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From Open-Access to Individual Quotas: Disentangling the Effects of Policy Reform and Environmental Changes in the Norwegian Coastal Fishery

Florian Diekert, Kristen Lund and Tore Schweder

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Department of Economics
University of Oslo

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P. O.Box 1095 Blindern
N-0317 OSLO Norway
Telephone: + 47 22855127
Fax: + 47 22855035
Internet: http://www.sv.uio.no/econ
e-mail: econdep@econ.uio.no

In co-operation with
The Frisch Centre for Economic Research

Gaustadalleén 21
N-0371 OSLO Norway
Telephone: +47 22 95 88 20
Fax: +47 22 95 88 25
Internet: http://www.frisch.uio.no
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From Open-Access to Individual Quotas: Disentangling the effects of policy reform and environmental changes in the Norwegian coastal cod fishery

Florian Diekert*, Kristen Lund, Tore Schweder

Department of Economics and CEES, Dept. of Biosciences, University of Oslo

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Abstract

Understanding the effect of introducing property rights to natural resources is central in economics, but empirical analysis is frustrated by the complexity of socio-ecological systems. We construct a detailed bio-economic model of the Norwegian coastal cod fishery, which was closed after 1989, to isolate the effect of environmental variability. We project stock and harvest forward in the counterfactual scenario of no intervention, showing that the policy had only a small positive impact on stock biomass, but a pronounced positive effect on profits. The main driver, uncovered by index-number decomposition, is savings in fuel and labor costs. (96 words)

Key words: Open access, Property rights, Quasi-experiment, Counterfactual control, Bio-economic modeling, Productivity, North-East Arctic cod

JEL codes: C43, D23, Q22, Q28

*Corresponding author: F Diekert, Department of Economics and CEES, Dept. of Biosciences, University of Oslo, PO-Box 1095, 3017 Oslo, Norway. E-mail: f.k.diekert@ibv.uio.no. This research is funded by NorMER, a Nordic Centre of Excellence for Research on Marine Ecosystems and Resources under Climate Change.

1 Introduction

The effective assignment of property rights to valuable resources is a core theme in economics. Maybe *the* canonical example of the "tragedy of the commons" are fisheries: Theory states clearly that rents are dissipated and fish stocks are depleted under open-access (Gordon, 1954), whereas well-defined rights to exploit the resource give rise to considerable profits and high stock values (Scott, 1955). Real-world processes are evidently much more complex than the theoretical dichotomy of rent-dissipation and rent-maximization. Nonetheless, cross-sectional studies have indeed identified negative effects of open-access (McWhinnie, 2009) and positive effects of secure rights-based management (Costello et al., 2008; Grainger and Costello, 2014). These studies convincingly document that more secure property rights are associated with better performance, but they are less able to establish the causal mechanism at work. Here, we attempt to analyze the results of establishing property rights for a specific fishery – so to say – in the spirit of program evaluation.

The North-East-Arctic cod fishery in the Barents Sea is currently the world's largest cod fishery (actually it is the most valuable whitefish fishery in the world). Dried cod from Lofoten has been a highly priced export commodity since the Viking Ages. Today, Russia and Norway agree on the annual total allowable catch (TAC) quota and its distribution. While the Russian and European fleets (obtaining roughly 50-60% of the total TAC) predominantly consist of trawlers, this is not the case for the Norwegian fleet. Here the main part are conventional boats that exploit the impressive spawning migration of the North-East-Arctic cod (*gadus morhua*) to the coastal areas around Lofoten. Up to 1989, access to this coastal fishery was basically open and the international TAC was not enforced on coastal vessels. At that time the cod stock had reached a record low and the Norwegian authorities pulled the emergency break. Afterwards, the coastal fishery has been closed and managed by individual quotas. This system has evolved into an individually transferable quota (ITQ) system, thereby effectively establishing property rights to the resource. Cod stock and profits have subsequently increased. In short, we ask: was this due to good luck or due to good management?

ITQ systems in various forms have now been used for more than thirty years, and their use has increased in scope and scale in the recent decade. Simultaneously, there has been a lively debate around this type of fisheries management (see e.g. Bromley, 2009, and the subsequent commentaries). Many studies have pointed to the positive economic effects of ITQ management (see for example Grafton et al., 2000; Fox et al., 2003; Dupont et al., 2005; Arnason, 2005; Schnier and Felthoven, 2013), whereas the ecological effects appear to be more mixed (Branch, 2009; Chu, 2009).[1]

In general, all case studies of time series face the same fundamental problem of empirically testing whether the privatization of common property has indeed improved profits; namely to correctly identify the causal effect of policy change. There are neither controlled nor natural experiments for large fisheries. First of all, spillover effects make it impossible to identify a treatment effect by randomization. Second, there is so much specific natural and social context to a given fishery that it is virtually impossible to find an adequate control among the set of other similar fisheries. Last, but not least, slow environmental changes obstruct even the comparison of economic units before and after the regulatory change.

It is this last aspect which we attack in this paper: Fish stocks, and consequently profits, might have risen due to policy change, but also due to more favorable environmental conditions. Therefore, we build an age-structured bio-economic model to simulate the counterfactual development of the fish stock, i.e. assuming that the relationship between stock and harvest did not change. The idea is to utilize the estimated recruitment to the factual population after the intervention. We assume that the counterfactual

[1]Most studies consider in fact only a rather short time horizon of a few years before and after the policy change. A notable exception is Walden et al. (2012) who study the Mid-Atlantic clam fishery over a period of 28 years. Here we are able to use data from 1985 up to 1997 (as the sampling methodology changed in 1998), i.e. we have 5 pre-event years and 8 post-event years.

recruitment in a year would have been the observed factual recruitment, adjusted by the stock-recruitment curve according to the counterfactual spawning stock. The counterfactual stock is then projected forward, subject to observed natural mortality and counterfactual fishing mortality. The resulting counterfactual stock can then be used to isolate the environmental changes in the resource stock.

The first objective of our study is thus to analyze the effect of "closing the commons" (Hersoug, 2005) on the stock biomass. The second objective is to analyze the effect of the policy change on profits. We do so by taking a structural model of a profit function to an extended dataset of boat-owner combinations in the Norwegian coastal cod fishery. After establishing that introducing individual quotas has indeed had a positive and significant effect on profits, we project the development of counterfactual profits to gauge the overall gains from the policy change. The third objective of our study is to investigate how abolishing the open-access regime has lead to increased profits. We do so by employing an index-number profit decomposition (Fox et al., 2003).

We are well aware of the gulf between the power of a randomized controlled experiment and the evidence that our study might bring. Nevertheless, we take an important step towards better understanding the effect of changing the property rights regime in our case-study fishery. Given the central role of institutions for economic performance, we argue that the case-study of the Norwegian cod fishery is of substantial general interest. In particular, we hope that our novel methodological approach, simple as it is, will come to be a useful contribution to the literature.

2 Material and Methods

2.1 Overview of the fishery

At first sight, the stock development of the North-East Arctic cod could serve as a textbook example of open-access and fisheries management. Biomass has declined from more than 4 million tons after WWII to less than one million tons in the 1980s. At the same time, the stock's age structure has been severely truncated, making the stock more susceptible to climatic variations (Rouyer et al., 2011). The trend turned around 1990 and the aggregate stock biomass has increased to values above three million tons again (although the age structure remains truncated).

Two boat groups are distinguished in the Norwegian cod fishery: Trawlers and conventional vessels. The latter group is considered to be the backbone of the Norwegian fishing fleet, landing on average 70% of the cod harvest. Trawlers have always been subjected to a licensing scheme, while access for conventional boats has traditionally been open. Although a Total Allowable Catch (TAC) quota was agreed upon by the Joint Russian-Norwegian Fisheries Commission since 1977, the quota was de facto not enforced for conventional vessels (Christensen and Hallenstvedt, 2005). The situation changed radically when the resource stock was in such a dire state that the authorities closed the fishery on April 18, 1989. After this shock, the unanimous slogan was "Never again April 18th!" (Hersoug, 2005). In the fall of the same year, the authorities issued individual vessel quotas. Though the vessel quotas were initially not meant to be transferable, they were so in practice: Boats have been sold with a quota and then bought back without the quota (Holm and Nielsen, 2007). Several regulatory changes throughout the 1990s aimed at increasing quota transferability and reducing state intervention without giving up the political aim of maintaining a diverse settlement pattern in Northern Norway. A delicate act of balance![2]

A further important management measure (which is beyond our study period) was the introduction of a "harvest control rule" in 2007, determining the TAC independently of political negotiations. Kjesbu et al. (2014) analyze the effect of this measure by, among other methods, asking how the stock and the landing would have been over

[2] For further information on details of Norwegian fishery regulation, see Årland and Bjørndal (2002) or Fiskeri og Kystdepartementet (2006). Hannesson (2013) gives a recent overview of Norway's experience with ITQs in the pelagic and demersal fisheries, arguing that the resource rent in these fisheries has been capitalized in boat- and quota values.

the years if this new harvest control rule had been implemented in 1993. They predict the contrafactual recruitment by assuming it being an estimated function of spawning stock size and temperature. They find that the substantially reduced fishing mortality on ages 5-10 would have lead to an increase in stock, but also in landings after some years. They give an excellent introduction to the natural environment and the current status of the Barents Sea cod. Our emphasis is the economics of the cod fishery. In contrast to Kjesbu et al. (2014), we predict contrafactual recruitment according to actually estimated recruitment modified by contrafactual spawning stock.

