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Technological change and the Tragedy of the Commons: The Lofoten Fishery over Hundred and Thirty Years

BY
RÖGNVALDUR HANNESSON, KJELL G. SALVANES, AND **DALE SQUIRES**

Norges Handelshøyskole

NORWEGIAN SCHOOL OF ECONOMICS AND BUSINESS ADMINISTRATION

Technological change and the Tragedy of the Commons: The Lofoten Fishery over Hundred and Thirty Years *

by

Rögnvaldur Hannesson
Department of Economics
The Norwegian School of Economics and Business Administration
rognvaldur.hannesson@nhh.no

Kjell G. Salvanes
Department of Economics
The Norwegian School of Economics and Statistics Norway, Center for the Economics of Education (CEP) and IZA
kjell.salvanes@nhh.no

Dale Squires
Southwest Fisheries Center
La Jolla, California
Dale.Squires@noaa.gov

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Abstract

Why did the Lofoten cod fishery in Norway – a fishery on one of the world's richest spawning grounds - remain less productive than alternative industries until the mid-1960s, despite important modernization of the fleet and fishing gear, improvements in technology and institutional change? We analyze the effect of technological change on labor and total factor productivity as well as exit and entry patterns using detailed data for 130 years. Our findings support the important role of natural resources in productivity and improvements in welfare in natural resource-based industries. The total factor productivity has risen faster than labor productivity in the fishery, indicating that the considerable technological progress in this industry has to some extent been neutralized by the decline in the fish stock. Open access to the fish resource most probably led to this situation.

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1. Introduction

The received wisdom from economics is that new knowledge and technological change is the only source of growth and improved welfare. How does this play out in industries based on common natural resources? The ongoing discussion about improvements in fishing technology threatening fish stocks indicates that the fruits of technological progress might not materialize in such industries.

Our point of departure is the puzzle raised by the low productivity of a resource based industry over 130 years; the Lofoten cod fishery. This fishery, taking place on one of the world's most productive spawning grounds, had several major occurrences of technological change over the last 130 years, and yet labor productivity remained low for a long time, lagging behind productivity development in agriculture and manufacturing over most of the period.[1] How could this be?

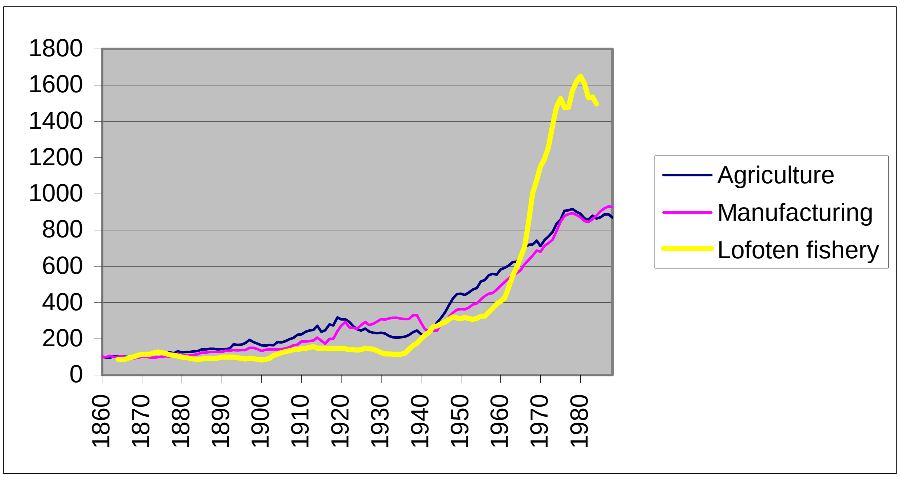


Figure 1: Indices of wages in agriculture and manufacturing, and 9-years moving average of revenues per fisherman.

Figure 1 shows the development of wages in agriculture and manufacturing, as well as the value of the catch per fisherman (9-years moving average). Except for two brief periods (around 1870 and in the 1940s), revenues per fisherman lagged behind wages in agriculture and manufacturing until the mid-1960s, when they took a big leap

[1] We do not have absolute values for productivity in agriculture and industry, only indices. Hence, what we can state unambiguously is that productivity grew more slowly in the Lofoten fishery than in the two other industries we compare with.

forward. Comparing the 1970s and 80s with the 1860s, fishermen did better than keep pace with agriculture and manufacturing, even allowing for some decline in their share of revenues. This was, however, no less due to a rise in price than a rise in catch volume per fisherman (cf. Figure 5 below).

Our main strategy for analyzing the effect of technological and institutional change on the development of productivity in the Lofoten fishery is to focus on the interaction between technological and institutional change in this fishery over 130 years and the natural resource on which it was based. The theory of open access natural resources tells us that they will be overexploited and that labor productivity of the associated industries will be on par with comparable occupations. It also tells us that people will flock into such industries as occupations of last resort if opportunities in the labor market dry up, a process that in the end is likely to be self-defeating and to make a negligible and possibly negative contribution to the total wealth of the economy. We will analyze this issue in the Lofoten fishery by estimating exit and entry rates combined with productivity measures of the fishery.

Even if an open access resource industry appears stagnant in terms of productivity, technology could still be progressing at a rate comparable to other industries, with its fruits rotting away as it were through excessive exploitation. To examine this we will calculate total factor productivity, with the fish stock as a factor of production in addition to labor and boats. This concept is analogous to total factor productivity in other industries with one exception; high total factor productivity in the fishery does not necessarily make anyone better off. Total factor productivity might grow in the fishery, and yet the total production of fish might decline for any given input of factors under human control, due to a declining fish stock. In an ordinary manufacturing industry, rising total factor productivity is good news because production can be maintained despite less use of labor and capital, making it possible to share the value produced among fewer people working and provide a higher return to the owners of capital. In addition the labor released and the capital no longer needed could be used for other purposes, making the whole economy better off. But a decline of fish stocks has no such effects. A declining fish stock does not mean that more fish become available for some purpose other than fishing; a declining fish stock is likely to put an upward pressure on the cost per unit of fish caught and will ultimately reduce the surplus growth of the stock, which sets the limits for sustainable fishing. Growth in total factor productivity in the fishery while fish stocks decline would indicate that the fishing technology is progressing well, but it would not necessarily result in larger or cheaper fish catches. Hence, taking the role of fish stocks for productivity into account could explain what the technological development in the industry really is, whether or not it is comparable to other industries, and why it might be that technological progress in the fishery would not translate into larger fish catches and higher wages for fishermen.

The Lofoten fishery has a long history. It is mentioned in Egil's Saga, which deals with events that took place in the 800s AD. Later, dried fish (stockfish) from Lofoten was a major item of trade for the Hanseatic League and the reason for their trading post in Bergen, which lasted for hundreds of years. It was an important source of income—or a gamble to bet on—even for people from distant parts of Norway and still attracts fishermen from afar. For hundreds of years it was by far the most important fishery in Norway and indeed one of the most important sectors of the economy, employing as late as in 1920 about 20,000 men stating fishing as their main occupation, compared to 90,000 farmers (Norwegian census, 1920). The fishery exploits the annual spawning migration of the Northeast Arctic cod, which in winter comes from the Barents Sea and the Norwegian Sea towards the Norwegian coast to spawn, mainly around the Lofoten islands. The fishery is seasonal, beginning in late January and ending in late April.

In the period analyzed in this paper, several important technological changes took place. Up to about 1880 the fishing fleet consisted mainly of small open boats using hand line, long line and gill nets. Most boats were less than 20 feet long and employed on average six men. From 1880 until about 1905 decked boats took over and sails were introduced¸ the boats became larger, but they still employed about the same number of men. From 1905 until 1920 the fleet was motorized and the boats became larger still. So, by 1920, the Lofoten fishery had a relatively modern fishing fleet where about 40 percent were decked boats, the majority of these with an engine. About half of these boats were less than 40 feet long, while the open boats were mostly under 30 feet (Brandal, 1982). A major institutional change took place in the 1930s when the first hand sale of cod was organized into a monopoly owned by the fishermen. From the early to mid-1950s onwards there was a major change in the quality of the gear when monofiber nets were introduced.[2] In the 1950s purse seine was used on a large scale and then outlawed. In 1959 Danish seine was introduced. From the 1970s increasingly sophisticated jigging machines for hand lines came into use.

This paper exploits data series which for some variables extend back to 1860. From that time on we have information on aggregate catches and the number of fishermen and boats participating in the fishery. This makes it possible to track the development in labor productivity (or boat productivity) over almost 130 years. Labor productivity is of direct relevance for the wages the industry is able to pay. In the Lofoten fishery, as in many other fisheries, labor is not paid a going wage but a share of the catch value, and unless the share parameter is changed there is a direct relationship between labor productivity and what the fishermen are paid. But even with a market-determined, parametric wage, the fishery's ability to compete with other industries for labor would for obvious reasons be closely related to the productivity of labor.

The paper unfolds as follows. In the next two sections we provide a description of the data and the industry, including descriptive statistics of labor productivity, entry into the industry, the stages of technological change seen in the industry, as well as development of prices and resource abundance. In Section 4 we conduct an extensive analysis of total factor productivity and technological change, taking the fish resource into account within a formal framework. The last section concludes.

2. Data

Since 1859, the year the Lofoten Law of 1857 took effect, a report on the Lofoten fishery has been published annually. These reports contain much information on the fishery and events related to it.[3] Up to the 1930s the information became increasingly detailed. There are records of how many fishermen and boats participated in the fishery, from 1875 broken down on the gear types used, how much fish they caught, on byproducts such as fish liver, on prices of fish and byproducts, the weather, the number of ships coming to

[2] See Brandal (1981, 1982), Johansen (1999), Mathiesen (1981), Martinussen (2006), and Gerhardsen (1946), for more details of the development of the fishery.

[3] Since 1906 these reports have been published by the Directorate of Fisheries (*Fiskeridirektoratet*), but prior to that by its forerunner (*Norges Fiskeristyrelse*) and the Department of the Interior (*Departementet for det Indre*). All the reports are available electronically from the Institute of Marine Research, Bergen.

Lofoten to buy fish, and much else.[4] After the 1930s the degree of detail in the reports declined gradually, and as of the early years of this century they are just a six page summary with a few graphs and tables, whereas in the 1930s they would run to over a hundred pages. This poses certain problems in getting long, consistent time series of variables.

The data on catches and participation in the fishery have been collected from these annual reports. The participation is based on a census of fishermen and boats at a certain date about half way through the fishing season when the fishery is close to its peak.[5] Participation varies throughout the season, increasing gradually up to a peak and then falling off towards the end. It is highly likely that people left the fishery early if the fishery was not going well, and their decision to begin fishing, or whether to participate at all, is likely to have been influenced by news about how well the fishery was going. After the telegraph and, later, telephone came on the scene the fishermen had access to up-to-date news about this. The participation measures thus are imperfect in that they say nothing about the intensity of participation; clearly the fishing effort by a thousand boats over four weeks is not the same as that of eight hundred over six weeks; in fact the latter would be greater, all else equal.

The Lofoten reports contain no data on how much capital was invested in the boats, and neither do they specify the size or other physical characteristics of the boats that might be used as proxies for the capital investment. From other sources we know, however, that even if most boats were small there were considerable differences in size and equipment. Beginning in 1936, cost and earnings studies of the Lofoten fishery were carried out until the 1960s, when such studies were extended to the entire Norwegian fishing fleet. These studies reported the size distribution of the boats participating in the fishery. Over this 30-year period this did not change a great deal; the range was wide,

[4] From 1879 there are detailed tables on the diseases treated by the resident doctors during the fishing season, from which we can find, among other things, how many persons were treated for syphilis (the maximum was 14 in 1895, and the last case was recorded in 1952) and how many teeth were pulled (a maximum of 1346 in 1935). We can also find how many tradesmen and other professionals of various kinds traveled to Lofoten during the fishing season to offer their services. One such was quacksalvers, of whom there was a maximum of four in 1898, but none in some years, and they dropped out entirely after 1935.

