Working Paper No. 35/08

The Norwegian winter herring fishery: A story of collapse and technological progress

by

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SNF Project No. 5255
Strategic Program in Resource Management

The project is financed by the Research Council of Norway

INSTITUTE FOR RESEARCH IN ECONOMICS AND BUSINESS ADMINISTRATION
BERGEN, December 2008
ISSN 1503-2140

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Abstract

This paper uses data from early 20th century to 1971 to estimate a production function for the Norwegian winter herring fishery, which collapsed in the early 1970s. The focus is on technological progress and the sensitivity of the catch per unit of effort to the size of the stock. This relationship appears to have become stronger rather than weaker as a result of the introduction of the sonar and the power block. The productivity increase appears to have been greatest for the power block, and then for echo sounders and engines used in auxiliary boats. Estimates of stock elasticity indicate little sensitivity of the catch per unit of effort to the size of the fish stock.

November 2008

1. INTRODUCTION

Around 1970 the herring stocks in the Northeast Atlantic were nearly fished to extinction. Spring spawning stocks at Iceland and the Faeroe Islands disappeared and have not returned, leaving only Norwegian spring spawning herring. Only in the mid-1980s did this stock begin to recover, after several years of virtually no fishing. North Sea herring and Icelandic autumn spawners also took years to recover.

This collapse is usually attributed to a technological revolution in the herring fisheries that occurred in the 1960s.[1] This revolution was two-pronged. A mechanical winch, usually called power block, was installed for pulling the seines used for catching the fish. This allowed the use of larger seines and, in turn, larger boats. Secondly, fish finding equipment (sonar) was developed. This made it possible to detect shoals of fish underneath the surface of the sea, whereas previously they had been located by observing ripples on the surface.

The power block was installed in virtually all Norwegian purse seine boats over just a few years. That in itself speaks volumes about the productivity gains obtained with this equipment. Unfortunately this was a passing episode. Shortly after the said technology revolution the herring stocks crashed, and catching herring was banned for years afterwards. In the meantime, the fishing fleet survived by turning to previously unexploited stocks of capelin that could be fished with this technology.

The effect on a fish stock of a leap in productivity depends critically on how sensitive the fish catch is to the size of the stock. If the catch per unit of fishing effort[2] is proportional to the size of the stock, catches will fall proportionally with the stock for a given level of effort, providing some protection as it were from increased effort or rising productivity.[3] If on the other hand the catch of fish is not very sensitive to the stock size it could be maintained at a high level even as the stock is depleted, increasing the risk of depletion below the critical level of viability. Needless to say, this turn of events is predicated on the absence of any fish stock management, but that was indeed the reality before the advent of the exclusive economic zone when stocks were fished on the high seas by fleets from many different nations competing with one another. The Norwegian spring spawning herring was exploited by fishing fleets from many nations, most notably Norway, Iceland and the Soviet Union. Any effort at saving the stock would have required a joint action by all three and probably others as well, as long as the stock was accessible on the high seas. This was not attempted, and it is doubtful if the problem was recognized in a timely enough fashion to initiate any such action. As the stock was depleted, its extensive migrations ceased and it became confined to Norwegian waters, which in 1977 were extended from 12 to 200 nautical miles with the establishment of the

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[1] The collapse of the herring stocks coincided with a falling sea temperature, which is also suspected for having contributed to the collapse (Toresen and Østvedt, 2000).

[2] Fishing effort is a measure of the activity of the fishing fleet aimed at catching the fish, such as the number of boats or men multiplied by the time fishing.

[3] For a formal analysis, see Hannesson (1993).

exclusive economic zone. Norwegian fishing of the stock virtually came to a halt and may have rescued it from irreversible depletion.

At about the time when the herring stocks were heading for a collapse, fisheries biologists began to notice the low sensitivity of the catch per unit of effort to the size of the stock. Ulltang (1980) found this to be the case for the Norwegian spring spawning herring, using data from the 1950s and 60s. Bjørndal (1987), using a different methodology, reached a similar conclusion for the North Sea herring. Bjørndal's data covered years after the new fishing technology had become established, while at least some of Ulltang's data were from years before the technological revolution had taken place. Still, one may ask whether this weak relationship between the catch per unit of effort and the stock size was of long standing or brought about by the new technology that made it easier to find and to encircle large shoals of fish.

In this paper we shall investigate the winter herring fishery in Norway, using data from the early 1900s until the crash in 1971. We will also use a more detailed data set available for the purse seine fishery from 1932. This fishery began in 1925, but due to its technological development and the dwindling of the fish stock it was the only one that remained in the end. The winter herring fishery exploited the spawning migration of the herring, which in winter comes in from the Norwegian Sea to the west coast of Norway. The duration of this migration varied; sometimes it began as early as late December, but could begin as late as early February. By March or April the fishery was over. There is a strong indication that the duration of the migration varied with the stock size, as will be seen in Section 3.

Our investigation is concerned with two things. The first is the sensitivity of the catch per unit of effort to the stock size. Is it low (close to zero), as often believed to be the case for stocks like herring, which aggregate in shoals? This would mean that the catch per unit of effort can be maintained despite a dwindling stock, so increasing the risk of a crash such as the one that in fact took place in the late 1960s. The second question we look at is the development of productivity in the fishery. How rapid was it? Is it possible to identify productivity gains with the coming into use of new equipment such as fish finders, echo sounders, nylon seines, or the power block? Did the new equipment make the catch per unit of effort less sensitive to the stock size, thus increasing the vulnerability of the stock?