2.2 Data

The Norwegian cod fishery has generally been a popular study object, from the early work on productivity (Hannesson, 1983) to its latest advances (Kumbhakar et al., 2013). It has served as example for calibrated simulations of e.g. cod-cannibalism (Armstrong and Sumaila, 2001), climate change effects (Eide, 2007), or the importance of age-differentiated management (Diekert et al., 2010).

The biological information on the cod stock and data on aggregate landings is usually obtained from ICES (here from the 2012-report). The economic data comes from the Norwegian Directorate of Fisheries' profitability surveys. It forms an unbalanced panel of fishing vessels with information on vessel characteristics, economic variables, the harvested amount and the harvested value.[3]

The trawler segment of the fishery has been studied by Asche and coauthors (Asche et al., 2009; Asche, 2009) to estimate the size of the resource rent (using data from 1997 and 1998) and to test for adjustment cost (using data from 1986-1994). Data from 1995-2007 for the entire demersal fleet has been used by Guttormsen and Roll (2011) to investigate technical inefficiencies. McWhinnie (2006) uses data for the coastal fleet from 1985-2000 to investigate productivity changes by means of index-number decomposition.

[3] All prices have been deflated using the consumer price index (1998=100) from Statistics Norway.

Here, we use data from 1985-1997. As the sampling methodology changed fundamentally in 1998 it is not advisable to extend a dataset that covers the 1989/1990 policy change further than 1997. However, we were able to pool the data from all Norwegian coastal vessels: The directorate classifies a boat as belonging to the "demersal fleet" only when more than 50% of its harvest is from demersal species. As the harvest composition varies substantially from year to year, it is important to obtain data from all boats, regardless of classification. This allows us to study the fate of a boat even if 52% of its catch are demersal species in 1994 (when it would show up in the Directorate's demersal dataset) and 48% of its catch are demersal species in 1995 (when it would show up in the Directorate's pelagic dataset). Moreover, we have combined this dataset with information on the boat owners from the vessel registry (obtained through the Directorate of Fisheries). In other words, we are able to control for vessel- and owner specific idiosyncrasies, and importantly, we are able to distinguish the fate of those that have entered or left the fishery. We have removed all observations where the share of cod in total harvest is less than 5% to exclude those catch cod only as undirected bycatch. The final selection contains 668 unique vessel-owner combinations over 13 years. In total, the panel contains 1818 observations, on average 140 observations per year.

Table 1: Summary statistics, selected variables

Statistic	N	Mean	St. Dev.	Min	Max
Length (meter)	1 818	17.20	3.53	13.00	27.80
Boat-age	1 817	22.03	15.91	0	90
Labor (Man-years)	1 818	4.27	1.61	1.00	12.06
Days in operation	1 818	278.65	44.71	62	364
Harvest	1 818	368.54	413.76	5.18	3 306.44
Share of cod in harvest	1 818	0.46	0.24	0.05	0.99
Revenue (1000 NOK)	1 818	1 970.99	1 439.69	97.08	10 843.85
Total cost (1000 NOK)	1 818	1 834.23	1 292.16	180.08	10 075.68
Variable cost (1000 NOK)	1 818	1 151.04	812.71	59.41	7 349.87

Table 1 shows the main variables of the economic dataset. A key measure of economic performance is the return on capital, or restricted profits. This is defined as the total revenue minus variable costs.[4] In the following, we will use the word profits to mean restricted profits. Table 2 shows the average value of profits in the dataset and the variance between and within different vessel-owner combinations.

Table 2: Mean, within- and between variation of restricted profits

Variable	mean	sd
Profits (overall)	819.95	660.84
(between)		654.18
(within)		197.15

2.3 Counterfactual simulation of cod stock

Simulating how stock biomass would have developed if the 1990 regulatory change had not taken place requires three steps: 1.) a function predicting the aggregate harvest for a given stock biomass, 2.) a biological model predicting the size of each cohort the next year, accounting for harvest and natural mortality, and 3.) a procedure calculating the number of new fish entering the fishery as a function of the reproductive part of the stock, while accounting for the historical environmental conditions.

Harvest

The function which predicts aggregate harvest for a given stock is given by equation (1), where H_t refers to the harvest *during* year t and B_t refers to the stock biomass *at the beginning* of year t.

$$H_t = \alpha + \beta B_t + \varepsilon_t \tag{1}$$

[4] To be precise, we define our right-hand-side variable *varprof* as the entry `DRIFTINNTEKTER`. We group `ARBEIDSGODTGJORELSE, PROVIANT, SOSIALE_KOSTNADER, PENSJONSTREKK DRIVSTOFF, AGN_IS_SALT_EMB` and `PRODUKTAVGIFT` as variable cost, whereas depreciation of vessel and quota, maintenance of gear and vessel as well as "other cost" (such as for external accounting services etc.) are grouped as fixed costs.

Equation (1) can be viewed as a reduced form of a model of open-access in the Norwegian coastal cod fishery. We then presume that the relationship between stock and harvest would have been the same also after 1990 were it not for the policy change. Details on the selection of the functional form, its estimation, and the parameter values are placed in Appendix A.1.[5]

Stock dynamics

In order to project the stock biomass to the next period for a given stock and harvest in the current period, we first need to convert the aggregate harvest at time t to the numbers of fish of given age a that are caught at time t. To this end, we assume that the selectivity pattern for a given year does not change with the regulatory regime.[6] The counterfactual Catch-Numbers-at-age $\hat{C}_{a,t}$ are calculated by weighing the observed Catch-Numbers with the ratio of simulated to observed harvest:

$$\hat{C}_{a,t} = \frac{\hat{H}_t}{H_t} C_{a,t}. \tag{2}$$

The aggregate stock biomass at time $t+1$ is the number of fish at age a at time $t+1$ times their average individual weight, summed over all ages: $B_{t+1} = \sum_a^A w_{a,t+1} N_{a,t+1}$. The first-age-at-recruitment is 3 years for NEA cod, and the oldest age-group A (a so-called "plus group", collecting all individuals of age A and above) is 13 years. We assume that the average individual weight-at-age $w_{a,t}$ does not change with the regulatory shift

[5]Although we arrive at the aggregate harvest equation (1) by searching for the most parsimonious empirical relationship with the highest explanatory power, it is possible to derive (1) theoretically from first principles. Consider the following aggregate harvest function with decreasing returns to total effort E(i.e. with infra-marginal rents): $H = E^{1-\alpha} B^{\beta}$. Further, suppose costs are proportional to effort by a factor w so that $c(E) = wE$. Solving harvest for effort, we can write costs as a function of harvest and stock size: $c(H, B) = w \left(H/B^{\beta}\right)^{1/(1-\alpha)}$. Under open-access, there will be zero rents at the margin, so that $pH = c(H, B)$, which can be re-arranged to give $H = \left(\frac{p}{w}\right)^{\frac{1-\alpha}{\alpha}} q^{\frac{1}{\alpha}} B^{\frac{\beta}{\alpha}}$. This function is approximately linear in stock biomass when $\beta \approx \alpha$.

[6]Indeed, the data shows no signs of systematic changes in the selectivity pattern. Diekert (2012) gives a theoretical argument that aggregate ITQs per se do not influence the incentives for changing gear selectivity.

and employ the yearly values as they are given in Table 3.7 in ICES (2012). The counterfactual Stock-Numbers-at-age $\hat{N}_{a,t}$ are calculated according to equation (3), which means that we assume that fishing occurs instantaneously in the middle of the year, and natural mortality $M_{a,t}$ occurs evenly throughout the year. The values for natural mortality are taken from the ICES report (2012, Table 3.17; $M_{a,t} = 0.2$ for most a, t).

$$\begin{aligned} \hat{N}_{a+1,t+1} &= \left(N_{a,t} e^{-\frac{M_{a,t}}{2}} - \hat{C}_{a,t} \right) e^{-\frac{M_{a,t}}{2}} \\ \hat{N}_{A,t+1} &= \left(N_{A-1,t} e^{-\frac{M_{A-1,t}}{2}} - \hat{C}_{A-1,t} \right) e^{-\frac{M_{A-1,t}}{2}} + \left(N_{A,t} e^{-\frac{M_{A,t}}{2}} - \hat{C}_{A,t} \right) e^{-\frac{M_{A,t}}{2}} \end{aligned} \tag{3}$$