[5] Before 1918 this was March 16, but March 22 from that year on.

from less than 20 to over 80 feet length, but most boats were between 20 and 50 feet.[6] Later on we will refer to some of the results from these investigations.

The data on the fish stock stretch back to 1900 and were obtained from the Institute of Marine Research in Bergen. These data are based on stock assessment models, which follow the age composition of the stock through time. Even if these methods are known to have their limits in providing up-to-date assessments of the stock, their accuracy for any given year improves as time goes by and more becomes known about the life history of the different year classes of fish. The data on the stock provide figures for the mature part (which is exploited by the Lofoten fishery) separately and are expressed in weight units. The fish mature at an age of six to seven years, and the spawning stock consists of several year classes, the oldest fish being over 10 years. The stock data for 1900-1912 were estimated using the catch per fisherman.[7] While these data undoubtedly are less than perfect, they certainly are the best ones available. There is reason to expect the more recent data to be more accurate than earlier ones, due to improvements in stock assessment methodology.

3. The Lofoten Fishery: Background and description

3.1 Major developments

Traditionally the Lofoten fishery was pursued with hand lines, each fisherman holding a line with a sinker and a baited hook. In the 1700s new types of fishing gear came into use; gill nets and long lines left lying in the water overnight. Originally there was much opposition to the novel gears from those who used the traditional hand line. A petition was sent to the King in Copenhagen (Norway was at that time under the King of Denmark), begging for these new gear types to be banned. The King was apparently sympathetic to the fishermen's arguments, and in 1744 he sent a letter to the governor of Nordland County, admonishing him to allow only the use of hand lines, which "since time immemorial have been used in the fishery by rich and poor alike"[8] Over time the

[6] These reports were published in the series *Årsberetning vedkommende Norges Fiskerier*, and later in the journal "Fiskets Gang," published by the Directorate of Fisheries (*Fiskeridirektoratet*), Bergen.
[7] For details on the data, see Hylen (2002).
[8] The King's letter refers to some of the arguments advanced against the new gear types. They were said to be too expensive for the common man to acquire and to cause much distress to Our Lord through encouraging the use of foul language and fights. The letter is quoted in Steen (1930), p. 30.

once so novel gear types became traditional and are now referred to as such, but opposition to new types of fishing gear or new technology has been a recurrent theme in the Lofoten fishery, and so have petitions to ban their use. Sometimes they have met with success, such as for seines in the latter part of the 19th century and purse seine in the 1950s, while at other times the new technology has carried the day, such as engines in the early 1900s and Danish seine after 1959.

In 1816, after the restoration of the Norwegian state, albeit in a union with Sweden, a law on the Lofoten fishery was enacted. This law went a long way towards establishing what lately has come to be known as territorial use rights (Christy, 1983). The fishing banks were divided into areas belonging to the nearest fishing base on land and further subdivided into fields where the boats were allowed to fish. The allocation of the fishing fields was in the hands of local governing committees, usually headed by the owner of the onshore facilities which the fishermen had to rent for accommodation and for drying the fish. In practice these fishing fields became an informal property of the owner of the onshore facilities, being rented out with the base on land, with good fields carrying a premium rent (Solhaug, 1983).

Over time, dissatisfaction with these arrangements developed. One important contributing factor seems to have been a shift in fish migrations from the eastern part of Lofoten to the western part (Solhaug, 1983), but such shifts occur from time to time, presumably depending on environmental factors. Being tied to one particular fishing place impeded pursuing the fish wherever they happened to be, and in the western area there was more space and less need for a spatial regulation. This resulted in a new law on the Lofoten fishery, enacted in 1857. This law did away with the previous spatial regulation and made it clear that anyone had the right to fish wherever he wanted, but allowed for division of the fishing grounds between different gear types if deemed necessary to avoid entanglements. The new law thus established the Lofoten fishery as an open access fishery, but subject to certain rules of conduct. The law established a regulatory authority for the Lofoten fishery, which purpose was ensuring that the rules of conduct were followed, such as not leaving harbor until the morning signal had been given, not setting any fishing gear after a certain hour in the evening, and respecting the division of the fishing areas between the various gear types.

The law of 1857 certainly resounded with the prevailing free enterprise spirit of the time. The Lofoten reports also made it quite clear that the purpose of the law was to increase the efficiency of the fishery by making it easier to follow the fish to wherever they happened to be and to allow the fishermen to use their skills and endurance to the utmost. This was long before overexploitation of fish resources had been recognized; on the contrary it was widely believed, even by prominent biologists, that fish resources were inexhaustible and that fishing made no difference whatever for their fecundity (Smith, 1994).

Over time, discontent also developed over the new law. As the number of fishermen increased, spatial control again became necessary to avoid gear collisions. The law allowed for dividing the fishing banks between different types of gear, but not between boats, and that arrangement apparently was not what the fishermen sought. Instead they sought influence over the division of ocean space between different gears and other regulatory issues, not least because of the development of new gears such as seines, which most of them wanted banned, and because of attempts by some landowners to close off certain areas where the fish concentrated and either have it all for themselves or charge fishermen for access to these areas. Yet another law was enacted in 1897, giving fishermen influence over management through consultative committees while keeping the ultimate authority and enforcement firmly in the hands of the state. This arrangement has basically prevailed until this day.

The Lofoten fishery remained an open access fishery until 1990. There were no restrictions on the number of boats, fishing time, or quantity of fish caught.[9] In 1989 a limit was set for the first time on how much fish could be caught, and the fishery was stopped half way through the season when this limit had been reached. In the following years individual boat quotas or quotas for groups of boats were used, which limited the amount of fishing time at least some boats could spend in this fishery. Because of this our analysis of the fishery will end in 1988, the last year without regulations affecting fishing time and the quantity caught.

[9] There were a few exceptions to this. In 1981-84 the fishery was stopped in-season for about two weeks, which included the Easter holiday, during which little fishing would have taken place anyway. In the 1950s and 60s it occasionally happened that the fishery was halted for a few days or limits set on the catches of individual boats because of market problems.

3.2 The Lofoten fishery 1860-1988: technical change and institutional change

In this section we will describe the development of participation, technological and institutional change taking place in different periods, as well as the development of catch and stock in the Lofoten fishery. The main aim is to identify different periods in the fishery in terms of technology and participation. .

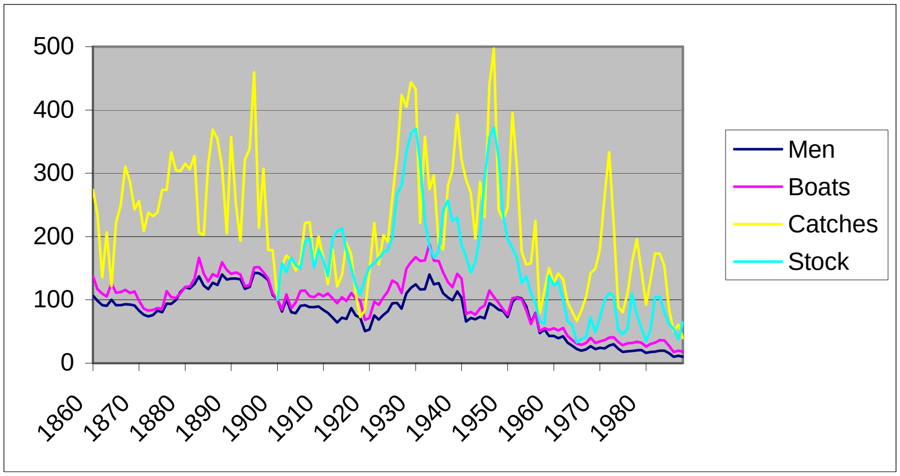


Figure 2: Fixed base indices for fish catch, the number of fishermen, fishing boats, and spawning stock in the Lofoten fishery 1860-1988. 1900 = 100.

Figure 2 shows the development of men, boats, catch, fish price and fish stock from 1860 until 1988. Participation in the Lofoten fishery, whether measured as number of fishermen or boats, evolved in a somewhat cyclical fashion; it was high in the 1880s and 1890s and peaked again in the 1930s. It declined sharply from the early 1950s to 1965 and continued declining after that, but at a lower rate and somewhat irregularly.

The development of participation is most likely connected to different periods in the fishery in terms of technological change in boat and gear types and institutional change. Based on Figure 2 and the somewhat scarce literature, we think five different periods can be distinguished (Brandal, 1981, 1982; Solhaug, 1983; Lefdalsnes, 1969; Iversen, 1937):

1. Until about 1880: mostly small and open boats without sail, using gill nets, long line and hand line.

2. From about 1880 to 1906: Open boats were replaced by decked boats with sail, even if many open boats remained. Decked boats were larger than the open boats. Sail boats used small boats ("dories") for net and long line.
3. From 1906 to 1920: Motorization of the fleet. By 1920 most of the decked boats had engines. Most of the change took place from about 1912 to 1920.
4. From 1920 to about 1940: Two distinct changes occurred; (i) mass increase in the participation of open boats using hand line and long line; (ii) enactment in 1938 of a law giving fishermen monopoly of sales of fish at the first hand (the so-called Raw Fish Law).
5. From the mid- to late 1950s: the introduction of nets made of synthetic fiber, and, later, development of increasingly sophisticated jigging machines for hand lines. Probably also general improvement in technology proceeding in small, incremental steps.

3.3 Participation in the fishery

We are interested in finding out whether the Lofoten fishery follows a pattern expected from an open access-common resource industry, which is that the net entry rate into the fishery follows the expected profitability or productivity in the industry.

The long term changes in participation (Figure 2) are probably related to both demographic development and "outside options." Before 1900 there was substantial immigration to Nordland County, whereas there was substantial emigration, both to the rest of the country and to America during the two decades after 1900. In the two decades 1920-1940 the emigration to America slowed to a trickle, because of restrictions in the United States, and emigration to the rest of Norway also declined because of a slowdown in industrial development and economic growth in general.[10] After 1950 the Norwegian economy entered a phase of full employment and rapid economic growth, coinciding with a rapid decline in the participation in the Lofoten fishery.

The variations in participation are rather moderate compared with the fish catches, which display both short term and long term variability. Much of this variability is evidently related to variations in the fish stock. Very roughly we can identify two periods

[10] On the demographic development up to 1940 and the importance of "outside options," see Vea (1988).

of large but variable catches, 1860 to 1900 and mid-1920s to 1950. From 1900 to the mid-1920s and after 1950 catches were much lower and less variable, except for a peak in the early 1970s.

The Lofoten fishery is a seasonal fishery, and even fishermen from distant parts of Norway sailed to Lofoten to participate in it. Their decision to participate undoubtedly depended on a number of things, such as the prospects in other fisheries or activities, but the prospects for the Lofoten fishery itself must have been an important consideration. In the early years before modern fish stock assessment was developed, allowing fisheries biologists to predict the size of the fish stock for the coming season, the boat owners are likely to have based their expectations of the coming Lofoten season on the results of the previous season. Even if they later based their decisions on up-to-date fish stock assessments their expectations might appear as being backward looking, because the prospects in the Lofoten fishery are largely determined by exceptionally strong year classes of fish, which persist over several years. Many of the Lofoten reports mention poor results of previous years as a reason for a decline in the number of fishermen and boats, and vice versa. As the communications technology developed (from telegraph to telephone and radio) the reports refer to prospective fishermen as following the development of the fishery from the start of the season, but the impression they give is that this primarily affected the decision when to depart for Lofoten rather than whether or not to participate in the fishery.