2. A PRODUCTION FUNCTION FOR THE FISHERY

The winter herring fishery was traditionally conducted with gill nets, land seines and purse seines. The first two are represented in the data from the beginning in 1909, while the purse seine came on the scene in 1925. Trawl was also used for a few years in the 1960s, but will be disregarded in what follows. Land seines disappeared from the statistics in 1960 and gill nets in 1969, so towards the end the winter herring fishery was increasingly conducted by purse seiners.[4]

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[4] The fisheries statistics were compiled and published by the Directorate of Fisheries. There is some ambiguity in the data as to which kind of gear was being used. In some years the statistics list various combinations of land seines and purse seines and even gill nets. Therefore, there is undoubtedly some error

A production function specification often used in fisheries economics is the following:[5]

(1) $$Y_t = E_t^a q S_t^b e^{gt}$$

where Y_t is the catch of fish at time t, E_t is fishing effort, S_t is the size of the fish stock exploited, and the exponential term takes care of technological progress.

If $a = 1$, there are constant returns to fishing effort. Dividing through by E, we get catch per unit of effort (y):

(2) $$y_t = q S_t^b e^{gt}\text{, } a = 1.$$

If $b = 1$, catch per unit of effort would be a perfect index of the stock size, except that with technical progress ($g > 0$) the catch per unit of effort would rise faster, or fall more slowly, than the stock. The parameter b shows the dependence of the catch per unit of effort on the stock size; as b falls it becomes weaker, and for $b = 0$ the catch per unit of effort is constant (but rising over time if there is technical progress) and independent of the stock.

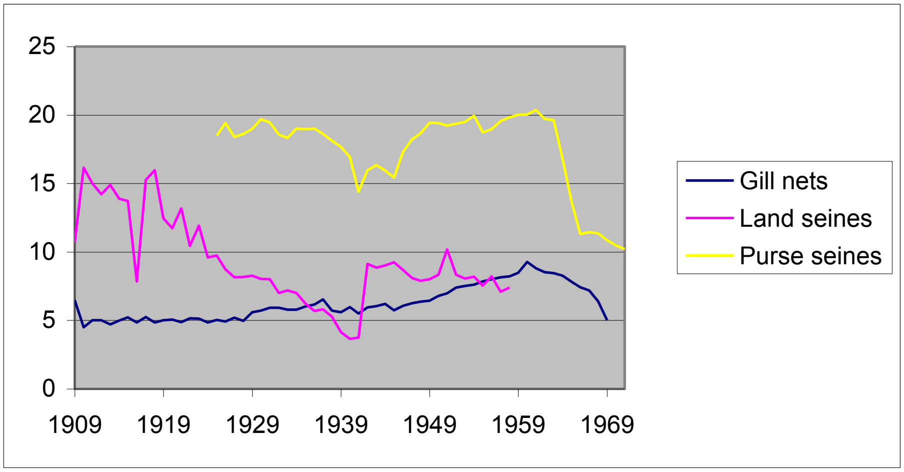

Figure 1: The number of fishermen per boat (team for land seines) 1909-1971.

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in the data on how the catches and participation in the fishery are split between the three categories we have used.

[5] This formulation is most appropriate for a continuous time model. With a discrete time model one would ideally have to take into account how the fish stock is fished down from the beginning to the end of the period as well as its growth over the period. We shall disregard this, and the available data would hardly allow this to be done properly. The fishing took place while the stock was on a spawning migration, so there may have been a more or less continuous flow of fish towards, and then away from, the spawning grounds, rather than an initial stock in place being thinned by the fishery. Hence Equation (1) is likely to be a good approximation.

Fishing effort is produced by combining real capital in the form of fishing boats and their equipment with manpower and intermediate inputs. There are data on the number of boats (teams for land seines) and the number of fishermen using various gear types, but the number of boats and the number of fishermen are too closely correlated to be used together as regressors, so we have to define effort as either the number of fishermen or the number of boats or teams. Nevertheless, there is some variation over time in the number of fishermen per boat or team. Figure 1 shows the number of fishermen per boat (team for land seines) over the period considered. The most conspicuous change is the abrupt fall in the number of fishermen per purse seiner in the 1960s. This was brought about by the introduction of the power block, clearly an effective labor saving device. The number of fishermen per purse seiner fell from about 20 in 1963 to about 11 in 1966. Over the same period the share of boats using power block rose from 3 percent to 99 percent. Other things we may note is a fairly steady decline in the number of men per land seine team from 1909 to 1940, and a jump upwards to a still low and relatively stable level after that. The number of fishermen per gill net boat stayed fairly constant at about five up until 1929, rising gradually after that to almost ten in 1960, and than falling rather abruptly back to five in 1969, when the gill net fishery came to an end.