Recruitment

Finally, the number of newly recruited fish has to be determined. Importantly, we would like to isolate the influence of the (endogenous) spawning stock biomass from the (exogenous) environmental forces determining recruitment. The link between biomass and recruitment is assumed to follow the Beverton-Holt form:

$$N_{3,t} = \frac{aSSB_{t-3}}{1 + bSSB_{t-3}} + \varepsilon_t \tag{4}$$

where the parameters a and b are obtained from a non-linear regression of the number of recruits on the spawning stock biomass (SSB). Since NEA cod is considered to recruit at age 3 to the fishery, the relevant spawning stock biomass is the one three years earlier.[7] The projected spawning stock biomass will differ from the observed values, and will hence drive a wedge between the projected and the predicted recruitment values. However, we add a time-specific residual from the regression to the recruitment values. The residuals are – by assumption – independent of the stock size and capture random environmental

[7] The spawning stock biomass is calculated as $SSB_t = \sum_a mat_{a,t} w_{a,t} N_{a,t}$ where $mat_{a,t}$ is the proportion of mature individuals in a given cohort (obtained from Table 3.10 in ICES, 2012).

fluctuations (climatic or oceanographic conditions, predator and prey abundance etc).[8]

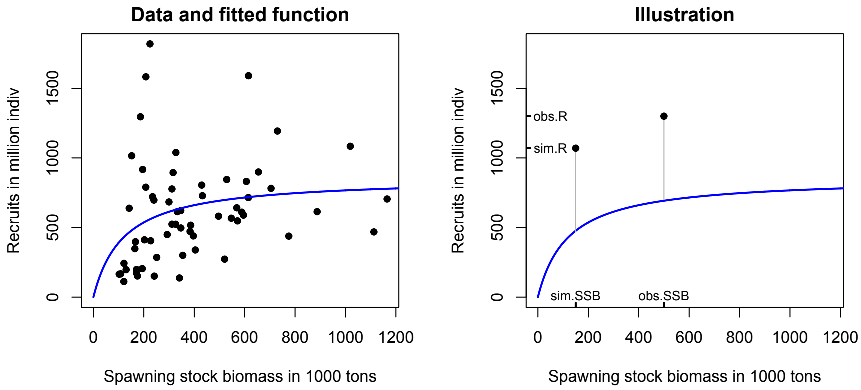

Figure 1: Stock-recruitment relationship. In the panel on the right, sim.SSB is the simulated counterfactual spawning stock while obs.SSB is the factual; similarly for the number of recruits.

The left panel of Figure 1 shows the observed scatter of SSB versus abundance at age 3 and the fitted Beverton-Holt function (blue line). The right panel of Figure 1 illustrates the simulation procedure: Suppose the observed SSB at time $t-3$ was at 500 thousand tons. The stock-recruitment function predicts that there would be 700 million recruits, while – due to environmental conditions – the actually observed recruitment was 1500 million individuals. If now the simulated SSB at time $t-3$ were at 150 thousand tons, the stock-recruitment function would predict 470 million recruits, but adding the observed residual, we end up with a counterfactual recruitment of 1070 million individuals.

2.4 Estimation of policy effect on profits

The second objective of our study is to estimate the effect of introducing individual quotas on profits. In order to do so, we use two complementary approaches:

First, we follow the same methodological framework as in the projection of the counterfactual biomass. We take a simple Cobb-Douglas approximation of the profit function to the data from 1985 to 1989 and use the estimated coefficients to project how profits

[8] Note that the residual would also pick up changes in recruitment that are due to other policy changes that aimed at protecting juvenile fish but had no impact on harvest (such as the stricter bycatch regulations in the shrimp fishery).

would have evolved if the same relationship held from 1990 onwards (using counterfactual instead of observed biomass values). That is, we fit

$$\ln \pi_{i,t} = f(\alpha_i, p_{i,t}, k_i, B_t) + \varepsilon_{i,t} \qquad \varepsilon_{i,t} \sim iid(0, \sigma^2); \quad t = 1985, ..., 1989. \tag{5}$$

$$\text{where } f(\alpha_i, p_{i,t}, k_i, B_t) = \alpha_i + \sum_l \beta_l \ln p_{l,i,t} + \beta_k \ln k_i + \beta_B \ln B_t$$

and we project:

$$\ln \hat{\pi}_{i,t} = f(\alpha_i, p_{i,t}, k_i, \hat{B}_t) \qquad t = 1985, ..., 1997. \tag{6}$$

Here α_i is an individual effect (at the level of boat-owner combination), $p_{l,i,t}$ is a vector of output input and prices, indexed by l, observed by individual i at time t, k_i is the fixed capital (proxied by the length of the vessel). B_t is the observed stock biomass and $\hat{B}_t$ is the counterfactual biomass.

As discussed above, profits $\pi_{i,t}$ are measured as the total revenue minus variable cost. The output price variables are the price of cod, the price of haddock, and a composite index of all other species. The variable inputs are labor as well as an index of fuel, bait, salt and ice, and a product tax.[9] The price of labor has been derived by dividing the expenses for provisions, wages and share to the crew, and social expenses and pension insurances by the amount of labour per boat, measured in man-years. The amount of fuel and bait used is not given directly but calculated by using an aggregator function (as in Bjørndal and Gordon, 2000 or Nøstbakken, 2006) giving equal weight to vessel length, vessel tonnage, total catch, and days of operation. An important maintained assumption for the structural estimation is of course that these prices are exogenous and that the individual firm adjusts in- and outputs. As the products from the demersal fish species are either a small part of the larger world-market for white fish, or go to the

[9]This product tax is generally levied on output, hence it correlated stronger with the overall scale of operations than with the prices of individual species.

specialized market for dried fish where the end price depends much on the idiosyncratic characteristics of the individual fish and the weather during the drying period, this assumption is likely to hold for the output prices. It also not unreasonable to think that prices of labour and fuel are determined at larger geographical scales and that these, relatively small, boats have indeed no perceivable impact.

Our second way of analyzing the effect of the policy change on profits is to follow a regression-analysis approach: That is, we approximate the profit function over the entire time horizon by a "transcendental logarithmic (translog) function" (Lau, 1978; Squires, 1987) and we include a dummy variable D which is 0 before 1990 and 1 afterwards. That is we fit (7) to the observed data on profitability from 1985 to 1997 ($\tilde{f}$ refers to the translog-function where – for easier notation – we have dropped the individual- and time-subscripts and the indexes l and m run over the different in- and output prices).

$$\ln \pi_{i,t} = \tilde{f}(\alpha_i, p_{i,t}, k_i, B_t; D) + \varepsilon_{i,t} \qquad \varepsilon_{i,t} \sim iid(0, \sigma^2); \quad t = 1985, ..., 1997. \tag{7}$$

$$\begin{aligned} \text{where } \tilde{f}(\alpha, p, k, B) = {} & \alpha + \beta_D D + \sum_l \beta_l \ln p_l + \beta_k \ln k + \beta_B \ln B \\ & + \frac{1}{2}\sum_l \sum_m \beta_{lm} \ln p_l \ln p_m + \sum_l \beta_{lk} \ln p_l \ln k + \frac{1}{2}\beta_{kk}(\ln k)^2 \\ & + \sum_l \beta_{lB} \ln p_l \ln B + \beta_{kB} \ln k \ln B + \frac{1}{2}\beta_{BB}(\ln B)^2 + \sum_l \beta_{Dl} D \ln p_l \end{aligned}$$

A first test of the effect of the policy reform in this methodological framework is to see whether the coefficient β_D for the dummy is significant and positive. However, the move from open-access to an ITQ-like regime will influence profits also indirectly, via the stock biomass. Therefore we project counterfactual profits also here by comparing the observed profit values with a projection of when the dummy variable is set to zero and the counterfactual stock values instead of the observed stock values are used:

$$\ln \hat{\pi}_{i,t} = \tilde{f}(\alpha_i, p_t, k_{i,t}, \hat{B}_t; D = 0) \qquad t = 1985, ..., 1997. \tag{8}$$

In other words, equation (8) gives us an alternative method to estimate how restricted profits would have evolved had the policy not changed and had also the cod-stock developed as in the counterfactual scenario.

For both the estimation of (5) and (7), a Lagrangian multiplier test strongly rejects homogeneity in the residuals and a Hausman test suggests the use of a fixed-effect within estimator. However, as the observed biomass is generally the same for all entities in a given year, there is relatively little variation in this variable to estimate its coefficient precisely. The available variation is further reduced by using an individual fixed effect as there are quite a number of boat-owner combinations that are observed only once (272 out of 668 in the panel spanning the entire time horizon and 124 out of 282 in the short panel from 1985 to 1989).[10] Hence, we have also fitted equation (5) and (7) using a random-effects GLS estimator (where accordingly $\alpha_i \sim \mathcal{N}(0, \sigma_\alpha^2)$). Further details on the regressions are found in Appendix A.3.

