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PRODUCTIVITY IN AMERICAN WHALING: THE NEW BEDFORD FLEET IN THE NINETEENTH CENTURY

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Productivity in American Whaling:
The New Bedford Fleet in the Nineteenth Century

ABSTRACT

From the end of the War of 1812 until the Civil War the New Bedford whaling fleet grew spectacularly; thereafter it declined, equally spectacularly. By the end of the century New Bedford's day was over. During the 88 years of this period, the technical configuration of the fleet, the hunting grounds visited, and the types of whales pursued all changed dramatically, and more than once.

The literature on whaling suggests that the collapse of the industry was due, in part, to declining productivity, occasioned by the disappearance of the whales (because of over-hunting) and the deterioration of the quality of labor. The shifts in the composition of the fleet are viewed, chiefly, as the result of efforts by whalemen to overcome their problems.

In this paper, productivity data (superlative indexes), by voyage, are employed in multiple regression analysis to trace the relationships between the changes in the composition of the fleet and productivity. The propositions that declining labor quality and whale stocks had important consequences for productivity are subjected to test, while the impacts of technical changes on productivity are measured.

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(1) Introduction

In economics, productivity change is often associated with technical change, an inward movement of a production frontier. Looking at the matter from the level of the firm, where, after all, the principal relevant decisions are made, it is customary to focus on the choice of an appropriate technology, with attention devoted to the role of factor prices in determining exactly where on the frontier the firm will locate its production activities.[1]

Life in the firm, however, is likely to be more complex than this model suggests. Frequently there are many productive operations, and each could be affected by a variety of alternative techniques. Each technique, in turn, may employ a range of types of labor and forms of capital. Over time, techniques, factor prices, and output prices all can change. New opportunities crop up and new problems appear. The defensive actions of the firm faced by a new problem may be as important (by preventing the deterioration of productivity) as the firm's decision to exploit a new opportunity. Finally, the level of productivity may be importantly influenced by decisions that are only peripherally (if at all) related to matters of production technique in the usual sense of the phrase. The decision to open a new source of a raw material or to exploit a new market are two obvious examples.

This paper examines productivity in the context of the complete web of entrepreneurial decisions influencing production. We are interested in the reactions of entrepreneurs to shifting opportunities and problems, the ways in which decisions about technique are related to other business decisions, and the relative weights of the factors influencing productivity.

Whaling was competitive -- the industry was made up of many, relatively small, firms. Major decisions were in the hands of the whaling agent who hired the crew, rigged and provisioned the vessel, laid plans for the voyage, provided the captain with access to overseas credit and with information and guidance before and during the voyage.[2] We are interested in the choices the agents made, the influence of exogenous developments on these choices, and the impact of the agent's decisions on the productivity of the venture. The unit of analysis is the individual whaling voyage, for the voyage was the focus of all of these decisions.

Part (2) provides a brief historical and economic background. Part (3) describes the data set, and Part (4), the system for measuring productivity. Part (5) lays out the opportunities and problems facing agents and the choices they were obliged to make. It also develops the variables that figure in the empirical analysis. Part (6) contains the empirical analysis, and Part (7) is a summary of conclusions.

(2) Historical Economic Background

In July of 1842 seaman Herman Melville deserted the whaler *Acushnet* in the Marquesas, where he spent a month with the natives of the Taipi Valley. He subsequently treated this experience in his novel *Typee*. Before he finally reached home he had material for three more books, *Omoo*, *Mardi*, and *Moby-Dick*. The first two were based on visits to Tahiti and Eimo, occasioned by a second desertion (this time from an Australian whaler), the last, on Melville's life aboard the *Acushnet* and later the Nantucket whaler *Charles and Henry*, on which he served as boatsteerer. The dates of Melville's sailing from Fairhaven aboard the *Acushnet*, January 1841, and of his publication of *Moby-Dick*, October 1851 (in London, under the title *The Whale*), nicely delineate the apogee of American whaling.