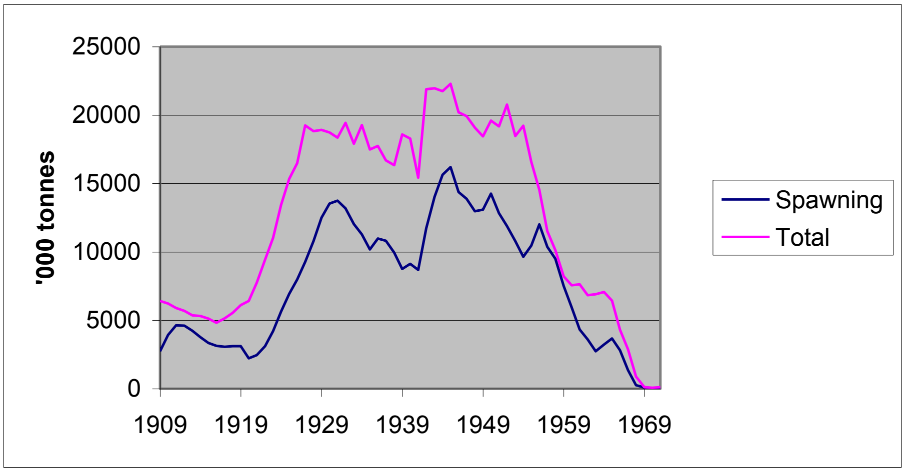

Figure 2: Norwegian spring spawning herring. Spawning stock and total stock. Source: Toresen and Østvedt (2000).

As to the stock, estimates of its size are available from Toresen and Østvedt (2000). These estimates show both the total stock and the mature (spawning) part of it. The fisheries we are concerned with here fished on the spawning migration of the stock, but younger year classes of fish were also at least partly available for the fishery. Here we will use both and try to ascertain which one is a more appropriate measure of the stock exploited by the fishery. Figure 2 shows how the stock developed over time. The spawning stock was usually well over a half of the total stock, and both developed in a roughly similar way, but over time the share of the mature part declined, as fewer fish survived to maturity due to a rising rate of exploitation. Note that even with a constant degree of exploitation the mature stock would have developed somewhat differently from the total stock, because the size of the stock is largely determined by exceptionally large year classes that appear from time to time and do not become mature until they are 4-5 years old.

Table 1 shows the results from estimating the parameters of Equation (1) for the three main gear types, using effort and catch per unit of effort, both lagged one period, as instrumental variables for effort. There is a strong correlation between the number of fishermen or boats each year and the number the year before, and there is a positive correlation between the catch per man (or boat/team) the year before and the number of fishermen (boats/teams) participating in the fishery in any particular year, although the latter is significant only for purse seining and land seine teams.[6]

Table 1: Results of estimating Equation (1), using effort and catch per unit of effort lagged one period as instrumental variables for effort. t-values in parentheses. ** (*) denotes significance at the 1% (5%) level.

Gear	Stock	Effort	*a*	*b*	*g*	Constant	R^2
Land seine (1909-1959)	Spawning	Men	.2853 (0.88)	.2735 (0.52)	-.0370 (0.89)	1.8183 (0.53)	0.4202
		Teams	.0908 (0.37)	.4517 (0.85)	-.0605 (1.86)	2.5077 (0.69)	0.3611
	Total	Men	.1869 (0.38)	.4988 (0.58)	-.0499 (0.79)	.6264 (0.15)	0.4026
		Teams	-.1124 (0.31)	.9970 (1.22)	-.0868 (1.88)	-1.1018 (0.21)	0.3319
Gill nets (1909-1968)	Spawning	Men	1.1505 (7.40**)	.5285 (3.01**)	.0231 (4.33**)	-8.7421 (12.38**)	0.9091
		Boats	1.3258 (7.64**)	.3748 (1.99)	.0414 (5.76**)	-7.0902 (10.23**)	0.9116
	Total	Men	1.2349 (8.89**)	.5093 (2.78**)	.0257 (5.15**)	-9.6677 (10.84**)	0.9046
		Boats	1.4343 (8.95**)	.2883 (1.42)	.0456 (6.79**)	-7.3728 (7.67**)	0.9051
Purse seine (1925-1971)	Spawning	Men	.6904 (2.12*)	.3977 (2.57*)	.0329 (2.76**)	-3.3482 (1.91)	0.6104
		Boats	.9264 (2.67*)	0.3946 (2.98**)	.0282 (2.38*)	-2.5095 (1.94)	0.6338
	Total	Men	.7731 (2.73**)	.4424 (2.76**)	.0341 (2.87**)	-4.7172 (2.83**)	0.6078
		Boats	.9970 (3.28**)	.4612 (3.33**)	.0303 (2.61*)	-3.8088 (2.78**)	0.6385

The results in Table 1 are not very decisive with respect to which would be the most appropriate measure of the available stock, the total stock or the spawning stock. For purse seine we get higher point estimates and *t*-values for the total stock than the

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[6] OLS gives similar results, but is plagued by serial correlation.

spawning stock, but for gill nets the opposite. It is of course possible that these two gear types fished on different stock components, but the results are hardly strong enough to support that conclusion. The point estimates for land seines indicate that the total stock is a better measure, but these estimates are not significantly different from zero and so do not really support a clear conclusion.