To examine this, we investigate whether the annual change in the number of boats is related to the productivity in the fishery. Two measures of productivity are available from the data at hand: (i) the catch per fisherman, and (ii) the catch value per fisherman, where for the latter we simply multiply by the fish price adjusted for changes in the value of money measured by the consumer price index.[11]

[11] Catch per boat could also be used, and one could argue that it would be more relevant, since the decision about participation is taken by boat owners, but the development in the number of fishermen and boats is in any case quite similar. By looking at catch per fisherman rather than per boat we avoid having the variable to be explained on both sides of the regression equation.

Table 1: Regression of the change in the number of boats on the change in catch per fisherman (Equation [1]). First differences of logarithms. *t*-values in parentheses. ** (*) significance at the 1% (5%) level.

	a_0	a_1	a_2	R^2
All boats 1860-1988	-0.0156 (-1.26)	0.00316 (0.08)	0.1787** (4.35)	0.14
Gill nets 1875-1988	-0.0138 (-0.83)	0.0371 (0.87)	0.2455** (5.74)	0.23
Long line 1875-1988	-0.0274 (-1.83)	-0.0649 (-1.52)	0.1624** (3.81)	0.15
Hand line 1875-1988	-0.0113 (-0.40)	-0.0921* (-2.29)	0.1456** (3.65)	0.18
Purse seine 1950-1958	-0.2378 (-1.01)	0.4442 (1.70)	-0.5113 (-1.43)	0.60
Danish seine 1959-1988	0.0207 (0.08)	0.0368 (0.32)	-0.0025 (-0.02)	0.00

Table 1 shows the results of regressing the change in the number of boats in the fishery on the change in the catch per fisherman, contemporary and lagged.[12] The regression equation is

(1) $$\ln B_t - \ln B_{t-1} = a_0 + a_1\left[\ln\left(Y/L\right)_t - \ln\left(Y/L\right)_{t-1}\right] + a_2\left[\ln\left(Y/L\right)_{t-1} - \ln\left(Y/L\right)_{t-2}\right] + u_t$$

where B is the number of boats, Y is the catch of fish, L is the number of fishermen, t denotes year, and u is an error term. The only significant coefficient in the regression including all boats is change in catch per fisherman lagged one year, indicating that participation in the fishery was indeed influenced by the catch per fisherman in the previous year's season (further lags were insignificant). This pattern is quite but not completely persistent as we lop years off the regression at either end. Ending the series about 1900 makes the lagged value of catch per fisherman insignificant (5% level of significance), but a significant *t*-value persists even if we begin the series in 1971. This indicates that the influence of the previous season on participation in the fishery was if anything less strong in the 1800s, even if participation and its variability were much greater then than in the latter half of the 20th century. Looking at the individual gear types, the results are similar for gill nets, long lines and hand lines, while for purse seine

[12] First differences of logarithms were used, as unit root is not consistently rejected for level variables and the Durbin-Watson statistic indicates serial correlation for some regressions in levels of variables. As the R^2's in Table 1 show, rather little of the variation in participation is explained by the variation in catches per fisherman. Regression in levels of variables shows that most of the participation in the fishery is explained by the number of boats lagged one year; the R^2's are around or above 0.9 and the regression coefficient for $\ln(Y/L)_{t-1}$ is significant for all boats and for nets, long lines and hand lines.

and Danish seine we do not get significant coefficients. The participation of long line and hand line boats is the most variable one (see Figure 4 below).

One might think that the catch value per fisherman would be a more appropriate explanatory variable for participation in the fishery than the catch quantity per fisherman. Running the same kind of regression with productivity defined in revenue terms gives poorer results; the *t*-value of the lagged productivity variable is lower (but still significant), except for gill net boats where it is slightly higher, and it becomes insignificant much more quickly as we lop off years at either end of the series for all boats.

One reason why catch volume rather than value is a determinant of participation could be that the price of fish is inversely related to the catch volume. The boat owners might not have been able to take this appropriately into account. Furthermore, this relationship has changed over time. Figure 3 shows the development of the (real) price of fish 1860-1988. Up to about 1900 the price was variable, but low and without trend. About 1900 it began to trend upwards and increased steeply during the First World War. Then it fell and stayed low during the Great Depression, but began to rise when the Second World War began and increased further, with some hiccups, until 1988. In that year the real price was about eight times what it had been in 1860.

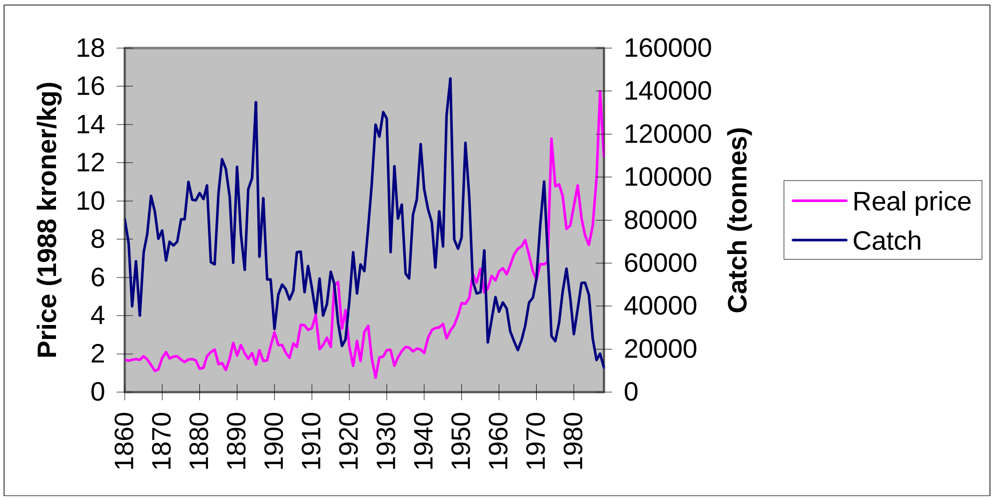


Figure 3: Catch and the real price of fish in the Lofoten fishery 1860-1988.

Table 2: Regression of change in real price on change in total catch (Equation [2]). First differences of logarithms. *t*-values in parentheses. ** Significance at the 1% level.

Period	a_0	a_1	R^2
1860-1988	0.0107 (0.48)	-0.3193 (-4.83**)	0.16
1860-1937	0.0031 (0.09)	-0.4408** (-4.11)	0.18
1938-88	0.0277 (1.34)	-0.1759** (-3,10)	0.16

Since price apparently has little effect on participation in the fishery and the abundance of fish is given by nature, it makes sense to regard price as depending on quantity, as follows:

(2) $$\ln P_t - \ln P_{t-1} = a_0 + a_1\left(\ln Q_t - \ln Q_{t-1}\right) + u_t \, .$$

Table 2 shows the results of estimating Equation (2). The coefficient a_1, which is the inverse of price elasticity and often called price flexibility, is negative and significant. In 1938 the fish market became regulated by a law giving a marketing board (the Raw Fish Marketing Board) acting on behalf of the fishermen the right to administer the first-hand sale of fish and to set prices, an arrangement that still persist. The purpose was to raise the price and lower its variability. The results from Table 2 are consistent with the latter being successful; the price flexibility parameter is significantly lower for the period 1938-88 than the earlier period, indicating less responsiveness of the price to changes in the volume of landings.

3.4 Changing gear type

Some of the change in the number of boats using a particular type of gear could be due to boats shifting fishing gear from one year to another rather than changes in the total number of boats. Different gear types select somewhat different age groups of fish. The strength of these age groups can vary substantially, so that the relative advantage of different gear types may change from one year to the next. Several of the Lofoten reports refer to boats changing gear types from one year to another, as well as some boats using different gear types in the same season, making the classification on the basis of fishing gear somewhat arbitrary. In any case the results in Table 1 indicate that catch results in the previous season influenced the total participation in the fishery as well as the participation of boats using a particular gear, whether the latter was due to gear-switching or not.

Figure 4 shows the number of boats using the three traditional gear types; gill nets, long lines, and hand lines. The most conspicuous feature is the enormous bulge in the number of hand line boats from 1920 to 1965, rising from a few hundred in 1920 to over 5000 in the early 1930s and then dropping off gradually, with some fluctuations. The surge in the number of hand line boats was accompanied by an increase in the number of fishermen per boat, so for a time that number was about the same as for the long line boats (see Figure 6), while both before and after it was much lower. The increase in the number of hand line boats in the 1920s was not due to a switch of gears; the number of long line boats was also increasing while the number of gill net boats changed little. It thus appears that many owners of relatively large boats decided to participate in the Lofoten fishery in the 1920s and then gradually pulled out (or switched gear) from about 1930 onwards. The number of long line and gill net boats has also been variable, but less so, especially the gill net boats. There is some evidence of gear-switching between gill net and long-line boats up to about 1920 in that we find significantly negative correlations for some sub-periods.

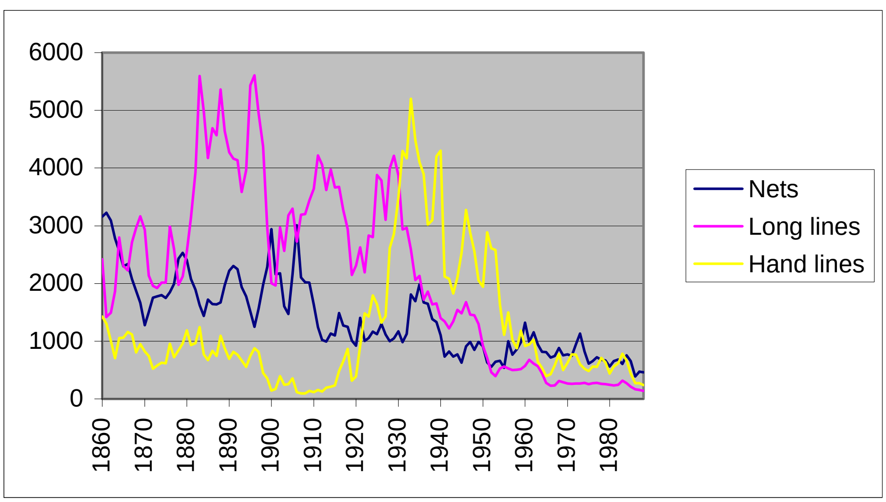
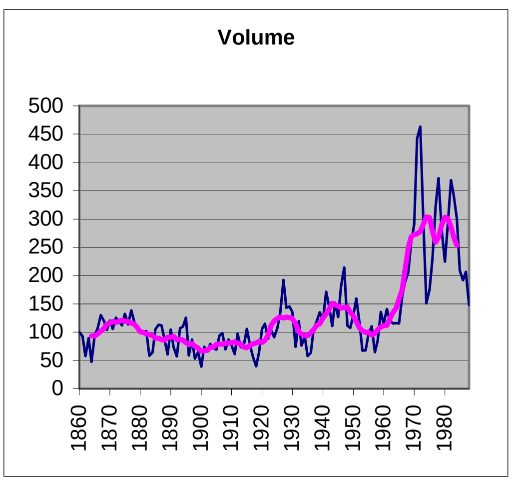


Figure 4: Number of boats using nets, hand lines and long lines.

It is very tempting to see this increase in the number of hand line boats in the 1920s as a result of poor outside opportunities together with a continuing population growth (Lefsdalsnes, 1969). The 1920s were a period of economic stagnation in Norway, and the emigration to the United States had declined substantially. Hand lines were the cheapest fishing gear available and so the poor man's choice. What is a bit surprising is that this development was to some extent reversed in the 1930s, also difficult times with few opportunities. Some of that may be due to frustrated expectations; the Lofoten reports in the 1930s make references to fishermen leaving Lofoten poorer than when they came and in need of financial help to go back home.