Although the peak of American whaling occurred in 1841-1851, the history of the industry spanned centuries. It began with the first colonial settlements along the east coast of North America and persisted, albeit weakly, until 1974 when whaling was finally outlawed.[3] Long before whaling became illegal, the mode of whaling celebrated by Melville had disappeared and had been replaced by modern methods pioneered by the Norwegians. The Americans never adopted the new techniques on a large scale and were effectively out of whaling by the beginning of World War I. The industry has changed in other ways as well. Modern whalers seek whale meat and cooking oils, rather than the illuminants, lubricants, and structural materials brought back by Melville's whalemen. Modern whaling is therefore an entirely new industry, prosecuted by new techniques in pursuit of new ends.

By the outbreak of the Revolution, the American whaling industry had evolved from a land-based operation into a deep-sea industry. In its earliest stages whalemen stuck close to shore. Whales were sighted from the beach and hunted down from small boats. The process of rendering the blubber into oil took place on land. Gradually, however, whalemen left the shore, and instead of waiting for whales to swim close to land, went looking for the whales. Technological change and geographical expansion occurred rapidly. By the 1770's the process of rendering blubber had been moved aboard the vessel, and Yankee whalemen were routinely cruising the Atlantic from Newfoundland to the Falkland Islands.[4]

Favorable market conditions helped to foster these developments. Blessed with a growing export market in Great Britain, the colonial whale fishery expanded until 1774 when, in the words of Alexander Starbuck, the Revolutionary War caught the industry in its "full tide of success."[5] For the next forty years it suffered a series of major economic reversals, and at no time were conditions stable long enough to allow it to experience any period of sustained growth.[6]

Although our subject is the American whaling industry, most of the material used in this paper refers to vessels that sailed from New Bedford, Massachusetts. Nantucket had been the principal American whaling port at the beginning of the nineteenth century, and San Francisco assumed that position at the end. In the years between 1825 and 1890, however, New Bedford dominated the industry. Subject to some year-to-year variation, over those sixty-five years, the port's vessels, on average, represented more than fifty percent of the nation's whaling tonnage (see Table 1). Moreover, while vessels from other ports tended to specialize in certain whaling grounds and in either sperm or baleen whales, the New Bedford whalers ranged over all the world's hunting grounds and sought both species of whales. Thus the New Bedford whalers not only constitute a representative sample of the American industry, but they also present a microcosmic picture of the behavior of the firms that made up the industry.

Our study encompasses more than half of the American industry; the Americans, in turn, operated about eight-tenths of the world's whaling fleet over the last eight decades of the 19th century. There had been some British competition before the 1840's; the Australians hunted whales throughout the period; and, after the mid 1890's, the Norwegians dominated the industry; but between 1820 and 1890 the industry was virtually an American monopoly.

Marine biologists inform us that there are two types of proper whales: the baleen (suborder Mysticeti) and the catchelot (suborder Odonoceti). In the 19th century the Americans hunted one variety of catchelot (the sperm whale) and four varieties of baleen: the right, the gray, the bowhead, and the humpback.

The five varieties do not all inhabit the same parts of the ocean. Sperm whales are found in the tropical and subtropical regions of the Atlantic, Pacific, and Indian oceans. The rights prefer cooler waters. They travel in the North Atlantic from Bermuda to Greenland, in the North Pacific from Japan to the Pacific Northwest and as far north as the Arctic circle, and in the South Atlantic from Brazil, and in South Pacific from Chile, to the Antarctic ocean. The whalers looked for bowheads in the Arctic ocean, the Okhotsk Sea, the Bering Straits, and the North Pacific above the 54th parallel; however, since those animals had discovered the Northwest Passage centuries before Martin Frobisher began his fruitless search, they also appeared in Hudson's Bay and in Davis Strait. Like the sperms and rights, the humpbacks and grays inhabit the more temperate climes.