2.5 Exploring potential pathways of the policy

To further explore how the policy shift in 1990 affected profitability, we decompose profits and productivity in contributing components of input- and output values. We follow the method developed in Fox et al. (2003) and Dupont et al. (2005) whereby any given observation is compared to the most efficient boat-owner observation. It should be emphasized that this index-number profit decomposition can be rigorously derived from a neoclassical profit-maximization model with a translog-production function as well as it can be motivated without making any behavioral or technological assumptions by the axiomatic approach to index numbers. (The following shortly sketches the method, please consult the two aforementioned papers for details.)

We start by defining the profit-ratio as the restricted profits of an arbitrary firm b,

[10]This limitation of the data is, naturally, also the reason why we fit the simpler Cobb-Douglas function to the restricted panel. A full-fledged translog model with all interaction effects could not be fitted well when using only the short time period of five years.

π^b, relative to the profits of the best-performing firm a:

$$\Gamma^{a,b} \equiv \frac{\pi^b}{\pi^a} \tag{9}$$

A stock-adjusted productivity index can then be defined as a output index $Q^{a,b}$ divided by an input index $K^{a,b}$ (where $stock^i$ refers to the cod biomass in the year that i is observed):

$$R^{a,b} \equiv \left(Q^{a,b}/K^{a,b}\right) \cdot (stock^a/stock^b) \tag{10}$$

The fixed input is taken to be capital k, which is proxied by boat-length. The netput quantity index $Q^{a,b}$ is implicitly defined by $Q^{a,b} = \Gamma^{a,b}/P^{a,b}$ where $P^{a,b} = \Pi_l P_l^{a,b}$, and $P_l^{a,b}$ is a Törnqvist price index for netput l. Let s_l be the profit share of netput l: $s_l = (p_l y_l / \sum p_l y_l)$, where p_l is the price and y_l is the quantity that is employed or produced. The Törnqvist price index is then given by:

$$P_l^{a,b} \equiv \exp\left[\frac{1}{2}\left(s_l^b + s_l^a\right)\ln\left(p_l^b/p_l^a\right)\right] \tag{11}$$

In practice, our decomposition of the profit ratio between observation a and b is:

$$\Gamma^{a,b} = R^{a,b} \cdot CodP^{a,b} \cdot HaddockP^{a,b} \cdot OtherP^{a,b} \cdot F^{a,b} \cdot L^{a,b} \cdot K^{a,b} \tag{12}$$

where *CodP* is the index of output prices for cod and similarly for the prices of haddock and other species. L refers to the variable cost of labor, the index F refers to the variable cost for fuel, bait, etc (see section 2.4 above). Since restricted profits are defined as the return on capital, the implicit price per unit of capital is one and $K^{a,b}$ is simply measured as the ratio of the length of the most profitable boat a to a given boat b. The productivity index $R^{a,b}$ is implicitly defined through equation (12).

3 Results

3.1 Counterfactual simulation of cod stock

Was the increase of the cod stock due to good luck or due to good management? In order to answer this question, we have projected how stock biomass would have developed if the relationship between stock and harvest after 1990 had been the same as before 1990: The black line with solid points in Figure 2 gives the actual observed stock development, while the blue line with open circles shows the counterfactual cod stock.

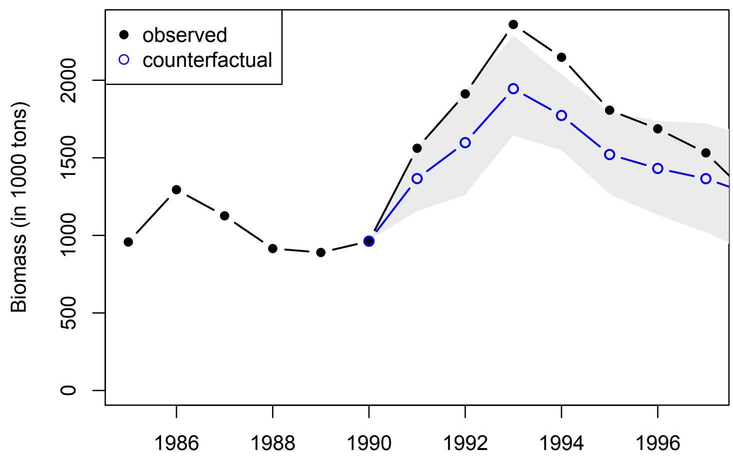

Figure 2: Observed values and counterfactual simulation of cod stock

It is clear that our projection is surrounded by considerable uncertainty. In order to quantify this, we run a thousand simulations where we, for each time step, add a randomly drawn residual for the harvest regression and a random error to the residual of recruitment function. The latter is taken from a normal distribution with a standard deviation that relates to the confidence interval from the 0-group abundances obtained from the joint Norwegian/Russian ecosystem survey (Anon., 2011). From these simulations, we plot the 95% confidence band (visualized by the gray area in Figure 2), showing how the uncertainty compounds as the projection interval increases.

While we do see a positive effect of the policy in the beginning, it appears that the main part of the post 1990 increase in the stock size was independent of the policy change. Three drivers are identified in the literature (see e.g. Godø, 2003; Hjermann et al., 2007): First a recovered capelin stock (the main prey of cod) significantly improved the feeding conditions and consequently reduced cannibalism. Second, warmer temperatures generally benefited the cod which lives on its Northernmost boundary in the Barents Sea. Third, oceanographic conditions were favorable in this period as they predominantly transported cod larvæ into nutrient rich waters. The effect of the policy, to the extent that it is present, seems to have attenuated over time and the observed stock is, for the most part, within the 95% confidence interval of the simulated counterfactual stock.

Hence, we conclude that the improvement in the fisheries management is likely to have had a positive effect on the stock development, but that the fluctuations in the stock are primarily driven by environmental factors.[11] This somewhat ambiguous finding is in line with previous difficulties to establish clear positive ecosystem effects of ITQ management (Branch, 2009; Chu, 2009). It also reflects the recent work of Rouyer et al. (2011), who argue that the qualitative changes of the stock's properties, in particular its age-truncation, has increased the importance of climatic conditions for stock dynamics. Further, a "both...and" answer to the question of good luck or good management is also supported by the study of Kjesbu et al. (2014). Investigating the 2007 harvest-control-rule they find, in their words, "synergies between climate and management".

3.2 Estimation of policy effect on profitability

Did the introduction of individual quotas have a significant positive effect on profits? In order to answer this question, we have first fitted a Cobb-Douglas profit function to

[11] This is at least the case in the period that we have observed. The quota system might have a much stronger effect in less favorable periods, e.g. by preventing depletion.

the data before 1990 and then extrapolated it, using the counterfactual cod stock as a co-variate, to the period after 1990. Figure 3 shows the box-plots of the observed profits (the thick bar in the boxes is the median in a given year). Moreover, we plot the annual mean of the profits with black dots connected by a line. The blue line shows the average values of the counterfactual profits.

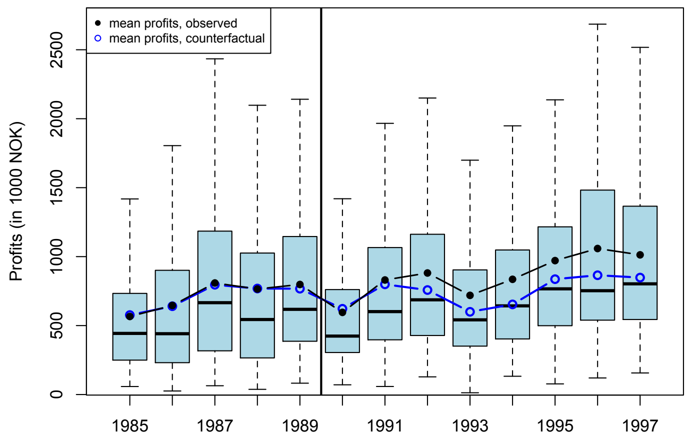

Figure 3: Average of observed profits (black) and average of counterfactual profits (blue); Boxplots of observed restricted profits from 1985 to 1997 in the background)

The average difference between the observed and counterfactual profits per boat is 125 thousand NOK (in 1998 value, with the 95% confidence interval being 71 and 178 thousand NOK). As there are roughly 2000 boats in the population, the total estimated gain for society from this policy over the period 1990 to 1997 amounts to 2 billion NOK. This corresponds to 323 million Euro (in 2013 value) or 432 million US-Dollar (in 2013 value). Moving from open access to individual quotas raised profits on average by 15%.

To complement the approach of extrapolating the simple Cobb-Douglas function, we have also followed a more traditional approach of a regression analysis. The results from fitting the translog profit function (7) to the data are given in Table A-3 (in the Appendix, as the tabulation of the 42 coefficients takes up a lot of space). Importantly, the coefficient on the dummy variable (which is zero before 1990 and takes on a value of 1 afterwards) is positive and significantly different from zero at the 1% level.