All the estimates for land seine are insignificant, but this is not entirely unexpected. Land seines were operated from land, and their success depended critically on the migration of the fish, i.e., whether they would pass sufficiently close to shore to be captured by the land seines. This varied considerably from one year to another. The results in Table 1 indicate that the passage of the stock critically close to shore was largely determined by random factors.

For gill nets and purse seines we get significant and reasonable coefficients. The coefficient for effort is in most cases not significantly different from one, implying constant returns to scale (the exception is gill net boats with total stock). For the fish stock we get significantly positive estimates, but all are significantly less than one. Hence the catch per unit of effort appears to have increased with the stock, but at a diminishing rate. For the time variable we get coefficients implying technical progress of 3-5 percent a year. This is a bit on the high side but not totally unbelievable, since we know that there was substantial technological progress in the fishery over the period in question.

The problem with these estimates is, however, that they are very sensitive to shortening of the time series. If we end the time series in the early 1960s both a and b become insignificant both for gill nets and purse seines, and the point estimates may even turn negative. Shortening the series at the beginning leads to less dramatic changes; for the gill net boats it raises the estimates of b to around 1. This instability of the estimates makes it difficult to take them seriously. Perhaps we may conclude that the “stock effect” is very weak; the stock elasticity (b) is probably small and close to zero, implying that the catch per unit of effort is nearly independent of how large the stock is. In fact, for gill net boats the said coefficient is not significantly different from zero.

3. A CLOSER LOOK AT THE PURSE SEINE FISHERY

The purse seine fishery was undoubtedly the one that experienced the most radical technological progress. Already before the Second World War, the auxiliary boats helping to close and pull the seine became equipped with engines. In the 1960s the sonar and the power block became widespread. The report published each year on the winter herring fishery contains information on how may of these devices the boats were equipped with, as well as information on boat values, participation in the fishery and the amount of fish caught.[7] Initially these reports covered only the fishery south of Stadt, but from 1942 on the herring fisheries north of there were also included. This is probably not a problem, since much of the fishing took place south of Stadt in the early period. We have pushed the time series back to 1932, but the degree of detail reported increased as

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[7] These reports are published in the series ”Årsberetninger vedrørende Norges fiskerier”, published by the Directorate of Fisheries.

time went on, until the late 1960s when the reporting again became less detailed. First we shall discuss the information that seems potentially useful for estimating a production function for the fishery and the technological progress that occurred and then report on the results from using this information.

Value of boats

For the years 1932-1963 the average value of purse seiners was published. This we have converted to constant value of money, using the consumer price index. For the years 1942-1968, with one exception, information was provided on the average size of boats, measured as cargo capacity volume (hectoliters). There is a very close relationship between the average size and the average value of the boats, which we have used to estimate the average value of the boats 1964-68. For 1969-1971 no special reports on the winter herring fishery were published, only summary statistics in the ordinary fishery statistics. For these years we have assumed a value of 650. Figure 3 shows the average size and value of purse seiners for overlapping years, as well as a curve fitted to them by a linear regression involving both size and size squared. The average boat size 1964-68 varied between 2100 and 2750 hl and was thus well within the range for which we have observations of both value and size.

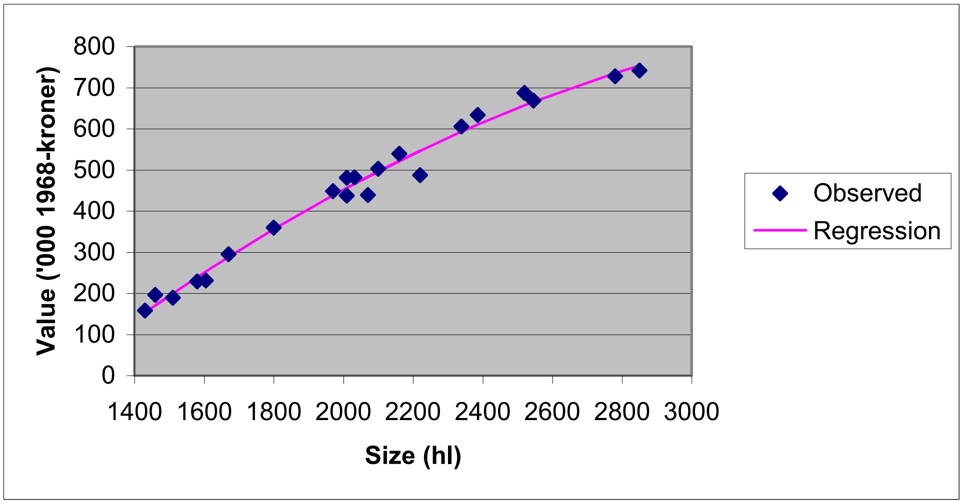

Figure 3: Average value ('000 1968-kroner) and size (hl. cargo capacity) of purse seiners 1942-1960 and 1962-3, with a parabolic curve fitted to the observations.