During the first few decades of the nineteenth century, sperm oil and spermacete were used primarily as illuminants. Spermacete, a solid, made the highest quality candles; sperm oil was burned in lighthouses and public buildings where high intensity illumination was required. In the second and particularly in the third quarter of the century, sperm oil came to be used increasingly as a lubricant to ease the movements of light, rapidly moving machines (the spindles of cotton and woolen mills, for example). In fact, the expansion of sperm oil production after 1830 matches very closely the rise of the cotton textile industry.

Whale oil, obtained from the blubber of baleen whales, was the illuminant chosen by the average consumer. Technically inferior to sperm oil both as an illuminant and as a lubricant, its relatively low price made it one of the most popular lamp fuels in the 1820's, '30's, and early

'40's.[7] By the latter dates whale oil began to face ever stiffening competition from new illuminants (coal oil, coal gas, and, in the 1850's, kerosene), but total sales held up fairly well as manufacturers began to use it to lubricate their heavy machinery.[8]

Whalebone, or baleen, is not really whale bone but the bone-like screen that the whale uses as a filter to separate its food (krill) from sea water. In the nineteenth century, whalebone was used in the manufacture of stays, corsets, hoops, whips, umbrellas, carriage shades, and almost any other product that required a strong flexible material -- needs now met by plastics and specialty steels.

The quantity of sperm oil that the fleet brought home increased rapidly from 1820 until the late 1830's. Then growth ceased, although output remained fairly constant until the middle of the next decade. By the late 1840's, however, the catch had begun to decline. The fall continued, although with some significant pauses, until the end of the century (see Table 2).[9] The real price of sperm oil doubled between 1820 and 1850 but then began to fall; by the end of the century the price was no higher than it had been in 1820.

The quantity of whale oil that the captains brought back to New Bedford increased until the early 1850's, stabilized until the Civil War, and then began an almost continuous decline. In no post-bellum year did output come close to matching its pre-war peak. Over the nine decades the real price of whale oil displayed a profile that was similar to that of sperm oil except that the decline in the second half of the century was more gentle. Over most of the period the ratio of the price of sperm oil to the price of whale oil averaged about 2:1; by 1900, however, the ratio had fallen to 3:2.

At the beginning of the nineteenth century whalebone was in such small demand that captains often refused to surrender the valuable storage space needed to bring it back. Gradually, as demand increased, returning cargoes contained more and more of the strong, flexible material. By the Civil War, high prices -- prices inflated by the fashions of the day -- made whalebone a very desirable addition to a whaler's catch. Indeed, the case can be made that it was the growing demand for whalebone that kept the fishery profitable and encouraged the pursuit of the Arctic bowhead. Like whale oil, the quantity of whalebone brought back increased yearly until the mid 1850's, peaked at that time, and then began to decline. Output recovered some ground in the 1880's, but even at that time it did not reach the levels attained before the War. Because of the rapid rise in price, however, the value of the bone brought back continued to rise.[10] The real price, in fact, rose from $.10 a pound in 1820 to more than $5.00 a pound in 1905. Exports of baleen (primarily to England, France, and Germany) commanded a significant proportion of total output over the entire nineteenth century.[11]

Given the similarity in the production paths of all three of the industry's major products, it should not come as a surprise that the fortunes of the industry improved steadily from the end of the War of 1812 until some time in the mid 1850's and then gradually declined. The industry had, in fact, all but disappeared by the time of the Archduke's assassination in the streets of Sarajevo. The real value of the industry's total output was about $1.2 million in 1820, it had reached $12 million by mid-century, but it had fallen to less than $1.2 million fifty years later.

The geographic dispersion of the stock of whales meant that New Bedford whalers could be found all over the world. The chronicler of the port's fleet lists no fewer than fifty-one whaling grounds, but for our analysis the fifty-one have been grouped into four: (1) the Atlantic Ocean, Hudson's Bay and Davis Strait, (2) the Indian Ocean, (3) the Pacific Ocean, and (4) the Western Arctic.