In order to gauge the size of the effect we project profits as described in section 2.4, taking into account that the policy had a direct effect as well as an indirect effect via the stock biomass. The results are shown in the lower left panel of Figure 4. (The upper left panel is the extrapolation of the Cobb-Douglas function, i.e. the blue line in Figure 3.) The right panels of Figure 4 additionally juxtapose the observed with the counterfactual development of mean profits when the latter is estimated by random-effects (RE) GLS. Again, the upper panel is the extrapolation of the Cobb-Douglas function and the lower panel is the projection of the translog function. The regression results behind these projections are given in Table A-2 and Table A-3 in the Appendix.

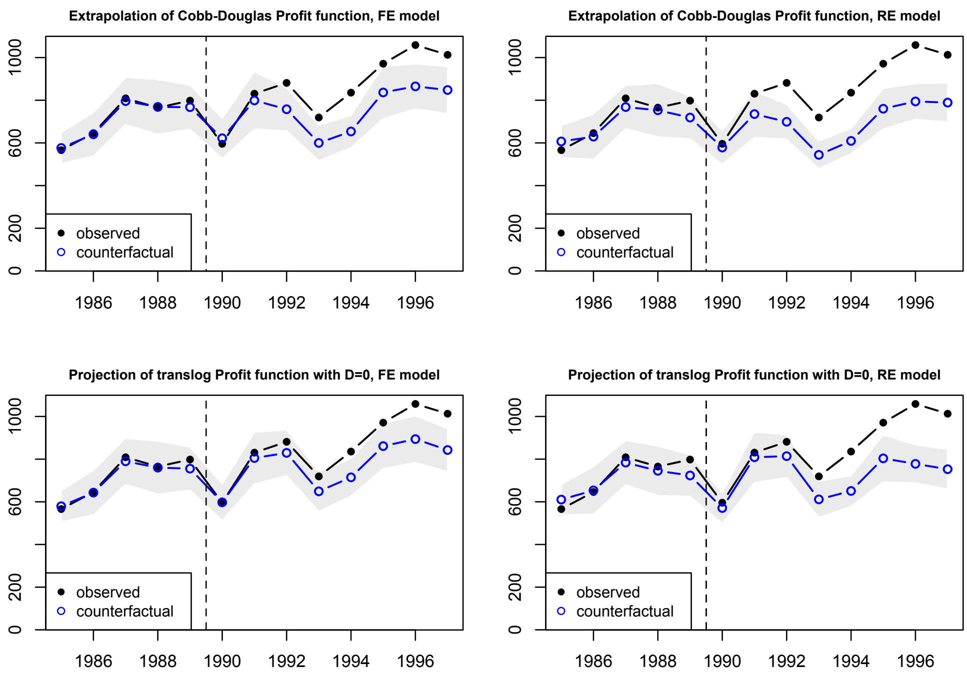

Figure 4: Development of observed average profits (black line, filled circles) and counterfactual average profits (blue line, open circles) under different model specifications.

What is noteworthy is not only the similarity of the plots, but also that the difference between the FE and RE projections of a given method are larger than the differences between the Cobb-Douglas extrapolation and the translog projection method. The estimated average increase in profits (in Thousand NOK) is 125 [C.I. 71; 178] for the Cobb-Douglas FE method, 184 [C.I. 135; 232] for the Cobb-Douglas RE method, 94 [C.I. 41; 147] for the translog FE method, and 147 [C.I. 97; 198] for the translog FE method. All in all, one sees that all methods yield results in the same ballpark, giving us confidence to conclude that introducing individual quotas was indeed worthwhile.

As an additional robustness check, we have investigated the restricted sample of those boat-owner combinations that were observed before and after the policy change. Also here the coefficient for the indicator variable of the policy change is significant and positive. We have further distinguished between those that have stayed in the fishery throughout the time period and those that have left between 1990 and 1997. Not surprisingly, the effect is larger for the boat-owner combinations that do not leave or are being sold (see Table A-4 in Appendix section A.3 for details).

3.3 Exploring potential pathways of the policy

What were the main mechanisms increasing profits after the 1990 policy change? In order to answer this question, we employed the index-number decomposition method sketched in section 2.5. The results are graphically presented in Figure 5. Each panel is ordered from 1985 to 1997 (where the years are separated by vertical dashed lines and the year 1990 is marked with a solid, slightly thicker line). Within each year, the boats are aligned according to increasing vessel length (this can be clearly seen in the last panel).

The most efficient observation was in 1992, from a 23 meter long boat, defining the value of 1 in all panels. For any other observation, a value smaller (greater) than one means that the respective netput contributes by contracting (expanding) the profit ratio (Fox et al., 2003). For example, observation 100 (in year 1985) earns but 12% of

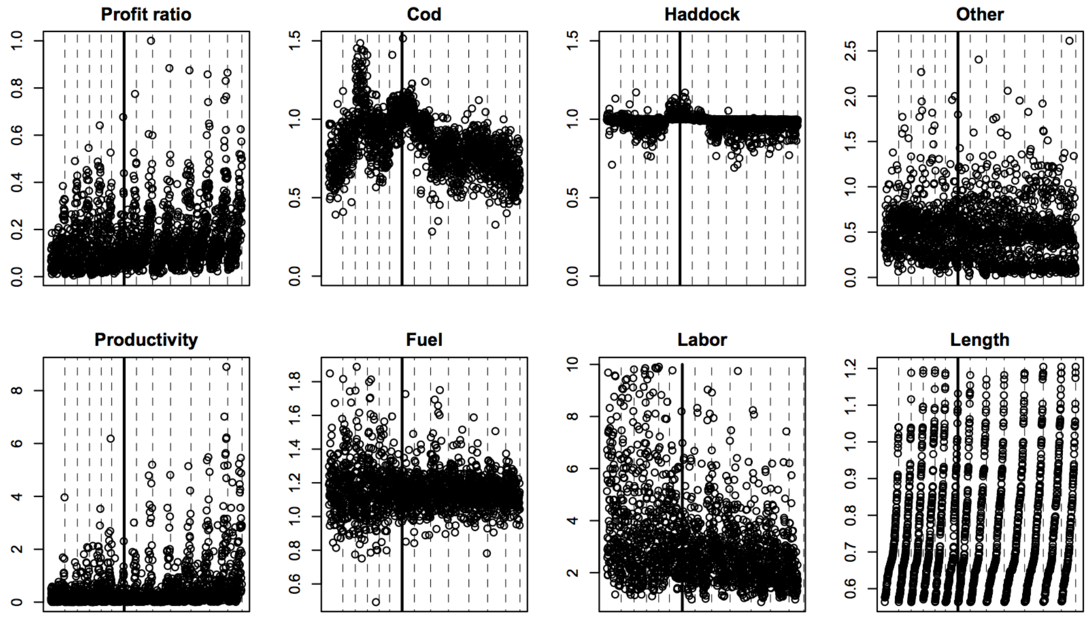

Figure 5: Decomposition of profit ratios

the short-run profits compared to the most efficient observation and it has an output price index of 0.26. This does not mean that output prices were only 26% of the most efficient firm, but that the contribution of the output price to the profit ratio is only 26% of that of the most efficient firm. In contrast, the contribution of wages is 3 times the contribution of the most efficient firm. This is in fact one of the main conclusion we can draw when analyzing the index numbers: The contribution of labor costs has fallen dramatically. Similarly, the contribution of fuel cost has declined (though not as strongly) as property rights have been installed and become more secure in this fishery.

In contrast, the policy change does not seem to have had an effect on output prices. In fact, there is substantial year-to-year variation in the contribution of cod prices (and to a lesser extent in haddock prices), but we do not see that prices play a more and more important role after the introduction of individual quotas. Saithe and other species show no changes in their relative contribution. Hence, there are no signs of an increased importance of unregulated species as the cod fishery becomes regulated (in contrast to the Norwegian pelagic fleet (Asche et al., 2007)). The main part of the action in the Norwegian fishery is apparently on the cost side, as it is predicted by basic theory. This stands in interesting contrast to some North American fisheries (Grafton et al., 2000; Fox et al., 2003; Dupont et al., 2005). The reason is probably that the pre-ITQ regulations in many North American fisheries lead to extremely short harvesting seasons, so that there was a lot to gain from alleviating these adverse market effects. In Norway the availability of fish has, on the one hand, always been determined by the seasonal spawning migration and, on the other hand, the season was never that extremely short so that latent potential gains were simply not present to the same extent.[12]