Weather and season length

The reports on the winter herring fishery contain quite detailed information on the weather, when the herring fishery began, and whether any fish was caught this or that day. From 1942 to 1961 diaries recorded by a skipper were published as a part of the winter herring fishery report. It is difficult, however, to construct an index of fishing days from this information; the area where the fishery took place is quite extensive and the weather not necessarily uniform over the entire area. In some years the diary-keeper quit the fishery early, so keeping to his diaries would provide too few fishing days. We settled for constructing a weather index on the basis of how each fishing season was characterized in the reports and the diary, compared to earlier seasons, giving a value of 0 to exceptionally bad years and 2 for exceptionally good ones, with 1 for normal years. This resulted in 9 bad and 8 good years out of 40, and hence 23 normal years. As to duration of season, tables of catches at the end of each week are published in the reports. From this we compiled the number of weeks, leaving out weeks with less than 1 percent of the aggregate catches. This provides some correction for length of season. In some years weeks with virtually no catches occurred in the middle of the season. This could be due to poor weather conditions, but could also be due to interruptions in the herring migration.

Technical change

In the period 1932-1971 the technology in the herring fishery changed beyond recognition. The winter herring reports make it possible to trace the technological innovations, at least to an extent. The indices in Figure 4 show the number of equipment recorded divided by the number of boats. This should come close to showing the share of the fleet using the equipment in question, but some boats could have had more than one piece of equipment and others none; for later years the statistics show more radio receivers, radars, and echo sounders than there were boats. For these cases the index has been set equal to one.

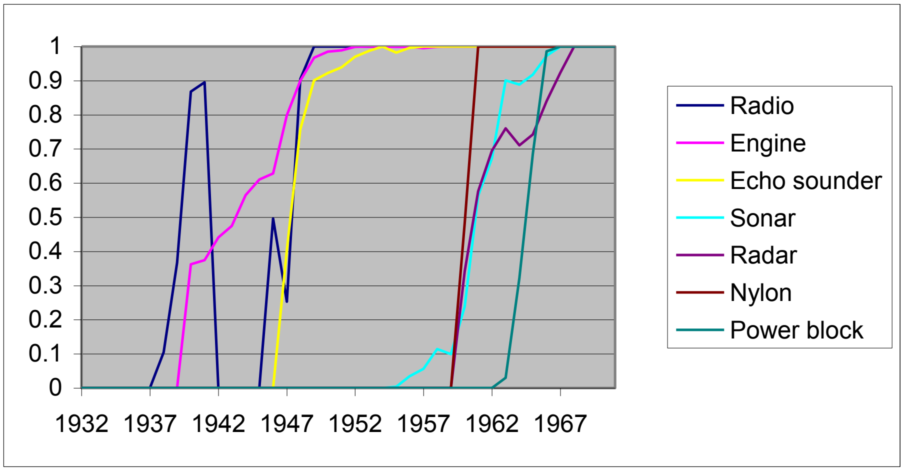

Figure 4: Indices of equipment used in the fishery. The index shows the number of equipment divided by the number of boats, but with a maximum of one.

The first major new equipment to be introduced was radio receivers. In 1938 10 percent of the boats had receivers. This is likely to have been helpful for following news about whether the herring had come within range and where it had been found, as well as weather reports. The number of radio transmitters (not shown) was in the beginning close to the number of receivers, and in most cases these were probably one and the same. The abrupt fall 1941-45 is due to the banning of this equipment by the German occupation authorities, although exemptions were usually granted as the season progressed.

The statistics for 1940 shows that 36 percent of the auxiliary boats used for hauling in the purse seine were fitted out with engines. Before the power block appeared on the scene the purse seine was hauled in by hand, a very demanding work. The engines did not make this any easier, but must have greatly increased the maneuverability of the boats and the likelihood that a shoal of herring would be enclosed in a timely fashion and prevented from escaping. In addition the engines should have saved much labor otherwise needed for rowing the boats. It is highly likely that the engines were introduced gradually already before 1940, as the fraction of boats using this equipment increased gradually from 1940 on, but on this the reports are silent.

In 1947 echo sounders suddenly appear, and their number was 40 percent of the number of boats. As for the engines in the auxiliary boats, this equipment may have been introduced more gradually, but it was undoubtedly difficult to obtain during the war, and the first post-war years were characterized by rationing, *inter alia* of foreign currency. Echo sounders were useful for finding fish, which showed up as black spots on a roll of paper.

Sonar equipment (asdic) came much later than the echo sounders.[8] This equipment makes it possible to detect fish concentrations underneath the surface of the ocean. They do not have to be right underneath the boat, as for the echo sounder, and their movements can be studied. Prior to the sonar, suitable concentrations of herring were usually detected as ripples on the water. Nevertheless, the sonar caught on more slowly than the echo sounder; two pieces of equipment appeared in 1955, but it was not until 1967 that the number of sonar equipment reached the same level as the number of boats. Nylon seines are reported for the first time in 1960 when their number was about half the number of boats, but the reports for earlier years mention nylon seines without noting their number. Nylon seines did not need to be dried as regularly as cotton seines and were stronger. Judging from this information on the nylon seines, some of the technology variables may show a too abrupt introduction of the equipment in question, especially when a large fraction of the boats suddenly seems to be equipped with it. The sonar and the power block are not in this category, as they first appear in small numbers relative to the number of boats.