If interest centers on their relative contribution to New Bedford's prosperity over the entire ninety-year period, the list, in order of importance, would be the Pacific, the Atlantic, the Indian, and finally, the Arctic; however, within those nine decades the contribution of individual grounds ebbed and flowed (see Table 3). There were, for example, no voyages to any of the western grounds in the last decade of the period. The Indian Ocean drew a significant fraction of the city's fleet only in the middle decades, a period that saw almost no vessels hunting in the Atlantic. Finally, although the Arctic drew whaling captains from New Bedford in only four of the nine decades, during those four decades it was by far the most profitable.

It is a long way from New Bedford to the Arctic Ocean. The vessels employed in the trade depended on the wind for power, and once on station it was still necessary to find the whales. As a result, voyages were long, averaging almost three years (see Table 4). Over time, the length of a typical voyage increased. Although the increase was due in part to the opening of grounds further and further removed from the New England coast, it was also due to a non-trivial increase in the length of stay in each ground. A trip to the Atlantic averaged less than two years while a typical voyage to the Arctic or Pacific, which might have taken only two years when the ground first opened, took almost four in the 1870's.

As the whaling fleets of New England began to hunt more extensively in the Pacific, captains found it efficient to restock and refit during a voyage. In response to these needs the ports of Honolulu and Lahaina emerged as rendezvous points. There whalers could pick up fresh provisions, recruit new seamen, and repair their vessels. Beginning about 1840 the Hawaiian ports and Panama also became important centers for transshipments of oil and bone.[12] Captains wishing to continue whaling were able to ship their catch on whalers or merchant ships returning to New England.

Despite the widespread innovation of iron ships and steam power in the passenger and carrying trades, the New Bedford whalers that undertook those three- and four-year voyages were virtually all sailing vessels. Ships, barks, brigs, sloops, and schooners all found employment in whaling, but most of the fleet was made up of ships and barks. Taken together the brigs, sloops, and schooners made up less than five percent of the number of vessels in the New Bedford total, and they represented only two percent of the city's total whaling tonnage.

Ships accounted for fifty-six percent of the number of vessels that sailed from New Bedford. They were relatively large vessels, averaging about 350 tons, but they were set apart from the barks, brigs, sloops, and schooners not so much by their relatively greater size as by their rigging. They had three square-rigged masts (i.e., sails were set on yard arms attached at the center to the masts). The barks that made up thirty-nine percent of the vessels operating out of New Bedford were on average, at 285 tons, smaller than the ships. More importantly, they were square-rigged on the fore and main masts and fore-and-aft rigged on the mizzen (i.e., on the rear mast sails were set vertically and were attached directly to the mast and to the stern of the vessel). The average size of both classes of vessel rose over the first four decades. For the increase was about twenty percent, for barks, about twice that. Thus by the 1860's when a typical ship had attained a size of about 380 tons an average bark was 320.

Ships were the rigging of choice when the industry emerged from the wartime doldrums and they retained that position through most of the period of expansion (see Table 5). Gradually, however, the number of barks increased in absolute and, even more impressively, as the fleet began to contract, in relative terms. In 1845 there had been one bark for every 5.3 ships; by 1875 the ratio had been reversed, and there was one bark for every .53 ships.

The post-bellum increase in the proportion of barks underscores two characteristics of the whaling fleet. First, the capital stock was very malleable. Even as vessels shifted from whaling to the merchant marine and the whaling fleet contracted, new barks were constructed and ships were rerigged as barks. Second, as the demand for whalebone rose, the bowheads of the Arctic became an ever more favored target; the rise in the importance of that northern ground, with its ice bergs and ice pack, put an increased premium on maneuverability -- an important feature of the bark-rigged vessel.

