to rising input prices. The contribution of cod to revenues has risen, suggesting that the new management regime has slightly improved the vessel owners ability to harvest optimally. The remaining output indexes, in contrast, have fallen or remained constant. In particular, the importance of other fish in the revenues of large vessels has dropped considerably. In sum, revenues have risen faster than costs despite rising input prices, which, in conjunction with the increasing contribution of cod, supports the earlier regression analysis of rising productivity since the introduction of the IVQ management scheme.

4.5 Conclusion

I have used a previously untapped dataset to examine the impact of a change to IVQ management on the productivity in the Norwegian coastal cod fishery. The analysis was conducted with two methodologies in a parallel fashion. The traditional data envelopment analysis was used to provide a standard comparison to previous studies that examine the effect of a regime switch. The index number decomposition proposed by Fox *et al.* (2003) was implemented here allowing for non-constant returns to scale and negative profits, both of which are observed in the coastal cod fishery, whilst retaining the ability to identify the component effects of individual inputs and outputs on productivity.

The results from both the DEA and IND indicate that management using individual vessel quotas has had a positive impact on productivity for the coastal cod fishery. The effects did, however, take some time to be felt. This is in contrast to the Dupont *et al.* (2005) study of the Nova Scotia mobile gear multi-species fishery that only had data prior to and the year of the management change yet was able to see an immediate increase in productivity, and the Fox *et al.* (2003) study of Pacific halibut that also found an increase in the first year of implementing quotas. The slower response can be attributed to at least two factors. First, curtailing the length of the Norwegian cod season had not, except for in 1989, been used as a strong tool in reducing the harvest so the dramatic six-to-214-day-season change as in the halibut fishery could not be felt. Second, the lack of transferability of quotas eliminates buying out less productive vessels' quotas as a way to improve fleet productivity. Individual vessels have realised increases in their productivity but further fleet-level gains may be possible with the transferability provisions introduced in 2003.

With respect to the species in question, the importance of cod in total revenues rose and the contribution of other fish fell after the introduction of cod quotas, indicating that the vessels were better able to manage their harvests as their property rights over cod became more secure. This impact is less strong than it may be due to the overregulation in the fishery where the sum of the individual quotas is greater than the total allowable catch. While this is done to avoid having to reallocate quota late in the season it means that as the fleet gets close to the TAC, there is less surety for the individual vessels. Transferable quotas in conjunction with eliminating overregulation would allow the fleet to work out the reallocation issues themselves as necessary while ensuring the harvest is restricted.

Combining the results of this study with the earlier ones highlights the importance of transferability and flexibility. The ability of vessels to opt in or out of a given fishery or fisheries as comparative advantage determines is vital to productive harvesting. If there are concerns about maintaining the ability of small operations to remain in a fishery then an annual allocation of transferable rights would give the smaller operations essentially the right of first refusal as to whether to participate or sell to others. The flexibility of when to participate is also of great importance. This was clearly seen in the Pacific halibut case where fresh fish supplied year-round garnered a much higher price than selling in a glut to frozen processors but it can also be seen in the Norwegian cod case where the contribution of other fish fell, indicating a greater ability to target cod as biological and economic conditions alter. Without individual quotas this might be achieved by setting monthly rather than annual catch limits.

Chapter 5

Concluding Remarks

This dissertation addresses three issues in managing the fisheries commons: international sharing; international agreements; and property rights management. In Chapter 2, I undertake an international study of whether shared fish stocks are worse off than their solely owned counterparts. To conduct this study I compile a unique two-period panel dataset of exploitation status on almost two-hundred fish stocks combined with economic and biological characteristics. With the standard Clark-Munro model as the framework of my empirical analysis, I use an ordered category analysis to consider the effects of the number of countries on the probabilities of a fish stock being depleted, overfished, fully fished, moderately fished, or underutilised. The result that a higher number of countries has a systematically detrimental effect on stock status is robust to a variety of specifications. This suggests that policy advice that ignores the role of international sharing does a disservice to the countries and fish stocks involved.

In the third chapter I push the international sharing issue one step further by appending information about international cooperative management and access agreements onto the dataset used in Chapter 2. The results from this broad, first-pass analysis unfortunately indicate that on average fully cooperative, multilateral agreements are associated with poor, and declining, stock status. Caution is required in discussing these results as there is some difficulty in disentangling the direction of causation, that is, poor stocks may require the most intensive management, and, while the average effect is negative, some international agreements have had positive results. Future work in this area will consider further the issue of who makes agreements with whom, what characteristics of the cooperative agreements are or are not performing, and what lessons can be learned to aid newer regional management organisations.

In Chapter 4, the scope of analysis contracts to a more usual fisheries level with a case study of a management regime switch in the Norwegian coastal cod fishery. In keeping, however, with the internationally comparable focus of the earlier chapters I conduct a parallel analysis to allow comparison to other case studies while using a modified version of a non-traditional index number decomposition to tease out the component effects of the property rights system. With vessel-level data that spans the introduction of individual vessel quotas I find that productivity rose in this fishery but that, in contrast to other fisheries with property rights systems, it took some time to occur due to lack of transferability of quotas. While the Norwegian study only considers productivity effects, in future work on the New Zealand quota management system I will combine the productivity analysis with an examination of the effect on stock status to address both the productivity question and whether sustainability rises with property rights regimes.

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