Radar is a navigation equipment. In 1960 the number of radars was about one-third of the number of boats. Its use spread rapidly; almost 60 percent had radar a year later and then 70 percent in 1962, and in 1968 there were more radars than boats (some may have had two and some none). But what spread most rapidly of all, apart from nylon seines, was the power block. In 1963 only three percent of the boats had it, a year later 30 percent, in 1965 almost 70 percent, and in 1966 virtually all boats were equipped with power block. The power block made it possible to haul in the purse seines mechanically, did away with the use of the auxiliary boats and was hugely labor saving; the average number of fishermen per purse seiner fell from about 20 in 1964 to 11 in 1966.

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[8] Asdic is a British acronym, the first three letters being derived from anti-submarine division. Sonar is an American acronym, derived from sound navigation and ranging. Both describe essentially the same type of equipment, but sonar is the one most widely used. These technologies, which originally had a military use, were adapted for fishing after the Second World War.

Estimating a production function

As already discussed, the fishing season varied in length, and the weather conditions certainly differed from year to year. It turns out that the season's length is highly correlated with the size of the fish stock[9] and that including it in the regression only reduces the value of the stock elasticity and makes it insignificant while the season's length variable is significant. It therefore makes little sense to include both in the regression. A likely explanation of this is that the larger the stock the longer the fish migration lasted, thus lengthening the fishing season. It thus appears doubtful whether the stock elasticity means that more fish can be caught per unit of effort, effort having a time dimension and being defined as the number of boats or fishermen times the days they were fishing. Instead, a larger stock simply could mean a longer fishing season. In Table 2 below we report estimates both for effort defined as the number of participating fishermen or boats and as fishermen or boats multiplied by the season's length in weeks. The regressions were run for both the total stock and the spawning stock, but the point estimates of b and their t-values were in all cases higher for the total stock, so these regressions are the ones reported in Table 2. This accords with the results for purse seiners in Table 1.

Table 2: Estimating a production function for the purse seine fishery 1932-71 by using effort and catch per unit of effort lagged one year as instrumental variables for effort and including the weather variable. t-statistics in parentheses, ** (*) denotes significance at the 1% (5%) level.

Effort variable	Effort	Stock	Time	Weather	R^2
Fishermen	0.6367 (2.30*)	0.4998 (2.83**)	0.0270 (1.58)	0.4052 (2.20*)	0.6589
Fishermen-weeks	0.8388 (3.02*)	0.2599 (1.29)	0.0319 (2.08*)	0.3858 (2.15*)	0.6776
Boats	0.9446 (3.43**)	0.4615 (3.38**)	0.0199 (1.28)	0.3662 (2.19*)	0.7197
Boat-weeks	1.0401 (4.09**)	0.2704 (1.73)	0.0305 (2.25*)	0.3517 (2.20*)	0.7464
Value of boats	0.6484 (2.78**)	0.4459 (2.80**)	-0.0193 (0.71)	0.4103 (2.32*)	0.6839
Value of boats-weeks	0.7498 (3.39**)	0.2805 (1.58)	-0.0199 (0.84)	0.3997 (2.37*)	0.6773

As discussed above, we constructed both a weather variable and a length of season variable from the reports on the winter herring fishery. The weather variable is significant at the 5 percent level in all cases and has the expected positive sign. In Table 2, effort is defined both as a "stock" of fishermen or boats and as man-weeks and boat-weeks. It is noteworthy that incorporating the time dimension into effort reduces the estimates of b and makes it insignificant, thus supporting the statement that the significantly positive

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[9] The correlation coefficient is 0.80 for the total stock and 0.75 for the spawning stock.

output elasticity of the stock found above may mean that a larger stock is available for capture for a longer period of time, but not necessarily that the catch per boat per unit of time (day or week) will increase with the stock.

The technical innovations discussed above should have either increased the output from the herring fishery, for any given level of effort, or lowered the cost of effort. Since we do not have any cost data, we can only investigate the first effect. The production function could have been positively affected in two ways: (i) it could have been shifted upwards, leaving the parameters *a* and *b* unaffected, or (ii) one or both of these could have been affected as well. We return to the second point below for the power block and the sonar.

Given the data at hand, the most promising way of dealing with the effects of the technological innovations discussed above is by variables showing the share of the boats using the equipment in question (see Figure 4). An introduction of a device such as the echo sounder should have shifted the production function upwards, more or less proportionately with the spreading of the echo sounder among the boats. Once all boats had this equipment, such shifts should have come to a halt, except that it may have taken some practice to learn how to use the echo sounder, and the equipment itself is likely to have improved over time. Ignoring these latter effects, the positive shift due to the echo sounder would have occurred over the period during which it was introduced, and thereafter the production function would have settled down at a higher but stable level. The introduction periods for new equipment sometimes overlap, and hence there is a high correlation between some of the variables showing the share of the fleet having a certain type of equipment. This causes multicollinearity problems, and so the most promising way of dealing with their effects is to incorporate them into the regression one at a time. The results from using the said technology variables in this way are shown in Table 3. Effort is defined with a time-dimension (man-weeks or boat weeks), as this tended to produce more significant coefficients for the technology variables. The estimates of *a*, *b* and the weather variable have been suppressed, but needless to say they change slightly from case to case.

Table 3: Estimating technological progress with Equation (1) augmented by innovation variables. t-statistics in parentheses, ** (*) denotes significance at the 1% (5%) level.