Although barks were better able to escape the winter freeze, losses at sea of all types of vessels were very high. Of the approximately seven hundred and fifty vessels that sailed at least once from New Bedford in search of whales, no fewer than two hundred and thirty-one were lost. The crude loss rate per voyage averaged almost nine percent; the loss rate per year at sea was 3.2 percent (2.6 for ships, 3.5 for barks, and an astounding 8.6 percent for the brigs, schooners, and sloops that made up the remainder of the fleet -- see Table 6).

No summary of the industry could be complete without some mention of the men who manned the whalers. On average, twenty-seven men (including three or four officers) were needed to sail and hunt a ship. Because a bark was, on average, smaller, it required only about twenty-three (see Table 7). However, although the bark used a smaller crew, it actually represented a more labor-intensive technology; the trade-off faced by the agent who planned the voyage was between greater maneuverability and higher labor costs. Over time, average crew size increased for both classes of vessel. In the case of ships, for example, the figure rose from twenty-one to thirty-three. Although average vessel size was increasing, the size of the crew was rising even more rapidly; between 1820 and 1905 the labor/capital ratio rose by about fifteen percent.

Whaling was a risky enterprise. A sailor risked life and limb. The owner risked the loss of his vessel, and, depending upon the luck of the hunt, he also faced financial feast or famine. In an attempt to spread the risk, the owners and seamen adopted a system of labor payments that made remuneration depend on the success of the voyage.

Every member of the crew was entitled to a fraction (a lay) of the net receipts of the voyage. On average, the total labor share amounted to slightly more than one-third of the receipts from the sale of the catch. Although there are examples of total lays as low as twenty-six percent and as high as thirty-seven percent, the average was about thirty-four. Individual crewmen were compensated on the basis of the position held and their level of skill and experience. Thus a captain's share was typically about one-sixteenth, but there were voyages where the captain received as much as one-eight and others where his pay fell as low as one-twentieth. Progressively smaller shares were allocated to the other officers, the cooper, the boatsteerers, seamen, other artisans (blacksmiths, carpenters, sailmakers, etc.), ordinary seamen, greenhands, and boys. The latter, the youngest and least skilled crewmen, typically received a share of about one-two hundred and fiftieth.

The industry expanded and then contracted, and that pattern is reflected in the catch and profit figures. In the case of sperm oil, there is evidence of some decrease in the catch as new vessels entered, but, as exit reduced competition, it appears to have rebounded strongly (see Table 8). For whale oil, however, the pattern is one of fairly continuous decline. Finally, while the pattern for whalebone is somewhat mixed, it appears that the "catch" increased to about 1850, remained at those levels until the mid 1880's, and then fell as the New Bedford fleet, faced with competition from vessels based on the West Coast, began to withdraw from the Arctic grounds.

The trends in catch correlate closely with the movements in profits (see Table 9). Profits appear to have declined through the mid 1850's -- a decline most likely associated with increased competition -- and then, as competition lessened, they increased once again. The post-bellum increase was sufficient to return industry profits to the levels that had prevailed in the earlier years.

Of perhaps even greater interest, however, is the average level of the industry's profits. Although subject to a great deal of year-to-year (and voyage-to-voyage) variation, the average appears to have been about forty-five percent per year (with allowance for vessels lost at sea). That figure is consistent with contemporary observations; it provides some insight into the level of "normal" profits in a risky, but competitive, industry. Certainly it does suggest the motivation that induced ship owners to continue to send their vessels out in search of whales even when there was one chance in ten that the vessel would not return. As late as 1900, although ships appear to have proved no longer profitable, the owners of the fifteen or so barks, brigs, sloops and schooners that remained in the fleet were earning nearly seventy percent per year on their investment.

(3) Sources of Data

At the heart of the analysis presented in this paper is a set of measurements of productivity computed at the level of the individual voyage. Most, but not all, of the whaling voyages that ended at New Bedford in the years 1820-1906 are represented in the data set. The productivity estimates enter as dependent variables in a regression analysis designed to explain the variations of productivity across voyages.