3.5 Labor productivity

Figure 5 shows the development of productivity, measured as catch volume and value per fisherman. There was surprisingly little trend in productivity until the mid-1960s, when it was in fact little higher in volume terms than a hundred years before. Because of the enormous inter-annual variability, moving averages provide a better basis of comparison than comparing just initial and final years. Figure 5 also shows 9-years moving averages, which give a reasonable smoothing of the curves. In volume terms, labor productivity was almost three times higher in the 1970s and 80s than in the 1860s, but in terms of real value it was 15 times greater. Given that the Norwegian economy grew impressively over the said period, fishermen would have been in dire straits indeed if rising prices had not come to the rescue.



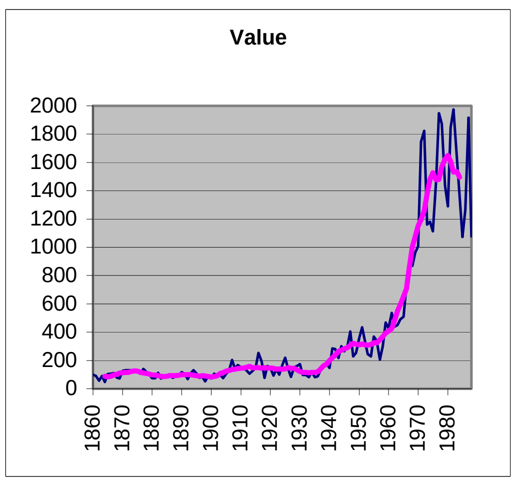


Figure 5: Fixed-base indices of productivity (catch per fisherman), in value and volume terms, annual values and 9-years moving averages.

This rise in the revenue per fisherman coincides with a decline in the number of fishermen per boat, as seen from Figure 6. Another noteworthy feature is that rising prices compensated for the fall in labor productivity in the 1940s and 50s. In this period as well as later prices were regulated by the Raw Fish Marketing Board.

Even if labor productivity in volume terms remained fairly constant for a hundred years, there was some variation in the number of fishermen per boat, as is seen from Figure 6. We can identify four phases. From 1860 to about 1900 the number of fishermen per boat increased for all three gear types. In the early 1900s the number fell significantly over a relatively short period, first for gill net boats, and later for the long line and hand line boats. The Lofoten reports mention two reasons for the decline in the number of men per boat in gill netting in the latter half of the 1890s. First, beginning in the early 1890s, winches were gradually introduced to pull the nets. This, according to the same reports, did not result in a smaller crew until a few years later, however. Second, from 1895 a new type of net, the so-called small fish net, came into use. This required a smaller crew than the other type of net.

That winches did not immediately result in smaller crews indicates that it takes time for a technology to diffuse and for fishing firms to adjust to the new technology. We see a similar pattern in the motorization of the boats. Although first introduced around 1900, this process did not take off until about 1915, but had largely run its course in 1920, even if many open boats still remained.

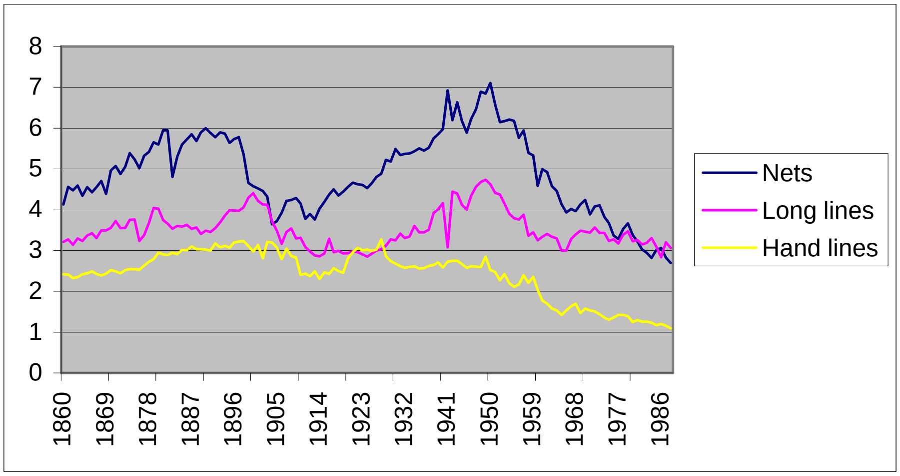


Figure 6: Fishermen per boat.

The first mention of engines in the Lofoten reports occurred in 1895, when a gill net boat was reported to have used a petroleum engine, which apparently did not work very well. Over the period 1907-1915 much of the fleet was motorized, although boats without motor would be in use for many years after that.[13] This period coincided with a decline in the number of men per boat in the long line and the hand line fishery. Replacement of oars and sails by engines is therefore likely to have been labor-saving, although the Lofoten reports make no mention of this. Shortly after 1910 the number of men per boat began to increase again, first for the gill net boats and later for the long line and hand line boats. This could possibly be because boats propelled by engines instead of sails and oars could be made bigger, accommodating a larger crew. Then, finally, since about 1950 the number of fishermen per boat has fallen almost uniformly. This period coincides with strong economic growth and growing real wages in the Norwegian economy, which is likely to have encouraged substitution of capital for labor, but only after 1965 did labor productivity increase substantially in volume terms (Figure 5).[14]

4. Productivity and fish abundance

4.1 Estimating productivity using OLS

As Figure 2 shows, the size of the spawning stock of the Northeast Arctic cod varies substantially from year to year. This figure also indicates that the catches in the Lofoten fishery are strongly influenced by the size of the spawning stock. A possible specification of a production function taking this into account is the following:

(3) $$Y_t = AE_t^a S_t^b e^{gt}$$

where Y is the catch of fish, E is fishing effort, and S is the size of the stock, while t is time measured in years. The time trend term g is usually thought of as picking up the rate of technical progress.

[13] That this transition was ongoing but incomplete by 1910 is clear from the Lofoten Report for that year. This was apparently not a good year, and many fishermen blamed the noise from motorized boats for having scared away the fish. The report concurred with these boats having been numerous and the noise formidable, but was otherwise out of sympathy with the complainants, considering the argument as being vicarious for arguing against competing and better equipped fishermen.

[14] The Lofoten Reports are surprisingly silent on what technical changes may have been involved. One change that apparently increased productivity, although probably not of a labor-saving kind, was the use of synthetic materials in nets and lines. This transition took place in the mid-1950s.

Equation (3) expresses the catch flow at any given time. If the entire stock becomes available in the beginning of the fishing season, the stock will be gradually depleted as the season progresses, and the catch flow will diminish. For a fishery that goes on with a given level of effort over a season of length Δ we would therefore have to integrate this function over that time period in order to get a correct expression for the total catch over the period. This procedure, and the bias inherent in using (3) under those circumstances, are discussed in the Appendix. In the Lofoten fishery the fish enter the spawning grounds somewhat gradually and not all at once. This, together with the fact that the fishery is relatively short (about three months) and with a peak in the middle, which tends to coincide with the main concentration of fish, means that Equation (3) is likely to be an acceptable approximation.

Fishing effort is a notional variable expressing the activity directed at catching the fish. This activity is produced by factors of production such as manpower, capital invested in boats and other equipment, and other inputs such as fuel. In the data set at hand there are only two such factors identified, the number of fishermen and the number of boats, but they are so closely correlated (see Figure 2) that both cannot be used simultaneously in the same regression, except when using a panel approach and gear type dummies. As mentioned in the section about the data used, both of these variables refer to a census taken at a point in time and do not reflect the intensity of use. One variable having an impact on the intensity of use is the weather. In stormy weather the boats cannot go fishing. Nets and lines that are left lying could still be capturing fish, but they often get entangled during storms and lose some or all of their fishing power. The only continuous weather time series available in the Lofoten reports is the number of pull-days; i.e., the number of days the boats can go out and pull up their nets or lines. This was used to construct a weather index normalized at unity at the average, with which the right hand side of Equation (3) was multiplied. Inclusion of this variable gave a significant result with the expected sign only for long line and purse seine, but did not much effect the numerical estimate of b and was dropped.

Taking logarithms of (3) we get a linear function which is straightforward to estimate. However, a unit root test indicates that at least some of the time series are not stationary and, furthermore, the Durbin-Watson statistic for regressions in variable levels indicates serial correlation of residuals. This suggests using first differences of logarithms, for which the unit root hypothesis can be rejected:

(4) $\ln Y_t - \ln Y_{t-1} = a_0 + a_1(\ln L_t - \ln L_{t-1}) + b(\ln S_t - \ln S_{t-1}) + u_t$

The results of estimating (4) are given in Table 3, using fishermen (*L*) as a proxy for fishing effort. Below we will use level variables, and boats instead of fishermen, letting the number of boats be predicted by the catch per fisherman in the previous season (cf. the discussion in the previous section). As will be seen, the results produced by the two types of regressions are not radically different.

For the traditional gears (gill nets, long line and hand line) the estimates of both a_1 and b are less than one, although for gill nets a_1 is not significantly different from 1, while for hand line it is not even significantly different from zero. As shown in the appendix, the estimates of a_1 are likely to be biased downward, but the values produced for long line and hand line are much lower than we would expect. The coefficient b is less than the often assumed value of one and indicates diminishing returns to the stock (for hand line b is not significantly different from one due to the wide confidence interval). The constant in these regressions reflects the time trend. None of the trend terms is significantly different from zero, but the point estimates indicate an increase of 1-2 percent per year for gill nets and hand line, but none at all for long line. This is not entirely surprising; as Figure 5 indicates there was very little upward trend in the catch per fisherman until the mid-1960s, whereafter it increased very rapidly.

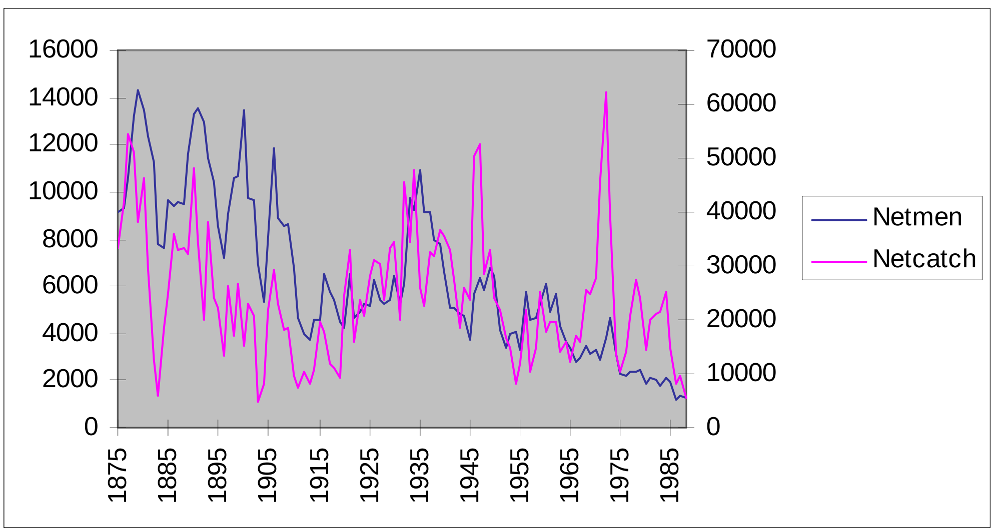
Table 3: Results of regressing change in catch on change in effort (number of fishermen) and the change in fish stock (Equation [4]). First differences of logs. ** (*) Significance at 1% (5%) level, *t*-values in parentheses.