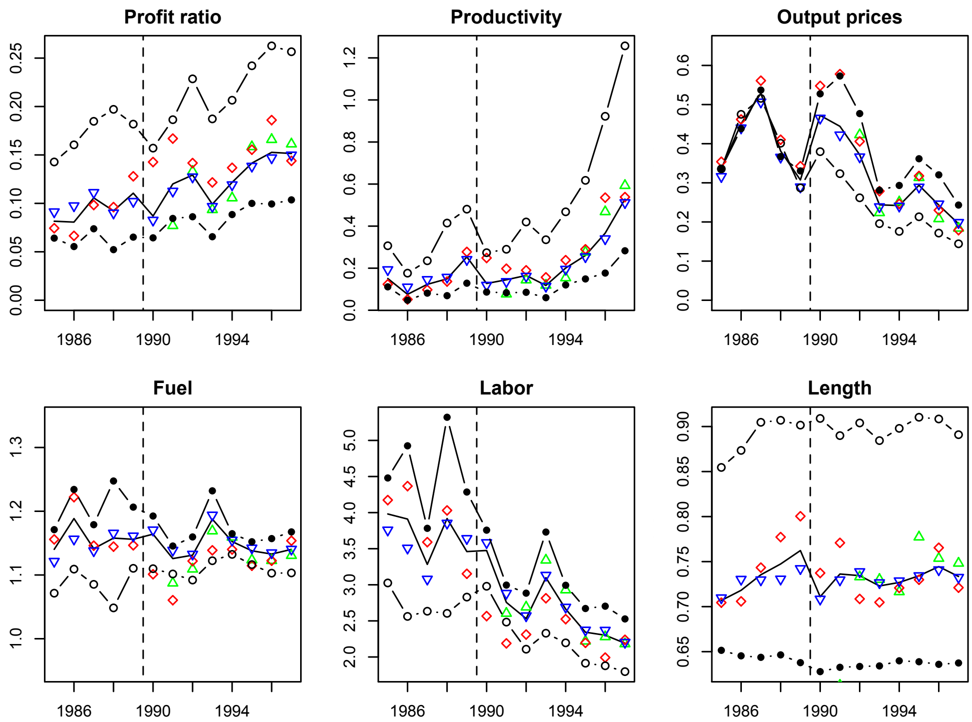

Figure 6: Time-series of mean profit ratio decomposition for various subgroups: Black line is overall mean, open circles = mean of boats larger than avg boat length, filled circles = small boats, green upward triangles = entering boat-owner combinations, blue downward triangles = exiting boat-owner combinations, red diamonds = mean of boat-owner combinations that stay.

The (geometric) means of the index numbers are plotted in Figure 6 and tabulated in

[12] We thank Frank Asche for discussion on this point.

the Appendix, section A.4. Inspecting these time series for different groups of boat-owner combinations yields further insights: While there are large differences in profit ratios and productivity between large and small boats, there are only small differences between the output prices of these boats (there is virtually no difference before 1990). Taking a closer look at the contribution of wages, we see that here the drop has been especially pronounced for the small boats. Similarly, the trend for fuel is declining for small boats, while it is increasing for large boats. Hence, we can see that it were particularly the small boats that have gained from the savings in input costs as the incentives to "race to fish" were abolished (or at least strongly reduced). Contrarily, it were particularly the large boats that experienced strong (and increasing) gains in productivity. Finally, consider the difference between those boats that stay in the fishery (marked by red diamonds), those that leave the fishery (marked by blue downward facing triangles), and those that enter the fishery (marked by green upward facing triangles). As the regressions presented in the Appendix Table A-4 corroborate, the mean profit ratios of those that stay are above the average. There is no systematic difference in terms of length or productivity; the difference between those that leave and those that stay is that the latter benefit from lower fuel- and labor cost.

4 Discussion and Conclusion

In this paper, we have taken structural models very seriously, perhaps too seriously. However, as sketched in the introduction, there are no randomized controlled experiments for large scale socio-economic systems. This frustrates the search for a clean causal estimate of the effect of introducing property rights to resources that were formerly governed by open-access regimes. Instead of giving up, we argue that one should turn to biological and economic modeling to obtain information on how the world might have looked like were it not for the policy change. Taking this interdisciplinary approach, we propose a way to disentangle the effects of policy reform and environmental changes and apply it to the Norwegian coastal cod fishery.

Evidently, it is not possible to test the validity of our predictions from within the model. What we can do is to first point to the validation exercise of the biological model that shows that we are able to reproduce past stock development for the open-access period (see Appendix A.2). Second, we demonstrate the robustness of our results to alternative model specifications (see Figure 4). Although our approach of augmenting the before/after comparison of individuals with help of a bio-economic model does, by its very nature, not adhere to the standards in other fields such as labor- or development economics, we do think that this sort of structural modeling is very fruitful in natural resource economics (see e.g. Smith and Wilen, 2003; Weninger and Waters, 2003).

Our analysis has been silent on one central aspect: Who gains and who loses from this reform (Armstrong and Clark, 1997)? The main challenge is to how to define a "winner" and a "loser": One would need to know much more about the socio-economic circumstances of the fishers, especially about those that have left the fishery. Did they get a golden retirement from selling their boat that now had a quota with good-looking prospects attached to it, or did they become unemployed and had to live of public welfare? Answering these questions is an important task for further research, in particular as the policy change was (and is) a contested political issue. Here, we would like to give a simple and superficial (pre-)view on this question, so to say to round off our analysis of the effects of closing the commons in the Norwegian coastal cod fishery.

Table 3 compares, from the sample of boat-owner combinations that were observed both before and after 1990, those that have experienced an increasing trend in profits with those that have experienced a decreasing trend. There is no big difference between these two subsamples, but looking at the point values of the average statistics, there is some indication that the boats that enjoyed an increase in profits after 1990 are smaller, older, and more specialized in catching cod. That there is correlation between catching more cod and an increasing trend after the introduction of cod quotas is not surprising at all. It also not too surprising that smaller and older boats gain relatively more from the avoidance of a derby fishery.[13] However, it is a little bit surprising in the Norwegian context, because a popular theme in the political debate was that individual quotas would hurt the small independent boat owners from the North.

Table 3: Summary statistics for the samples with increasing or decreasing trend of profitability

	increasing trend			decreasing trend		
Statistic	N	Mean	St. Dev.	N	Mean	St. Dev.
Boat-age	414	23.98	14.27	277	19.75	13.83
Length	414	17.10	3.12	277	17.45	3.19
Man-years	414	4.25	1.46	277	4.58	1.53
Total harvest	414	314.81	358.05	277	329.88	271.75
Share of cod	414	0.46	0.25	277	0.44	0.21
Profits	414	782.38	738.75	277	865.99	568.35

Another aspect that was beyond the scope of this analysis are industry dynamics. Who are those that enter and exit the fishery, what determines whether boat-owners invest in capital or quotas? One major constraint with the current data is that the volume of transactions is very low. Even for the purse seiners in the Norwegian pelagic fishery, which are substantially more capital intensive and where quota trading has occurred much more frequently, the usual suspects of prices, operating costs, capital-, quota-, and fish stocks explain only 10% and 1% of the variation in quota- and physical capital, respectively (Nøstbakken, 2012). Clearly, a better understanding of investment drivers and industry dynamics is very important from a policy perspective as it determines future harvesting possibilities. It is also relevant from a theoretical perspective as it allows to further specify the effects of quota management. Was it indeed the case that the rent generated by better management has been absorbed in the capital values as argued by Hannesson (2013)? This issue will be the theme of future research.

[13] Of course also here, we cannot tell whether we observe the decreases in fuel and labor cost as the main effect because smaller and older boats gain more than larger and faster boats from avoiding a “race to fish”, or whether we observe that smaller and older boats gain more because the main effect of avoiding a “race to fish” is to save fuel and labor.

For this analysis, it is important to note that abstracting from the entry/exit dynamics means that our estimates are a lower bound of the efficiency gains. The counterfactual profits without the regulatory shift would have been even lower when the increased cod-stock invited more boats to participate in the fishery, thereby dissipating rents to a larger extent (we based our projections of counterfactual profits on the the observed sample).

Conclusion

Property rights solutions to the "tragedy of the commons" problem in many fisheries have been proposed in theory for more than fifty years and they have been used in practice for more than thirty years. We add to the cross-sectional evidence and the existing before-after comparisons by proposing a method to correctly control for changes in the resource base. We construct an age-structured bio-economic model to isolate the exogenous environmental influences from the endogenous effect of the policy change in the Norwegian coastal cod fishery in 1989/1990. Moreover, we present a detailed data-set over 13 years (5 years pre intervention and 8 years post-intervention) with information on vessel and owner characteristics. Augmenting this quasi-experimental setting with our modeling efforts, we find that the change from open-access to individual quotas has lead to an increase in the average profits of about 15% by 125 thousand Norwegian Kroner per boat. The main driver of these gains were cost savings, as predicted by basic theory. In contrast to the findings for many North-American fisheries, we do not find that output prices have played a role in this. Also the cod stock did not significantly affect profits, while we do find a positive effect of the management change. However, this effect is rather small, the main part of the observed increases in the resource base appears to have been due to favorable environmental conditions.

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Appendix

A.1 The stock-harvest relationship in the biomass simulation model

Table A-1 gives the parameter values of the model we employed in the simulation (Model 1) as well as several simple alternative models that we have considered (Model 3-4). Interestingly, the average price of cod $\hat{p}_t$ (instrumented by the price of the previous year*) did not turn out to be significant. Hence we use the simplest model: It has the best overall fit and soundly passes the Durbin-Watson test (dw-statistic of 1.98).