The principal source of data is a Baker Library manuscript produced by Joseph Dias, probably a whaling captain himself, and certainly the son and grandson of whaling captains.[13] Dias apparently took his data from ships' logs, newspapers, and port records, as did those better- known students of whaling, Alexander Starbuck and Reginald B. Hegarty.[14] The Dias manuscript covers a longer period of time than do the works of Starbuck or Hegarty, and it is organized by vessel. Both the Starbuck and Hegarty volumes are organized by voyage, a much less convenient system. The Starbuck and Hegarty volumes, together with Whaling Masters, were used to check Dias and to fill out his record, but Dias is the primary source of the analyses in this paper.[15]

Dias recorded the following information for each New Bedford whaling vessel:

(1) the dates of each of its voyages (sailing and return),

(2) the names of the captain and agent at each voyage,

(3) the vessel type (ship, bark, brig, sloop, schooner)

(4) the date and place of construction (usually),

(5) incidents of rerigging (ships were sometimes rerigged as barks),

(6) the mode of exit from the fleet (condemnation, transfer to another port, loss by sinking, running aground, fire, etc.),

(7) the product of each voyage, in physical units (sperm oil, whale oil, whalebone, occasionally other products),

(8) hunting grounds visited (Dias identified 51, which we combined into four: (a) the Atlantic Ocean, Davis Strait, and Hudson's Bay; (b) the Indian Ocean; (c) the Pacific Ocean; (d) the Arctic Sea north of the Pacific, Bering Strait, and Okhotsk Sea),

(9) the tonnage of the vessel (a measure of capacity),[16]

(10) quite rich notes on events of the voyage, particularly touching the loss of men to disease, accidents aboard, desertion, and the attacks of whales, mutineers, islanders of the northern and southern seas.

The mode of entry into the fleet -- construction or transfer in from another port or the merchant marine -- can be inferred from the construction and voyage data.

While the Dias data set contains a good deal of information on capital, output, and firm organization, as well as various vessel traits and activities that might have affected productivity, it does not report output prices, factor shares in income, or labor and land (i.e., the stock of whales) inputs -- information necessary to estimate productivity and interpret the estimates. Price data are readily available, notably in Starbuck and Tower. Officers and crewmen were paid subsistence and a share of the product, each man's share being referred to as a "lay." Lays commonly ranged from ten to twenty percent for captains to .2 to .4 of a percent for green boys, and summed to about one-third of the value of output; we assumed a total lay of thirty-four percent for all voyages. Subsistence has been estimated to have been about $35-60 per man per year, in prices of 1844.[17] As between these two values the choice does not appear important. The productivity results obtained are virtually identical, regardless of which is used.

There are three important sources of labor data; none is perfect; the two that appear most comprehensive were used.[18] Two caveats: First, while the labor data cover all of the years under consideration they are more nearly complete for the periods 1820-1834 and 1840-1880. Second, the data refer chiefly to crewmen recruited before vessels left New Bedford. Extra crewmen were sometimes added in the Canaries or Hawaii; more often, crewmen who died or deserted were replaced at a port of call. The data provide, therefore, no more than a rough index of the average number of men aboard during a voyage, but there is no reason to believe that errors in the labor data bias our results.

(4) Productivity Indexes[19]

The measure of productivity chosen is a translog multilateral productivity index, a so-called "superlative index."[20] The index has characteristics that are very well suited to the industry and the problems under analysis. It is designed to handle multi-product firms and industries, of the type represented by nineteenth-century American whaling. The underlying model assumes optimizing behavior and is, therefore, clearly suited to competitive activities of the likes of American whaling. The measure was developed to permit multilateral comparisons and as a result it is not subject to base reversal problems, a very important characteristic since the voyage productivity estimates were to be used in a regression analysis. Moreover, it is readily computed and economical of data, requiring no more evidence than is available.