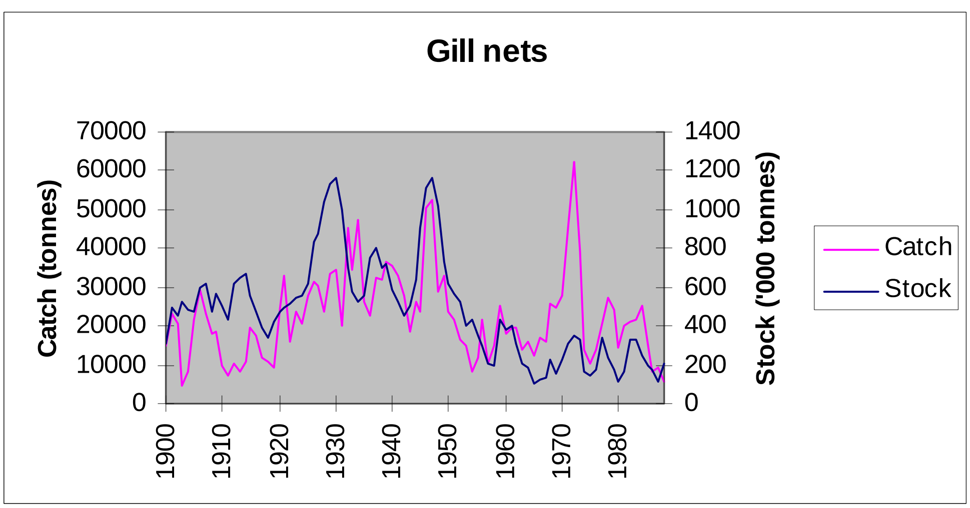
	a_1	b	a_0	R^2
Gill nets 1900-1988	0.8508** (4.51)	0.3930** (2.71)	0.0133 (0.33)	0.27
Long line 1900-1988	0.3651** (2.07)	0.6465** (5.68)	-0.0010 (-0.33)	0.34
Hand line 1900-1988	0.3302 (1.59)	0.5698** (2.17)	0.0257 (0.36)	0.10
Purse seine 1950-1958	0.9608** (4.11)	2.1560 (1.84)	0.1481 (0.48)	0.83
Danish seine 1959-1988	1.4751** (4.25)	0.6048** (2.46)	-0.0777 (-0.79)	0.47

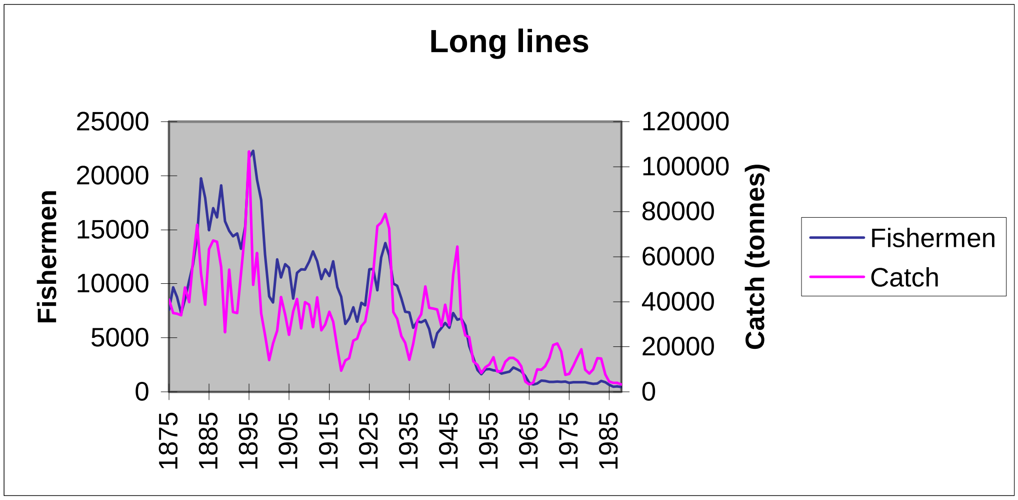
The result for purse seine shows a value of a_1 close to one, as expected, but an insignificant value of b, even if the point estimate is quite high and way above what we would expect to be the upper limit (one). The time series for this gear is probably too short (8 years) to produce meaningful results, and we will disregard it in the following.

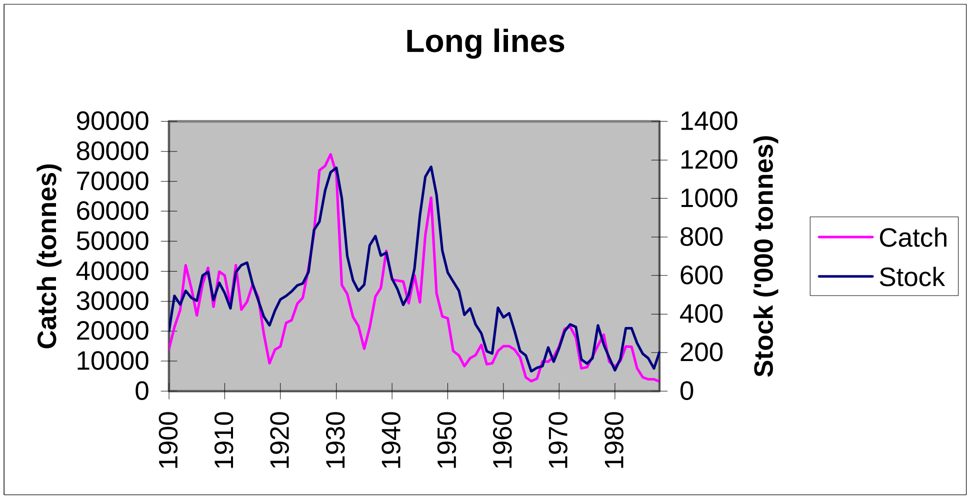
For Danish seine we get diminishing returns to the fish stock, as for the traditional gear types, although $b = 1$ is within the confidence limits. The value of a_1 is quite high, but also here with $a_1 = 1$ within the confidence limits. The estimate for the time trend is strongly negative, but insignificant.

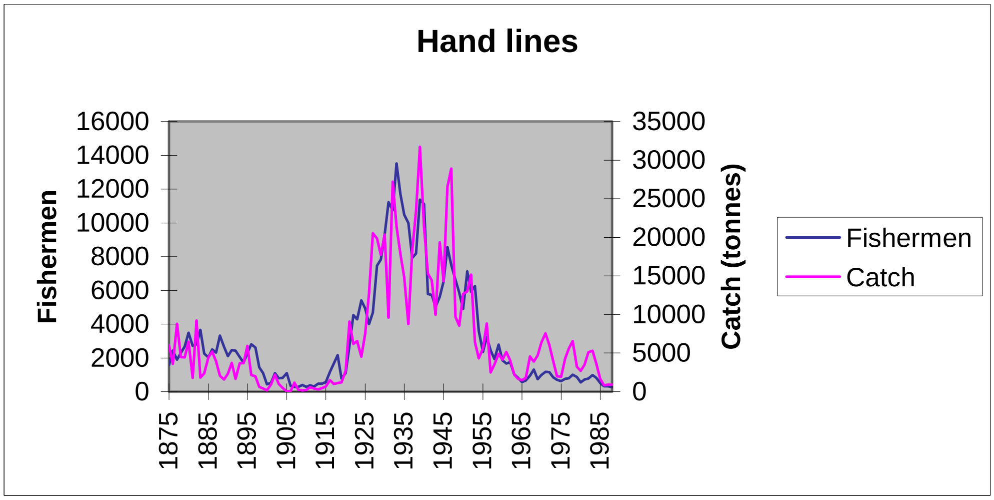
Figure 7 shows catch versus labor input, and catch versus the size of the spawning stock, for the five types of gear. The figure illustrates the positive correlation we have found between catch and labor and catch and the spawning stock. For all gear types the correlation between the catch and the two said factors of production appears strong.

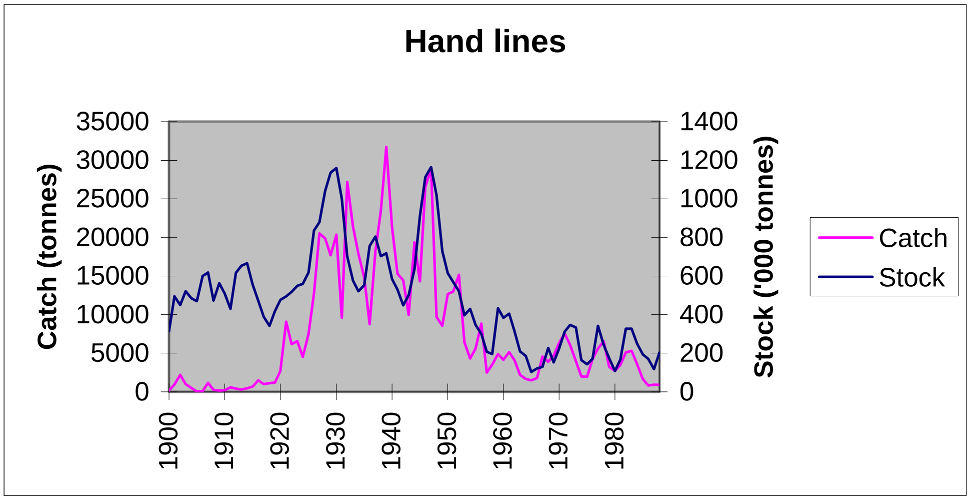


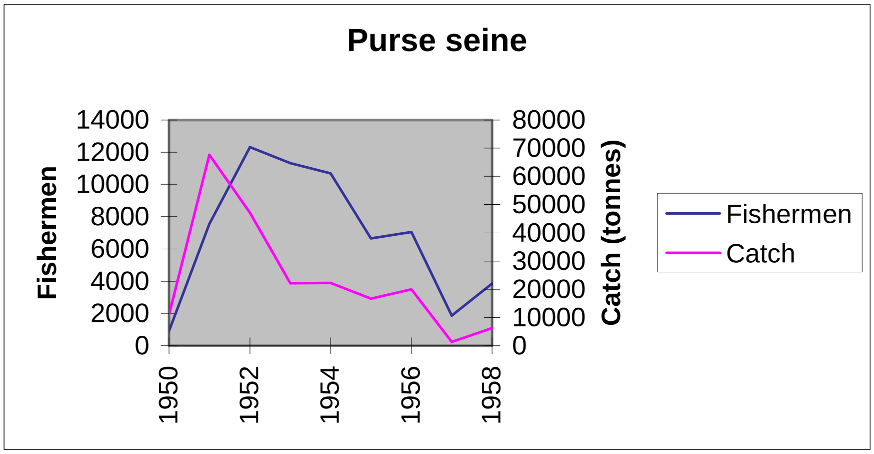


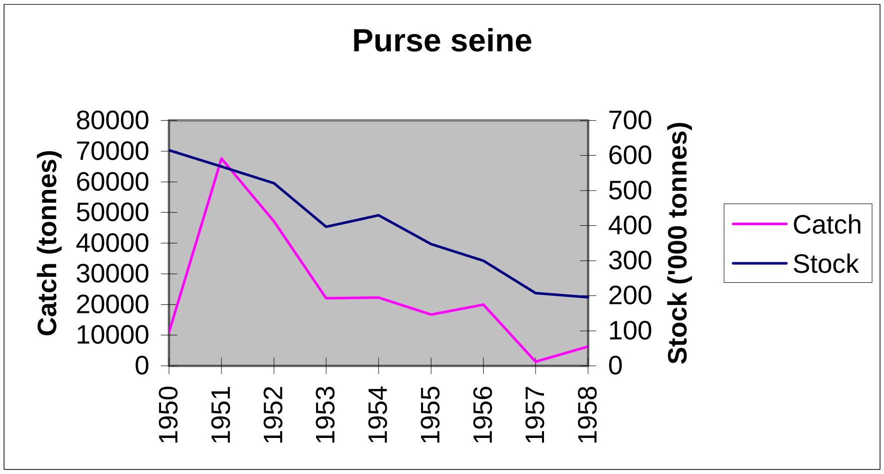

Long lines
Fishermen
25000
20000
15000
10000
5000
0
120000
100000
80000
60000
40000
20000
0
Catch (tonnes)
1875
1885
1895
1905
1915
1925
1935
1945
1955
1965
1975
1985
Fishermen
Catch