Table A-1: Regression results of harvest by total biomass

	Model 1	Model 2	Model 3	Model 4
H_t	$\alpha + \beta B_t$	$\alpha + \beta \ln(B_t)$	$\alpha + \beta B_t + \gamma B_t^2$	$\alpha + \beta B_t + \gamma \hat{p}_t$
(Intercept)	-23.98	-7756.39^{***}	-116.59	-243.69
	(54.70)	(753.61)	(192.46)	(231.10)
B_t	0.43^{***}		0.57^{*}	0.46^{***}
	(0.04)		(0.29)	(0.05)
$\ln(B_t)$		592.26^{***}		
		(53.53)		
B_t^2			$-4.75 \cdot 10^{-11}$	
			$9.45 \cdot 10^{-11}$	
price $\hat{p}_t$				23.79
				(24.31)
adj. R^2	0.88	0.86	0.87	0.88
N	20	20	20	20

Robust standard errors in parentheses, $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$

*The first-stage model $p_t = \alpha + \beta p_{t-1} + \epsilon$ has an R^2 of 0.69 with coefficients $\alpha = 2.34(1.02)$ and $\beta = 0.71(0.13)$. The coefficient for the lagged price is significant at the 1% level.

The parameters are estimated on ICES-data[†] for the time from 1970 to 1989. This strikes a balance between obtaining sufficiently many observations and not extending the time series too far into the past when conditions may have been different, due to, for example, technological change. A possible concern could be that we use the harvest data from all boats, instead of explaining only the harvest from the Norwegian coastal vessels. There are two reasons for doing so. First, while the harvest from these boats account for up to 70% of Norwegian harvest and about 32% of total harvest, it is important to predict the entire harvest in order to simulate the development of the cod stock. Second, there are clear signs that a more general change in the management of this fishery has occurred at 1990. This is visualized by Figure A-1. It shows a scatterplot of biomass against harvest, where the blue points and line refer to the relationship before 1990 and the red points and line to the relationship after 1990. The black solid line is the regression-line from the pooled sample. A Chow test clearly rejects that there is a common relationship between stock and harvest before and after 1990: The test statistics is 7.31, which is larger than the relevant value at 1% significance $F_{2;36;0.99} = 5.248$.

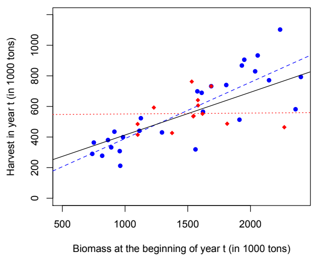

Figure A-1: A different stock-harvest relationship before and after 1990

A.2 Validation of biomass simulation model

Figure A-2 shows the development of the cod stock from 1970 to 1990. The purple line plots the result from our simulation model (equation (1) to (4) in section 2.3) when we use the actual observed harvest and recruitment values as inputs. Thus it shows the difference between our reconstruction technique and the virtual-population analysis from ICES. The red line shows the results from the simulation when we use the harvest values estimated according to equation (1)

[†]Table 3.24 on page 180 in ICES (2012).

but still use the observed recruitment values. The blue line finally incorporates both estimated harvest and a projection of the recruitment values.[‡] Although the error does increase progressively, it is comforting to see that our model succeeds in replicating the overall trend of the stock development in the seventies and eighties. Moreover, it is almost always within the 95% confidence interval band of a simple first-order auto-regressive process.

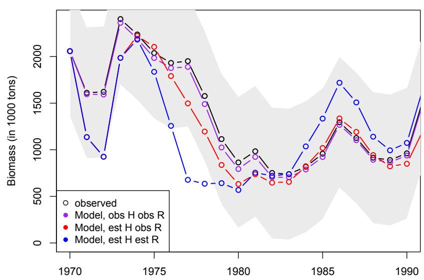

Figure A-2: Observed and simulated stock biomass values 1970-1990

A.3 Regression results for profit function

The results from estimating equation (5) and equation (7) in section 2.4 of the main text are presented in Table A-2 for the Cobb-Douglas function and in Table A-3 for the translog function. In both tables, column 2 refers to the coefficients from the random-effects model and the coefficients from the fixed-effect model are shown in column 4. As discussed in the main text, we have also estimated a random-effects model as the estimate of the biomass effect was deemed more reliable when using this method, in spite of the fact that a Hausman test suggested the use of a fixed-effect model (with a chi-squared value of 18.81 (7 df) and 77.4 (37 df) for the Cobb-Douglas and the translog function, respectively).[§]

[‡]Since recruitment depends on the spawning stock three years ago, the first three years of the red and blue simulation are identical.

[§]Upon inspection of Table A-2 and Table A-3, one sees that the coefficient on biomass is negative (though it is not significantly different from zero in the fixed-effect regression of the translog profit function.) This may seem strange at first sight: Although total stock biomass is only a very rough proxy for the harvesting opportunities of an individual boat, more biomass should give better profits, all else equal. We control for price effects, but there could be some other interaction effect which we fail to pick up. Two candidates stand out: First, a negative crowding effect which is likely to be larger the larger the spawning migration is, as more boats will then be attracted to the area. Second, the total quotas after 1990 were divided according to the so-called "trawl-ladder" that gave the coastal boats a larger

Table A-2: Regression Results for Cobb-Douglas Profit Function t=1985:1989

	Dependent variable: logVP			
	Random-effect GLS		Fixed-effect within	
cp	0.174***	(0.0569)	0.117*	(0.0633)
hp	0.00377	(0.0404)	0.0570	(0.0514)
op	0.0112	(0.0316)	0.0426	(0.0387)
lab	0.783***	(0.0515)	0.819***	(0.0792)
fue	0.168***	(0.0535)	0.0722	(0.0818)
len	0.570***	(0.119)	1.225*	(0.741)
bio	-0.319***	(0.0873)	-0.271***	(0.104)
_cons	0.526	(0.601)	-1.429	(2.251)
N (n)	578 (282)		578 (282)	
R^2	0.63		0.63	

Standard errors in parentheses
(clustered at the level of boat-owner combination)
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A-4 shows the results from estimating a Cobb-Douglas type of profit function for the restricted sample of those boat-owner combinations that are observed both before and after the policy change. Column 2 reports the coefficients when we look at all boats, column 3 reports the coefficients when we look at those boats that stay throughout the sample period, and the last column reports the coefficients when we look at those boats that leave in the time between 1990 and 1997.[¶]

A.4 Tabulation of Mean values of profit decomposition

Tables A-5 to A-10 give the annual (geometric) means of the index numbers as well as the constituting numbers of observations and the arithmetic mean of the variable profit. The time series of these average values are plotted in Figure 6 in the main text.

relative share of the quota the smaller the cod stock.

[¶]We restrict ourselves to estimate the first order effects as we have only very few observations, in particular for those boats that stayed. There are in fact only 6 different groups in this category, so that the we refrain from interpreting the significance of the coefficients. For the other two regressions however, one can see that the effect of the policy is significant. Not surprisingly, the effect is larger for those boat-owner combinations that stayed in the fishery than for those that have left.

Table A-3: Regression Results for Translog Profit Function

	Dependent variable: logVP			
	Random-effect GLS		Fixed-effect OLS	
policyD	2.592***	(0.560)	1.709***	(0.643)
cp	-1.032	(2.219)	-1.839	(2.317)
hp	-2.558	(1.828)	-0.264	(1.872)
op	-0.435	(0.528)	-0.526	(0.622)
lab	-2.525**	(1.264)	-1.774	(1.303)
fue	2.590**	(1.274)	1.756	(1.391)
len	-3.000	(1.953)	1.542	(5.451)
bio	-3.746*	(1.957)	-2.360	(2.151)
cp_cp	-0.240	(0.356)	-0.238	(0.421)
cp_hp	-0.238	(0.206)	-0.160	(0.251)
cp_op	0.147*	(0.0774)	0.146	(0.0919)
cp_lab	0.199	(0.125)	0.226	(0.145)
cp_fue	-0.249*	(0.143)	-0.202	(0.165)
cp_len	0.0406	(0.278)	-0.314	(0.330)
cp_bio	0.265	(0.328)	0.430	(0.345)
hp_hp	0.00645	(0.144)	-0.0564	(0.142)
hp_op	-0.0407	(0.0563)	-0.0202	(0.0627)
hp_lab	-0.0326	(0.0900)	-0.00801	(0.0903)
hp_fue	0.0138	(0.106)	-0.0787	(0.114)
hp_len	0.0129	(0.195)	0.230	(0.207)
hp_bio	0.469*	(0.269)	0.0810	(0.272)
op_op	0.0179	(0.0339)	-0.0245	(0.0371)
op_lab	-0.0854*	(0.0509)	-0.0253	(0.0591)
op_fue	0.0717	(0.0490)	0.0508	(0.0595)
op_len	-0.00578	(0.0994)	-0.0863	(0.121)
op_bio	0.0492	(0.0699)	0.0643	(0.0733)
lab_lab	-0.421***	(0.125)	-0.395**	(0.159)
lab_fue	0.299**	(0.117)	0.264*	(0.151)
lab_len	0.497***	(0.178)	0.551**	(0.234)
lab_bio	0.399**	(0.177)	0.248	(0.190)
fue_fue	-0.212*	(0.123)	-0.167	(0.156)
fue_len	-0.620***	(0.181)	-0.479*	(0.252)
fue_bio	-0.148	(0.168)	-0.0886	(0.181)
len_bio	0.0245	(0.144)	0.0502	(0.171)
len_len	1.114	(0.728)	-0.863	(2.033)
bio_bio	0.0104	(0.208)	-0.0497	(0.225)
D_cp	-0.129	(0.212)	-0.186	(0.221)
D_hp	-0.430**	(0.186)	-0.146	(0.195)
D_op	-0.0154	(0.0562)	-0.0637	(0.0636)
D_lab	-0.232**	(0.113)	-0.138	(0.124)
D_fue	0.0475	(0.104)	0.0259	(0.117)
_cons	26.05***	(9.547)	13.93	(12.52)
N (n)	1818 (668)		1818 (668)	
R^2	0.60		0.61	