Variable	Effort = man-weeks	Effort = boat-weeks	Effort = value of boats-weeks
Power block	2.1781 (3.88**)	1.3570 (2.61*)	1.4526 (2.86**)
Engine aux. boat	0.7434 (2.17*)	0.7728 (2.66*)	-0.1941 (-0.37)
Sonar	0.6437 (1.19)	0.3898 (0.85)	-0.4525 (-1.01)
Nylon	0.2333 (0.53)	0.1597 (0.42)	-0.6179 (-1.80)
Echo sounder	0.7689 (2.30*)	0.6782 (2.38*)	-0.0630 (-0.08)
Radar	0.5578 (0.88)	0.3272 (0.61)	-0.6526 (-1.30)
Radio	0.5371 (1.47)	0.4868 (1.56)	-0.2591 (-0.51)
War	-0.4003 (-0.86)	-0.2418 (-0.57)	-0.3635 (-0.90)

In the regressions with effort defined as man-weeks or boat weeks, all the technology variables have the expected sign, and the war variable has the expected negative sign. Only three of the technology variables, the power block, engines in auxiliary boats, and the echo sounder, are significant however (at the 5 percent level). The magnitudes of these estimates can be compared, given the way the technology variables have been defined. The power block is the variable which has the largest effect, and it is greater for man-weeks than for boat-weeks, which is not surprising; as discussed earlier the power block drastically reduced the number of fishermen per boat, thereby enhancing the productivity of labor.

The relative significance and magnitude of these estimates also make sense. The power block was probably the most important of them all; the drastic fall in the number of men per boat, earlier discussed, certainly indicates so. We would also expect the engines in auxiliary boats, the sonar and the echo sounder to have been important, the latter two because they made it easier to locate the fish. It is surprising, however, that the estimate of the sonar variable is not significant; one would have expected it to be at least as important as the echo sounder. That nylon seines and radar neither score particularly high nor pass tests of significance is not entirely surprising; nylon seines are stronger than cotton seines and need less care, but do not necessarily catch more fish, and radar is primarily a navigational equipment.

The results for effort defined as value of boats-weeks are quite special, as all the estimates except for the power block are negative. The reason could be that the effects of the said innovations are already included in the reported value of the boats; the reports on the winter herring fishery do not inform us how these were calculated and whether equipment such as echo sounders was included or not. The introduction of this equipment may have coincided with boats becoming better and more expensive in general, so their effect would be drowned by the effect of the rising value of boats.

Table 4: Estimating Equation (1) with weather and technology variable replacing time trend. t-statistics in parentheses, ** (*) denotes significance at the 1% (5%) level.

Effort variable	Effort (*a*)	Stock (*b*)	Weather	Technology	R^2
Man-weeks	0.6895 (3.03**)	0.5698 (3.23**)	0.3170 (2.13*)	0.6272 (4.59**)	0.7786
Boat-weeks	0.8086 (3.40**)	0.4884 (3.15**)	0.3151 (2.24*)	0.6325 (3.92**)	0.8014

Using the estimated values in Table 3, it is possible to define a technological progress variable as the sum of the products of these coefficients and the corresponding technology variable. This we have done for the three significant technology variables in the regressions for man-weeks and boat-weeks and used in a new regression, reported in Table 4. The results are reasonable, especially for boat-weeks; both a and b are significantly positive, b is significantly less than one, while a is not significantly less than one. The technology variable is significantly positive in both cases, and R^2 is high.