Long lines
Catch (tonnes)
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
1400
1200
1000
800
600
400
200
0
Stock ('000 tonnes)
1900
1910
1920
1930
1940
1950
1960
1970
1980
Catch
Stock


Hand lines
Fishermen
16000
14000
12000
10000
8000
6000
4000
2000
0
35000
30000
25000
20000
15000
10000
5000
0
Catch (tonnes)
1875
1885
1895
1905
1915
1925
1935
1945
1955
1965
1975
1985
Fishermen
Catch


Hand lines
Catch (tonnes)
Stock ('000 tonnes)
35000
30000
25000
20000
15000
10000
5000
0
1400
1200
1000
800
600
400
200
0
1900
1910
1920
1930
1940
1950
1960
1970
1980
Catch
Stock


Purse seine
Fishermen
Catch (tonnes)
14000
12000
10000
8000
6000
4000
2000
0
80000
70000
60000
50000
40000
30000
20000
10000
0
1950
1952
1954
1956
1958
Fishermen
Catch


Purse seine
Catch (tonnes)
Stock ('000 tonnes)
80000
70000
60000
50000
40000
30000
20000
10000
0
700
600
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400
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200
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1950
1951
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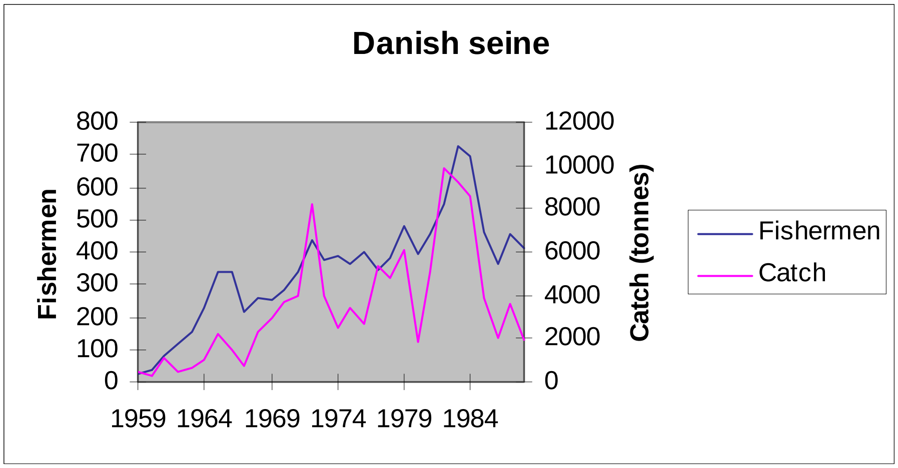
1957
1958
Catch
Stock



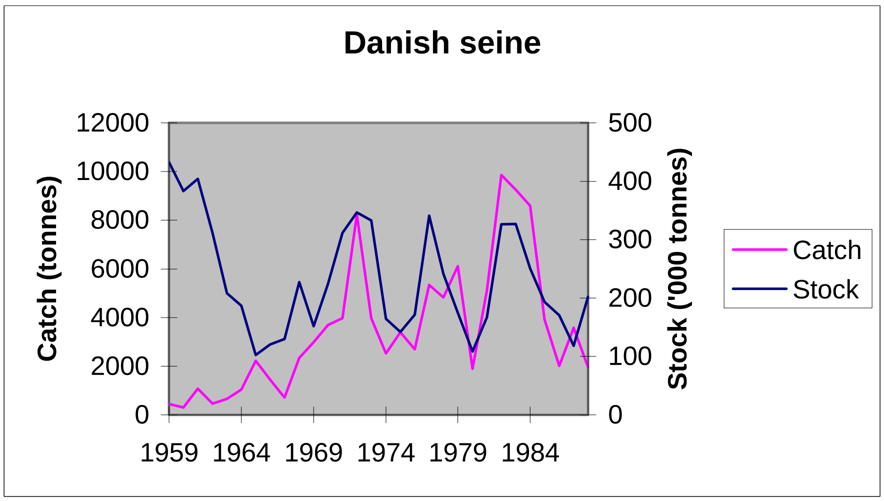


Figure 7: Catch, labor input, and spawning stock for the five types of gear used in the Lofoten fishery.

4.2 Estimating productivity using instrumental variables

An endogenous participation rate in the fishery will lead to a bias in the estimated parameter in the production function. It is expected that the bias will be downward in this case, since more fishermen, possibly negative selected, are entering the industry in good years or when the alternative employment possibilities are low. Hence, we decided to instrument the number of boats when estimating the production function. Above it was shown that the participation in the fishery by the boats using traditional gear has partly been determined by the catch per fisherman the previous year. This suggests using lagged catch per fisherman as an instrumental variable to determine the number of boats engaged in the fishery. These estimates are carried out in levels of variables, as most of the participation each year is determined by the participation the year before, which is also used as instrumental variable to determine participation each year. We estimate separate equations for each gear. The estimating equation is

(5) $$\ln Y_t = a_0 + a_1 \ln B_t + b \ln S_t + d_0 D_0 + ... + d_7 D_7 + u_t$$

(6) $$\ln B_t = \beta_0 + \beta_1 \ln B_{t-1} + \beta_2 \ln(Y / L)_{t-1} + \beta_3 \ln S_t + \delta_0 D_0 + ... + \delta_7 D_7 + \nu_t$$

where Equation (6) is the first stage equation, using $\ln B_{t-1}$ and $\ln(Y/L)_{t-1}$ as instrumental variables for $\ln B_t$. D_0 to D_7 are dummy variables for decades, leaving out the incomplete decade 1980-1988. Including a log-linear time trend, as in (3), indicates a technological progress of around 2 percent per year for gill nets, hand line and Danish seine, but none for long line. A constant rate of technological progress over such a long time period as 89 years is perhaps none too likely, as technological progress often occurs by leaps and bounds and is rapidly diffused. The decadal dummies allow us to account to some extent for the possibility of an uneven technological progress. The results are shown in Table 4 and indicate a somewhat uneven rate of technological progress; note that the technology is measured with reference to the decade 1980-1988, so the decadal dummies should be negative and rising towards zero. With an even technological progress, as implied by the log-linear trend term in (3), the coefficients of the decadal dummies would increase monotonically. They do increase, as expected, but somewhat unevenly. The coefficients for the first two decades (1900-1919) are negative and significant for all gear types. For the hand line boats it appears that technological progress mainly occurred in the 1920s; the coefficients of the decadal dummies are all insignificant and small from that time on. This could possibly be due to bigger boats being used in the 1920s than before or since; in Figure 6 we see that the number of fishermen per boat increased suddenly in the 1920s and then fell again. More generally, technical progress here simply means that each boat becomes more efficient, either due to being bigger or better equipped.

Both gill nets and long line have negative coefficients for the decadal dummies from the 1920s up to the 1960s, some of them significantly so, and with a rising trend, as expected. The boats thus gradually became bigger or better equipped, or both. Curiously the 1970s seem to have been technologically superior to the 1980s for all types of gear. Danish seine, which came on the scene in 1959, also seems to have experienced technological progress in the 1970s, the dummy for the 1960s is significantly negative.

Table 4: Regression (Equation [5]) with catch per man lagged one year and the number of boats lagged one year as instrumental variable to determine number of boats. d_0-d_7 are coefficients for dummy variables for decades. t-values in parentheses.

	a_1	b	d_0	d_1	d_2	d_3	d_4	d_5	d_6	d_7	a_0	R^2
Gill nets	.9319 (2.56)	.3586 (3.28)	-1.39 (2.87)	-1.26 (4.17)	-.45 (1.57)	-.51 (1.40)	-.02 (0.11)	-.34 (1.91)	-.19 (0.86)	.23 (1.29)	1.74 (0.78)	.66
Long line	.7082 (3.16)	.6417 (4.66)	-.96 (1.86)	-1.27 (2.26)	-.97 (1.89)	-1.02 (2.30)	-.50 (1.41)	-.51 (2.41)	-.20 (1.06)	.43 (2.98)	1.65 (1.88)	.86
Hand line	.7685 (3.77)	.4138 (2.01)	-1.53 (3.74)	-1.26 (3.46)	-.003 (0.01)	-.12 (0.24)	.09 (0.21)	-.16 (0.45)	.04 (0.14)	.36 (1.31)	.83 (0.64)	.86
Danish seine	1.1173 (5.26)	.7296 (3.28)							-.53 (2.16)	.06 (0.33)	-.69 (0.36)	.84

As to the coefficients a_1 and b, the results for b are quite similar to the ones in Table 3, especially for gill nets and long line. All are significantly greater than zero and (except for Danish seine) less than one. The a_1-values are quite different, except for gill nets, and closer to one; none is in fact significantly different from one. There are two reasons to regard these results as more satisfactory than the previous ones. First, constant returns to scale in producing fishing effort implies $a_1 = 1$, but as discussed in the Appendix, the estimate of a_1 could be biased downwards. Second, as already mentioned, the OLS estimates are likely to be biased downwards. The instrumental variable approach corrects for this.[15]

The question arises whether the technological progress that apparently has taken place in the fishery is biased in the sense of affecting the parameters a_1 and b. Especially the latter appears to be a possibility. One type of technological progress that has taken place in the fishery is the development of fish finding equipment, from depth meters showing concentrations of fish as shades close to the ocean bottom to sonar searching for fish in all directions. A b-coefficient close to one would reflect either of two different situations: (i) the fish are always uniformly distributed over a given area, so that a small stock is less dense than a large one: (ii) the fish become more difficult to find the smaller the stock is. Fish finding equipment would clearly be helpful in the latter situation and could thus reduce the value of b. To examine this we looked at the interaction between the stock and the decadal dummies. The coefficients of these interaction terms vary in

[15] In fact, OLS estimate in levels gives very similar results to those in Table 4, with a lower estimate of a_1 only for long line.

sign without any trend and are never significant. There is thus no sign that technological progress has been biased in the sense of making the fish stock more or less important as a factor of production. The same kind of interaction between the time dummies and the number of boats was also examined. For long line there is some indication of such interaction; two of the interaction coefficients are significant, but the implied values of a_1 are unreasonable, being close to zero.[16]

5. Labor and total factor productivity growth

As Figure 5 indicated, labor productivity in the Lofoten fishery has grown unevenly and often declined from one year to another. For about a hundred years there was negligible growth in productivity, but a lot of variation. What could account for this comparatively poor performance? Was it due to a depletion of the fish stock or absence of technological progress? Since we have data on the fish stock only from 1900 we are not able to push the comparison further back in time. This is a bit unfortunate, because 1900 was a bad year with low labor productivity (cf. Figure 5).