Standard errors in parentheses
(clustered at the level of boat-owner combination)
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A-4: Fixed-effect within regression Results for Cobb-Douglas Profit Function, subsample of boats that are observed before and after policy change

	Dependent variable: logVP					
	All boats		Boats that stayed		Boats that left	
policyD	0.118***	(0.0448)	0.304	(0.191)	0.111**	(0.0470)
cp	0.125**	(0.0585)	0.314	(0.202)	0.128**	(0.0615)
hp	-0.0115	(0.0401)	-0.0457	(0.0230)	-0.0166	(0.0444)
op	-0.00170	(0.0405)	-0.0344	(0.0783)	0.00601	(0.0427)
lab	0.743***	(0.0548)	0.924***	(0.144)	0.741***	(0.0579)
fue	0.203***	(0.0651)	-0.0486	(0.0895)	0.209***	(0.0694)
len	0.345	(0.493)	-0.262	(0.407)	0.324	(0.716)
bio	-0.152***	(0.0574)	-0.284	(0.190)	-0.145**	(0.0597)
_cons	0.259	(1.439)	2.895	(1.653)	0.240	(2.029)
N (n)	691 (123)		38 (6)		653 (117)	
R^2	0.63		0.74		0.63	

Standard errors in parentheses
(clustered at the level of boat-owner combination)
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A-5: Overall mean values of profit decomposition, by year

year	No.	Profit	Γ	R	OP	F	L	K
1985	133	566	0.08	0.15	0.34	1.14	3.98	0.71
1986	119	646	0.08	0.08	0.45	1.19	3.91	0.72
1987	115	809	0.11	0.12	0.53	1.14	3.28	0.74
1988	112	765	0.09	0.15	0.38	1.16	3.92	0.75
1989	99	798	0.11	0.25	0.31	1.16	3.46	0.76
1990	119	596	0.09	0.13	0.47	1.16	3.48	0.71
1991	117	831	0.12	0.14	0.44	1.13	2.76	0.74
1992	154	881	0.13	0.17	0.37	1.13	2.53	0.73
1993	170	719	0.10	0.12	0.24	1.19	3.10	0.72
1994	194	836	0.12	0.20	0.24	1.15	2.66	0.73
1995	178	971	0.14	0.26	0.29	1.14	2.34	0.73
1996	172	1059	0.15	0.37	0.24	1.13	2.30	0.74
1997	136	1013	0.15	0.53	0.20	1.14	2.19	0.73

Table A-6: Mean values of newly entering boats profit decomposition, by year

year	No.	Profit	Γ	R	OP	F	L	K
1991	1	414	0.08	0.08	0.71	1.09	2.60	0.61
1992	9	1001	0.13	0.14	0.42	1.11	2.69	0.73
1993	24	795	0.09	0.12	0.22	1.17	3.34	0.73
1994	31	711	0.11	0.15	0.25	1.16	2.93	0.72
1995	42	1150	0.16	0.28	0.31	1.12	2.22	0.78
1996	46	1105	0.17	0.47	0.21	1.12	2.28	0.75
1997	51	1030	0.16	0.59	0.18	1.13	2.18	0.75

Table A-7: Mean values of eventually exiting boats profit decomposition, by year

year	No.	Profit	Γ	R	OP	F	L	K
1985	60	609	0.09	0.19	0.32	1.12	3.76	0.71
1986	60	701	0.10	0.11	0.44	1.16	3.51	0.73
1987	67	820	0.11	0.15	0.51	1.14	3.08	0.73
1988	71	723	0.09	0.16	0.37	1.17	3.85	0.73
1989	64	741	0.10	0.24	0.29	1.16	3.64	0.74
1990	108	557	0.08	0.12	0.47	1.17	3.58	0.71
1991	98	766	0.11	0.14	0.42	1.14	2.88	0.73
1992	132	858	0.13	0.16	0.37	1.13	2.57	0.74
1993	146	701	0.10	0.11	0.24	1.19	3.13	0.73
1994	157	821	0.12	0.19	0.24	1.15	2.69	0.73
1995	148	952	0.14	0.25	0.29	1.14	2.37	0.73
1996	142	1027	0.15	0.34	0.25	1.13	2.37	0.74
1997	108	1016	0.15	0.51	0.20	1.14	2.20	0.73

Table A-8: Mean values of boats that stay profit decomposition, by year

year	No.	Profit	Γ	R	OP	F	L	K
1985	73	531	0.07	0.12	0.35	1.16	4.17	0.70
1986	59	590	0.07	0.05	0.46	1.22	4.37	0.71
1987	48	793	0.10	0.10	0.56	1.15	3.59	0.74
1988	41	837	0.10	0.14	0.41	1.14	4.03	0.78
1989	35	902	0.13	0.28	0.34	1.15	3.15	0.80
1990	11	979	0.14	0.25	0.55	1.10	2.57	0.74
1991	19	1164	0.17	0.20	0.58	1.06	2.19	0.77
1992	22	1020	0.14	0.19	0.41	1.12	2.31	0.71
1993	23	858	0.12	0.16	0.28	1.14	2.81	0.70
1994	33	933	0.14	0.24	0.25	1.14	2.52	0.72
1995	26	1061	0.16	0.29	0.32	1.11	2.20	0.73
1996	25	1255	0.19	0.54	0.23	1.12	1.99	0.77
1997	20	907	0.14	0.54	0.18	1.15	2.24	0.72

Table A-9: Mean values of small boats' ($\leq$17.2 m) profit decomposition

year	No.	Profit	Γ	R	OP	F	L	K
1985	93	416	0.06	0.11	0.34	1.17	4.48	0.65
1986	77	387	0.06	0.05	0.44	1.23	4.93	0.65
1987	70	547	0.07	0.08	0.54	1.18	3.78	0.64
1988	64	377	0.05	0.07	0.37	1.25	5.32	0.65
1989	48	444	0.07	0.13	0.33	1.21	4.29	0.64
1990	79	397	0.06	0.09	0.53	1.19	3.76	0.63
1991	65	517	0.08	0.08	0.57	1.15	3.00	0.63
1992	90	522	0.09	0.09	0.48	1.16	2.88	0.63
1993	103	426	0.07	0.06	0.28	1.23	3.73	0.63
1994	121	550	0.09	0.12	0.29	1.16	2.99	0.64
1995	108	619	0.10	0.15	0.36	1.15	2.67	0.64
1996	96	608	0.10	0.18	0.32	1.16	2.70	0.64
1997	79	636	0.10	0.28	0.24	1.17	2.53	0.64

Table A-10: Mean values of large boats (> 17.2 m) profit decomposition, by year

year	No.	Profit	Γ	R	OP	F	L	K
1985	40	915	0.14	0.31	0.34	1.07	3.03	0.85
1986	42	1121	0.16	0.18	0.47	1.11	2.56	0.87
1987	45	1216	0.18	0.24	0.52	1.09	2.63	0.90
1988	48	1283	0.20	0.41	0.40	1.05	2.60	0.91
1989	51	1132	0.18	0.48	0.29	1.11	2.83	0.90
1990	40	989	0.16	0.27	0.38	1.11	2.98	0.91
1991	52	1222	0.19	0.29	0.32	1.10	2.48	0.89
1992	64	1387	0.23	0.42	0.26	1.09	2.11	0.90
1993	67	1170	0.19	0.34	0.20	1.12	2.33	0.88
1994	73	1309	0.21	0.47	0.18	1.13	2.20	0.90
1995	70	1514	0.24	0.62	0.21	1.12	1.91	0.91
1996	76	1628	0.26	0.92	0.17	1.10	1.88	0.91
1997	57	1535	0.26	1.26	0.14	1.10	1.80	0.89