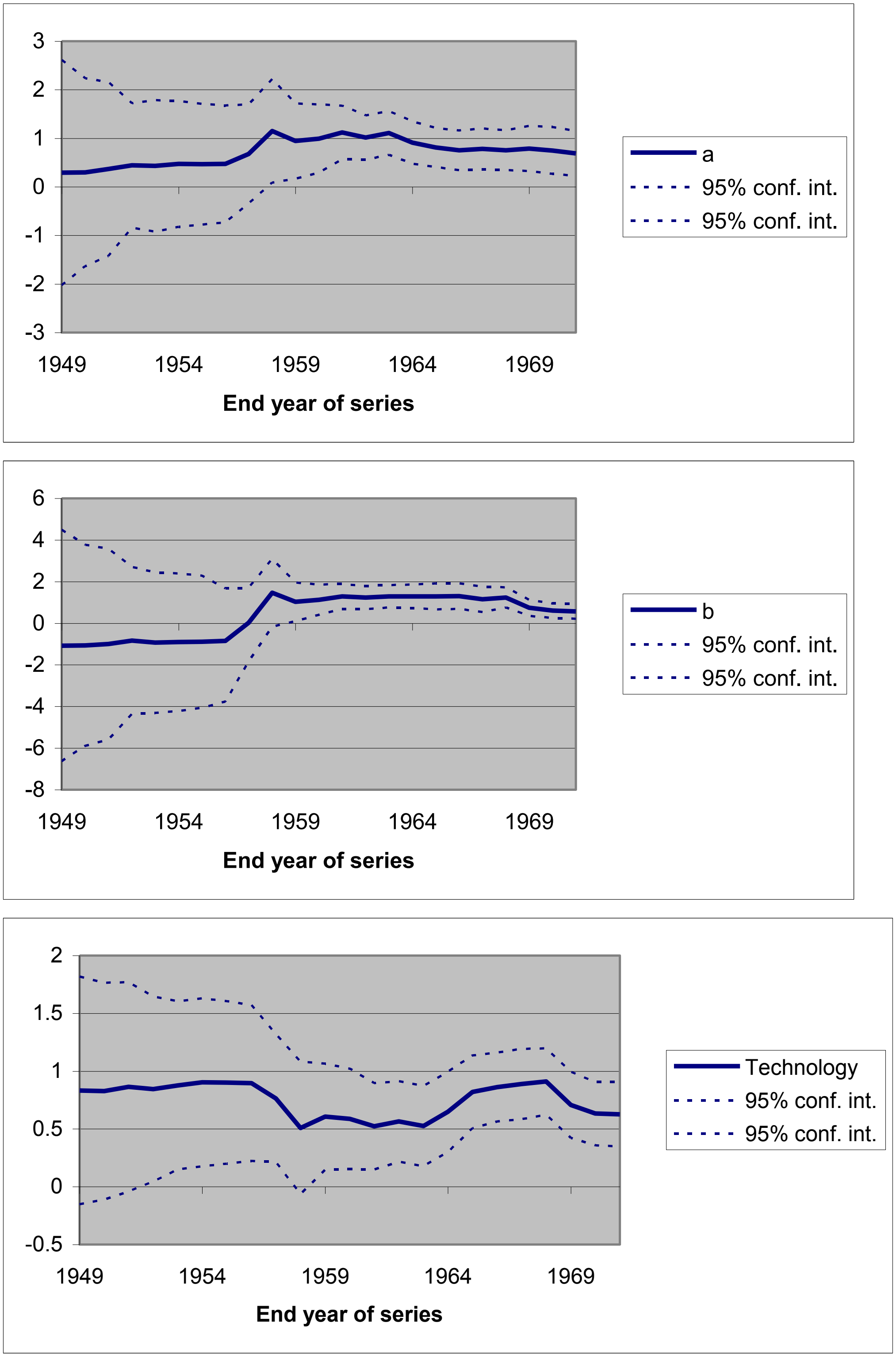

Figure 5: Results of shortening the time series for estimating *a*, *b* and technological progress.

Even if *b* is significantly positive in Table 4, we are not confident that the catch per unit of effort has been sensitive to the stock size throughout the whole period under consideration. If the time series is shortened from the end, the point estimate of *b* falls and becomes insignificant as we get back to the late 1950s, as shown in Figure 5. Shortening the series from the beginning and up to 1950 has on the other hand a rather small effect on the estimates of *b* and the other parameters.

From Figure 5 we see that the estimates of *b* as well as *a* and the technology variable suddenly change as we end the series in 1957 or earlier. So what happened in 1957? The purse seine catches in the winter herring fishery dropped from 4.9 million hectoliters in 1957 to only 1.8 in 1958, while the stock size and the number of men and boats participating in the fishery were about the same in both years. The report on the winter herring fishery for 1958 tells us that the fishing was poor because there were few concentrations of fish and that the fish was not attracted by lights (in those days and earlier it was common to use electric lights to attract the fish at night).

It is noteworthy that this “marker year” was a few years before the power block was introduced, and the sonar was just beginning to be introduced (about 5 percent of the boats had sonar in 1957, but 10 percent in 1958 and 1959). This leads to the hypothesis that the sonar and the power block could in fact have made the catch per unit of effort more sensitive to the stocks size. Regression with an interaction term between the (logarithm of) the stock variable and the technology variable for sonar and power block, respectively, produces a positive estimate, which for the power block is significant at the 1% level, indicating that the power block (and perhaps the sonar as well) did raise the value of *b*. The reason why this could have happened is that these devices made it easier to detect shoals of fish and encircle them. Hence, if for some behavioral reason the fish were difficult to detect or perhaps located far offshore these devices made it possible to detect and to pursue them wherever they were whereas in earlier years they would not have been available. The fact that a similar effect, albeit less strong, could also be noticed for the gill nets (cf. Section 2) detracts from this evidence; perhaps there was something special about the availability and migration of the stock prior to the late 1950s that produced this result.

4. CONCLUSION

As stated in the Introduction, the technological revolution in the herring fishery in the 1960s could have brought about the stock collapse in two ways, by (i) increasing the efficiency of the fishery, and (ii) qualitatively changing the production relationship so that the catch per unit of effort became less sensitive to the stock size. The first effect was undoubtedly there, although it seems primarily to have been associated with the power block and not so much with the sonar. The second effect does not seem to have been present. On the contrary, the catch per unit of effort seems to have become more sensitive to the size of the stock after 1957, at about the time the sonar was being adopted and a few years before the power block was introduced. A possible interpretation of this is that the said devices made it easier to find and scoop up the fish wherever it was located, whereas earlier the fishermen depended on seeing shoals of fish surface or attracting them with lights. When the fish did not “cooperate” by being in the right place at the right time or being visible on the surface they were protected as it were before the sonar and the power block came on the scene. But even with this new technology in place, the catch per unit of effort did not increase linearly with the stock but at a diminishing rate. This made the herring more vulnerable to exploitation than it would otherwise have been.

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