To examine this, we look at the development of total factor productivity. The growth rate of total factor productivity is

$$(7) \qquad G_{t,t+1}^{TFP} = \frac{Y_{t+1}/Y_t}{\left(L_{t+1}/L_t\right)^{a_1}\left(B_{t+1}/B_t\right)^{a_2}\left(S_{t+1}/S_t\right)^{b}} - 1$$

Because of the high correlation between fishermen and boats, it is not possible to estimate the coefficients a_1 and a_2 separately for each gear type, as one of the variables involved picks up most of the influence of the other. Using panel methods and dummies for two of the three traditional gears gives reasonable estimates of these coefficients, however:[17]

$$(8) \qquad \ln Y_t = a_0 + a_1 \ln L_t + a_2 \ln B_t + bS_t + d_{HL}D_{HL} + d_{LL}D_{LL} + gt + u_t$$

where D_{HL} and D_{LL} are dummy variables for hand line and long line, respectively.

The results of estimating (8) are reported in Table 5. The two a's nearly sum to one, implying that fishing effort is produced with a constant returns to scale technology,[18]

[16] An F-test of including the interaction terms is just barely significant (5% level) for gill nets and all interaction terms (time dummies and stock and time dummies and boats), but insignificant for all others.
[17] Purse seine and Danish seine were not included in this exercise.
[18] An F-test of the restriction $a_1 + a_2 = 1$ is insignificant and in fact produces a slightly negative F-value.

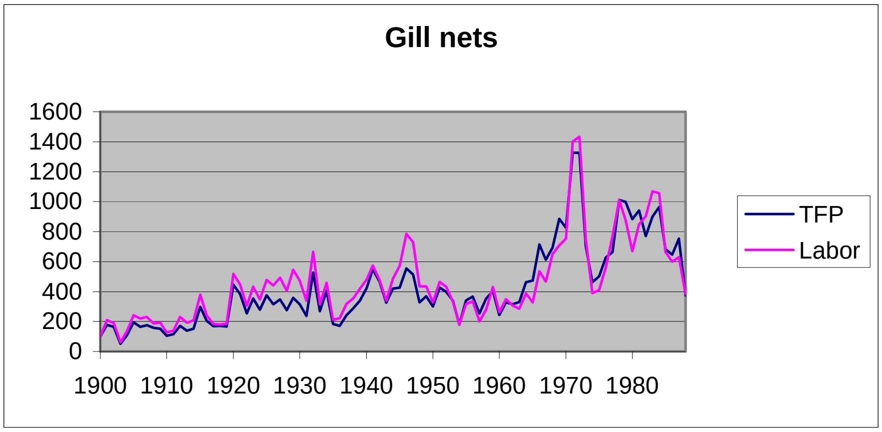
and in what follows we shall use the values a_1 = 0.65 and a_2 = 0.35.They also come close to agreeing with the revenue shares of labor and capital. The cost and earnings studies of the Lofoten fishery referred to in the section on the data report these revenue shares, determined by rules agreed between fishermen and the boatowners, who often were fishermen themselves. A part of the revenues was for the boat and so a compensation for the capital equipment used, another part was shared among the fishermen, and a third part was for defraying the expenses for the fishing gear, which the fishermen provided themselves. The reports for 1936-1951 show the combined share of labor and gear, which was fairly stable at 70-75 percent. The reports 1955-1962 show all three. If we treat the gear as short term inputs and not as capital investment and adjust the boat and labor shares accordingly, we find that the average labor share was 61, 57 and 64 percent for gill net, long line and hand line boats, respectively.

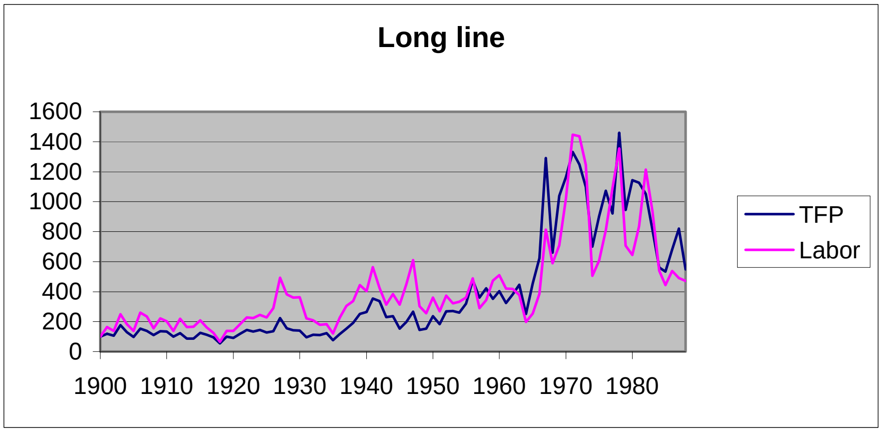
Table 5: Estimates of a_1, a_2 and b using panel data (Equation [7]). t-values in parentheses. *(**) significance at the 5% (1%) level.

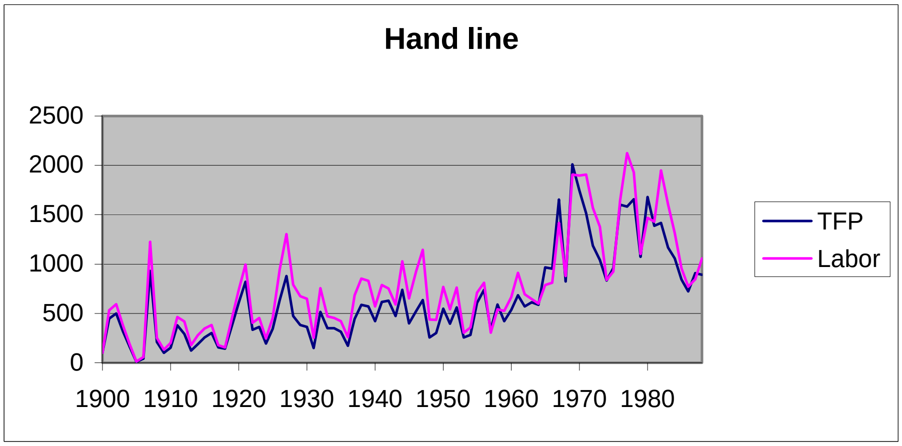
a_1	a_2	b	d_{HL}	d_{LL}	g	a_0	R^2
.6376 (4.16**)	.2965 (2.03*)	.4393 (5.82**)	-1.0524 (-7.74**)	.1200 (1.48)	.0233 (15.91**)	-1.2188 (-2.79**)	0.87

Using interaction terms of time and boats and gear types and boats, it was investigated whether these shares might differ between gear types or change over time. The only significant (at the 5 percent level) interaction term was obtained for long line and boats and indicated that the share of boats using long line is lower than for the other two. We find this difficult to believe, given that long line boats are larger than hand line boats, and it also disagrees with the results in the 1955-1962 cost and earnings studies, which show the lowest labor share for long line boats. Interaction terms for time and boats and time and men were insignificant, indicating no change in the a's over time.

Other results in Table 5 are also sensible. The b-value is about the same as obtained for gill nets in Table 4, but lower than the ones obtained for the other two traditional gear types. Interaction terms for the fish stock and these two gear types were nevertheless insignificant, but the point estimate for hand line very nearly agrees with the result in Table 4. Technological progress is estimated at about two percent per year, and hand line boats are shown to be significantly less productive than gill net boats, while there is no significant difference between long line and gill net boats. This agrees with the fact that hand line boats employ fewer fishermen than gill net boats (cf. Figure 6). Given that the same is true for long line boats, albeit to a lesser extent, we would have expected also to see a negative point estimate for the long line dummy, but smaller in absolute value than for hand line boats.







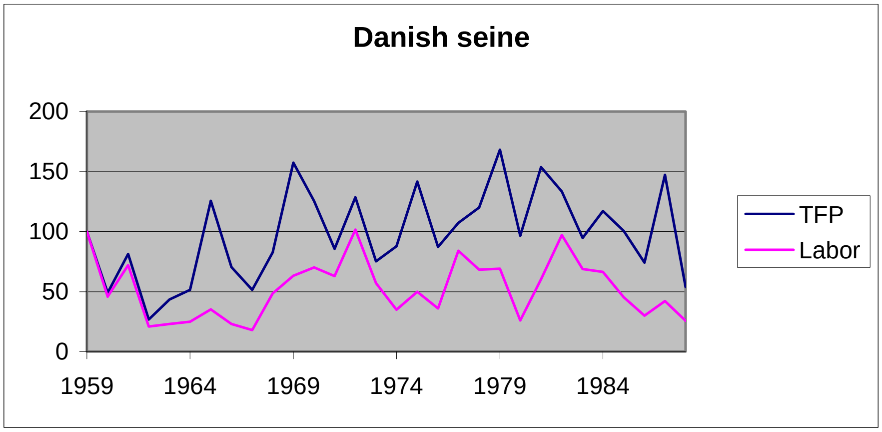


Figure 8: Labor productivity and total factor productivity in the Lofoten fishery.

Figure 8 shows the development in total factor productivity and labor productivity. In calculating total factor productivity, we have used the *b*-values in Table 4. For the three traditional gear types there is not much difference between the two productivity measures. Up to the 1960s the development in total factor productivity was more even than for labor productivity alone. This is as expected; some of the variability in labor productivity is due to variations in the fish stock, which is taken into account by total factor productivity. In the 1920s and again in the 1940s and 50s the stock was plentiful (cf. Figure 1), which gave labor productivity a boost while the total factor productivity was not so great once the stock abundance had been accounted for. For gill nets we see that productivity was low in the first two decades of the 20th century, which accords with the significantly negative dummy variables for these two decades reported in Table 4. In the period 1920-60 total factor productivity was higher than in the first two decades of the 20th century, and labor productivity higher still; this accords with the higher decadal dummies we found for gill nets in Table 5 for this period. Then, from the mid-1960s on, both total factor productivity and labor productivity shot up and also became more variable; this is captured by the high decadal dummy for the 1970s.

The pattern for long line is similar to that for gill nets, the main difference being that productivity did not begin to rise until the 1940s instead of the 1920s, which accords with the low decadal dummies for long line in the 1920s and 30s (cf. Table 4). Both labor productivity and total factor productivity are a lot more variable for hand line, but the pattern is not very different from the one for gill nets. Total factor productivity for hand line reached a peak in the 1920s, not to be surpassed until the 1960s. This accords with the small and insignificant dummies for the decades from the 1920s to the 1960s (cf. Table 4). This high productivity of boats in the 1920s may have been due to the employment of more fishermen; for a brief period in the 1920s there were about as many fishermen per hand line boat as there were per long line boat (Figure 6).

Danish seine, which did not appear until 1959, shows quite a different pattern. Here labor productivity fluctuates without much trend while total factor productivity is on a weakly rising trend and in all years higher than labor productivity, except for the initial reference year. This could indicate an ongoing technological progress being neutralized by a decline in the fish stock; the fish stock in 1988 was only about one half of what it was in 1959 (cf. Figure 2).

Table 6: Rates of growth of total factor productivity and labor productivity based on 9-years moving average.

Gear	Gill nets	Long lines	Hand lines	Danish seine
Average growth rate of labor productivity	0.0181	0.0165	0.0153	0.0111
Average growth rate of TFP	0.0209	0.0232	0.0163	0.0222
TFP-index for end year	536	641	370	162

Because of the large inter-annual variability, it is of doubtful value to look at average (geometric) growth rates based on annual data, as this affords undue weight to initial and final years, which may be untypical. Instead we shall calculate the average growth rate based on the 9-year moving average (cf. Figure 5). The results are reported in Table 6. Total factor productivity has grown faster than labor productivity for all gear types, slightly more than two percent per year for gill nets and long line, and a bit less for hand line. There are two potential reasons for this, more fishermen per boat and a decline in the fish stock. Consider total factor productivity and labor productivity in year T versus the initial year. Total factor productivity in year T relative to year 0 is (cf. [3] and [7]):

(9) $$\left(1+\bar{G}^{TFP}\right)^{T} = \frac{Y_T / Y_0}{\left(L_T / L_0\right)^{a_1}\left(B_T / B_0\right)^{a_2}\left(S_T / S_0\right)^{b}}$$

$\bar{G}^{TFP}$ being the average growth rate of productivity. Dividing by labor productivity in year *T* relative to year 0, denoting the average growth rate of labor productivity by $\bar{G}^{LP}$, and noting that $a_2 = 1 - a_1$, gives

$$(10) \qquad \frac{\left(1+\bar{G}^{TFP}\right)^T}{\dfrac{Y_T / L_T}{Y_0 / L_0}} = \frac{\left(1+\bar{G}^{TFP}\right)^T}{\left(1+\bar{G}^{LP}\right)^T} = \frac{\left(\dfrac{L_T / B_T}{L_0 / B_0}\right)^{a_2}}{\left(S_T / S_0\right)^b}$$

From (10) we see that total factor productivity will grow faster than labor productivity if the number of fishermen per boat rises or if the fish stock declines. That an increase in the number of fishermen per boat accounts for the difference between the growth in total factor productivity and labor productivity can be dismissed. For gill nets and hand line the number of fishermen per boat declined from the early 20th century to the 1980s, while for long line it was nearly the same. The fall in the number of fishermen per boat masks the deleterious effect of the decline in fish stock on productivity; for hand line the growth rate of total factor productivity is nearly the same as for labor productivity, while the difference is not very large for gill nets. For long line the effect is clearer; for this gear the growth rate of total factor productivity is appreciably higher than for labor productivity. For Danish seine the number of fishermen per boat increased over the time considered (1959-1988), but only by about 12 percent, while the fish stock fell by about one half. So even here the difference in growth of labor productivity and total factor productivity is due to a falling fish stock

6. Conclusion

For about a hundred years labor productivity in the Lofoten fishery varied a great deal but hardly increased, while from the mid-1960s to the 1980s it almost trebled. Still, this would not have been enough to prevent the fishery from lagging behind agriculture and manufacturing; but with prices rising still more rapidly, revenues per fisherman in the end did better than keeping up with the wages in these sectors, using 1860 as a base year. Productivity in value terms began to outpace physical productivity in the late 1930s, at which time price regulation was introduced. This may have resulted in higher prices, and seems to have stabilized prices, making them less dependent on the quantity caught. From the mid-1950s price subsidies were provided, which is likely to have led to higher and more stable prices. These subsidies were not eliminated until after the end of the period being analyzed here (Hannesson, 1996).

It is puzzling how the Lofoten fishery could continue for about a hundred years without any increase in productivity while wages in other sectors of the economy rose. The answer may lie in the fact that the Lofoten fishery is a seasonal fishery, combined with participation in other fisheries and agriculture. The returns from these activities may have been sufficient to justify participation in the Lofoten fishery, especially since this coincided with low activity in the other occupations. Furthermore, the Lofoten fishery provided cash income, while the farming activities with which it was combined were largely for subsistence. This may have meant an extra premium for the Lofoten fishery, even if the results were meager. Many fishermen did, however, combine the Lofoten fishery with other fisheries which also provided cash income.

From the early 1950s the participation in the Lofoten fishery, both in terms of the number of fishermen and the number of boats, fell steeply. This was a time when the Norwegian economy reached full employment and attained a high rate of economic growth. In the mid-1960s and possibly earlier, productivity (in value terms) in the Lofoten fishery began to outpace wages in agriculture and manufacturing, and from the mid-1960s the decline in the participation in the Lofoten fishery was slowed considerably, but not reversed. The productivity improvement in the Lofoten fishery was largely due to rising prices; in terms of volume it still lagged behind wages in agriculture and manufacturing. It is possible to argue that the rise in prices soothed the impact of open access and kept people in the fishery to a greater extent than warranted.

Total factor productivity has risen faster than labor productivity in the Lofoten fishery. While the technological progress in the fishery has probably been comparable to other industries in the long term, even if it has been uneven over time, it has to some extent been neutralized by a decline in the fish stock. This decline would have prevented the Lofoten fishermen from reaping the full benefits of technological progress, but rising prices came to the rescue.

It is tempting to ascribe this discrepancy between the development in total factor productivity and labor productivity to the classic open access curse. As discussed above, the Lofoten Law of 1857 established the Lofoten fishery as an open access one and did away with whatever exclusive use rights that had developed in the fishery prior to that time. Improving the lot of fishermen was the most likely intention; this was well before the concept of biological overfishing had been generally recognized, and the science of fisheries biology was yet to be developed.[19] In the longer term, however, this may have been self-defeating through encouraging excessive participation in the fishery and exposing it to the familiar evils of open access. There are three types of problems caused by open access that we may identify for the purpose of this discussion:

(i) excessive fishing, leading to a diminishing fish stock and lower future returns;

(ii) overcrowding on the fishing banks, with one fisherman's gear taking fish that another could have taken later in the season;

(iii) overcrowding so that one fisherman's gear intervenes directly with another's, for example through entanglements.

As to the first effect, this was most likely present to some extent. The mature part of the cod stock consists of several year classes of fish. Increased fishing effort in any one year lowers the survival rate of the year classes, which reduces the stock of fish available in later years. The number of boats and fishermen was at its highest in the two decades before 1900 and again in the 1920s and 30s, and so the stock externality is likely to have been most prominent in those years. These were also periods of declining productivity, preceded by a period of higher productivity that may have called forth greater fishing effort (cf. Figure 4). But each year the mature stock is replenished with new cohorts. This was increasingly determined by what was left over by the ocean fisheries that developed over the last century and mainly fished young, immature fish. Until the early 1930s the catches in the Lofoten fishery were in some years almost one half of the catches of the Northeast Arctic cod, but after 1950 they seldom exceeded 10 percent. As the 20th century proceeded, the decline in the fish stock available for the Lofoten fishery was increasingly due to a rising fishing pressure in the offshore fisheries.

[19] The history of the science of fisheries biology is told in Smith (1994).

The Lofoten reports in the 1930s make repeated references to excessive participation in the fishery, alleging that the revenues per fisherman would most likely improve if there were fewer of them. It was never made explicit exactly why this would happen: there is no reference to a "dynamic stock externality" by which excessive fishing in one year would reduce the catches in the coming years. By the 1930s it was certainly well known that the Lofoten fishery was based on several year classes, and that the survival rate of the fish to a large extent determined how much would be available the next year; in fact, there are supplementary chapters on this in many of the annual reports in the 1930s and even earlier, contributed by fisheries biologists. It is likely, however, that those who penned the annual reports had in mind problems Two and Three above, i.e., conflict between gears or gear types on the fishing banks, which increasingly had to be divided between different gear types to avoid conflicts, and fish being caught early in the season instead of being available later if there had been fewer fishermen and boats. With respect to the latter, it does not seem to have been serious enough to affect the time pattern of landings.

In the difficult years of the 1930s, new and more productive technology was the solution envisaged in the Lofoten reports. Experimenting with new types of gear had a long history in the Lofoten fishery, and so did the opposition to any such or other novelty. The opposition in the 1700s to gill nets and long line was mentioned earlier. The Lofoten reports in the 1800s inform that some fishermen believed that the underwater telegraph cables killed the fish; dead fish were reported to be deposited along the tracks of these cables (how did people know?). The report writers in the 1800s promoted scheduled calls by steamships to outlying parts of Lofoten during the fishing season, but some fishermen thought this would scare the fish away. As the boats became equipped with engines, the sound from these was alleged to do so. Experiments with seines were made in the late 1800s, but in the 1890s all seines were banned from Lofoten, due to pressure from fishermen. From the 1920s on government-financed experiments with various types of seines took place, and around 1950 the Lofoten reports were enthusiastic about the purse seine. In 1950 this gear began to be used on an appreciable scale, but it took only a couple of years for the reports to express great doubts about this. The fishermen using the "traditional" gear saw it as a threat, in the spirit of their forerunners in the 1700s who felt the same way about gill nets and long lines. The purse seine took up a lot of space, and it was quite effective, threatening to make a large number of fishermen redundant. In 1958 it was outlawed.

The “long waves” in participation in the Lofoten fishery are consistent with the role of an open access fishery as livelihood of last resort, where people enter or exit as a result of demographic pressures or rise and falls in outside options. The immigration to Nordland County before 1900 was accompanied by increasing participation in the fishery, the emigration, both to America and to the rest of the country, coincided with a decline in participation, and participation in the fishery reached new heights as emigration, both to America and the rest of the country, more or less came to an end in the 1920s and 30s. Then, as the Norwegian economy entered the era of full employment and economic growth after the Second World War, participation in the fishery declined, especially as regards the number of fishermen, and labor productivity in the fishery rose.

The history of the Lofoten fishery has a familiar ring to it; this is not unlike the situation in the fisheries of many of the world’s poor countries today. For a long time the Lofoten fishery played the role of an employment opportunity of last resort; when times were bad people had resort to it, because of its open access character. There was political pressure from fishermen to keep things that way, and pressure to ban new technologies that would save labor in the fishery and would be expensive for fishermen to acquire. Open access and prohibition of some efficient technologies (but not all) may have succeeded in distributing incomes more widely, but one may ask whether increased participation led to lower returns and only succeeded in distributing poverty more widely. Banning more efficient technologies and the development of access rights in suitable localities is certainly likely to have meant foregoing increases in productivity.

And as times got better, the exodus began. Productivity improved, partly through technological improvement but probably because of less participation as well. The productivity improvement may well have been self-enhancing, due to a positive feedback on technology; new technology is typically expensive and its returns uncertain, so poor fishermen are unlikely to introduce it, as is also abundantly clear from the opposition to new methods that always has come from the less well-off fishermen.

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APPENDIX

Assume the catch flow function is

$$\frac{dY}{dt} = -ES^b$$

With no stock growth and no natural mortality during the fishing period, we have

$$\frac{dY}{dt} = -\frac{dS}{dt} = ES^b$$

or, in other words, catch over a period of length Δ will be simply the difference between the stock at the beginning of the period and the stock at the end of the fishing period:

$$Y = S_0 - S_\Delta$$

To find S_Δ we solve the above differential equation for *S*. For *b* = 1 we get the following:

$$\int \frac{dS}{S} = \int d\ln S = -\int Edt$$

$$S_\Delta = S_0 e^{-E\Delta}$$

$$Y = S_0\left(1 - e^{-E\Delta}\right)$$

Since $1 - e^{-E\Delta} < E\Delta$ and diminishing in *E*, we will have diminishing returns to effort, which will give a lower estimate of *a* than is valid for the instantaneous yield function.

For *b* < 1 we get

$$\int S^{-b} dS = \frac{S^{1-b}}{1-b} = \int -E dt$$

$$S_\Delta = \left[S_0^{1-b} - (1-b) E\Delta \right]$$

$$Y = S_0 - S_\Delta = S_0 - \left[S_0^{1-b} - (1-b) E\Delta \right]^{1/(1-b)}$$

Also here there are diminishing returns to *E*, and more so than with $b = 1$, so the estimate of *a* will be lower than what holds for the instantaneous yield function.

NHH

Norges Handelshøyskole

Norwegian School of Economics
and Business Administration

NHH
Helleveien 30
NO-5045 Bergen
Norway

Tlf/Tel: +47 55 95 90 00
Faks/Fax: +47 55 95 91 00
nhh.postmottak@nhh.no
www.nhh.no