There are, however, few examples of absolute perfection, and the index, while superlative, is not one of them. It poses one minor and readily handled computational problem. Two other difficulties arise out of the application of the index to whaling and to individual whaling voyages.

As to the computational problem, whalers typically returned with whale oil, sperm oil, and whalebone, but not infrequently, they returned with only two, say whale oil and bone, or one, say sperm oil. Occasionally they even came back "clean," that is, with no marketable catch. Since the superlative index cannot handle zeroes, these cases posed problems. The first two might have been solved by distinguishing three separate whaling industries, one specializing in baleen whales, one in sperm whales, and the third a generalist baleen-sperm industry.[21] Such an approach, however, would distort the reality of nineteenth-century New Bedford whaling. Whalers did not regularly specialize to the exclusion of one type of whale. It is true that a vessel setting out for the Arctic was after bowheads (baleens), but between New Bedford and the Arctic it passed through waters inhabited by sperm whales and was prepared to take them, as opportunity afforded. Once the western Arctic was opened, a common pattern was to hunt bowheads and then, in the off season, move to California to take gray whales, or to the coasts of New Zealand and Australia for humpbacks and sperm whales. Moreover, as prices and opportunities shifted, vessels emphasized one type of activity over another. Thus it appears that New Bedford whaling should be regarded as one industry, not three.

A better solution to the computational problem is to substitute small positive values for the zeros. If values much less than e (the base of natural logs) are selected, large negative weights are assigned to the shares accorded the missing products, and the results that emerge are counter-intuitive. For example, with a value of .001, a relatively unsuccessful voyage that resulted, nonetheless, in three types of output might register a higher level of productivity than a successful voyage with only two. These anomalies disappear with values in excess of e. Three and ten, both very small values when compared with typical whaling output levels, were tried. The results of the two sets of calculations were similar, suggesting that the index is not very sensitive to the specific value selected as long as it is small but greater than e.[22]

A second and more serious problem emerges because there is no obvious way to introduce land -- that is, the stocks of whales -- directly into the productivity calculations. Thus, the indexes do not measure total factor productivity, but only the productivity of labor and capital. In an attempt to work around this problem, whale stocks were introduced on the right-hand side of the regression, as independent variables helping to explain the level of productivity of labor and capital.

Finally, and most seriously, the calculations do not include the effects of truly disastrous voyages -- voyages from which vessels failed to return. The indexes refer only to vessels that came back to New Bedford. The omission is unlikely to have affected the long-term drift of our productivity measurement for the industry as a whole, since, over time, loss rates do not seem to have changed dramatically, on average. (See Table 6.) Of course, the level and the year-to-year variations are affected, but the former is unimportant and the latter are not the chief concern of this paper.

Of more importance, however, is the effect of the exclusion of disastrous voyages from the regressions. Whaling was a risky business in which luck and the skill of the agent and captain -- neither figuring directly in our regression analysis -- played important roles. One therefore has to expect a substantial amount of unexplained variance. If the disastrous voyages were introduced into the analysis, the unexplained variance would, no doubt, increase. Moreover, since older vessels had higher loss rates than younger ones, and since loss rates varied among hunting grounds, the age and hunting ground variables would also be affected but, happily, in predictable ways.[23]

The form of the productivity index is as follows:

$$\ln\eta_{kn} = 1/2\ \Sigma_i (R_i^k + \bar{R}_i)(\ln Y_i^k - \overline{\ln Y_i})$$
$$- 1/2\ \Sigma_n (W_n^k + \bar{W}_n)(\ln X_n^k - \overline{\ln X_n}),$$

where: the R's are the shares of total revenue produced by the three individual outputs;

the Y's are quantities of individual outputs;

the W's are factor shares of income;

the X's are quantities of factor inputs;

the $\overline{R}$'s, $\overline{Y}$'s, $\overline{W}$'s, and $\overline{X}$'s are average values across all observations.

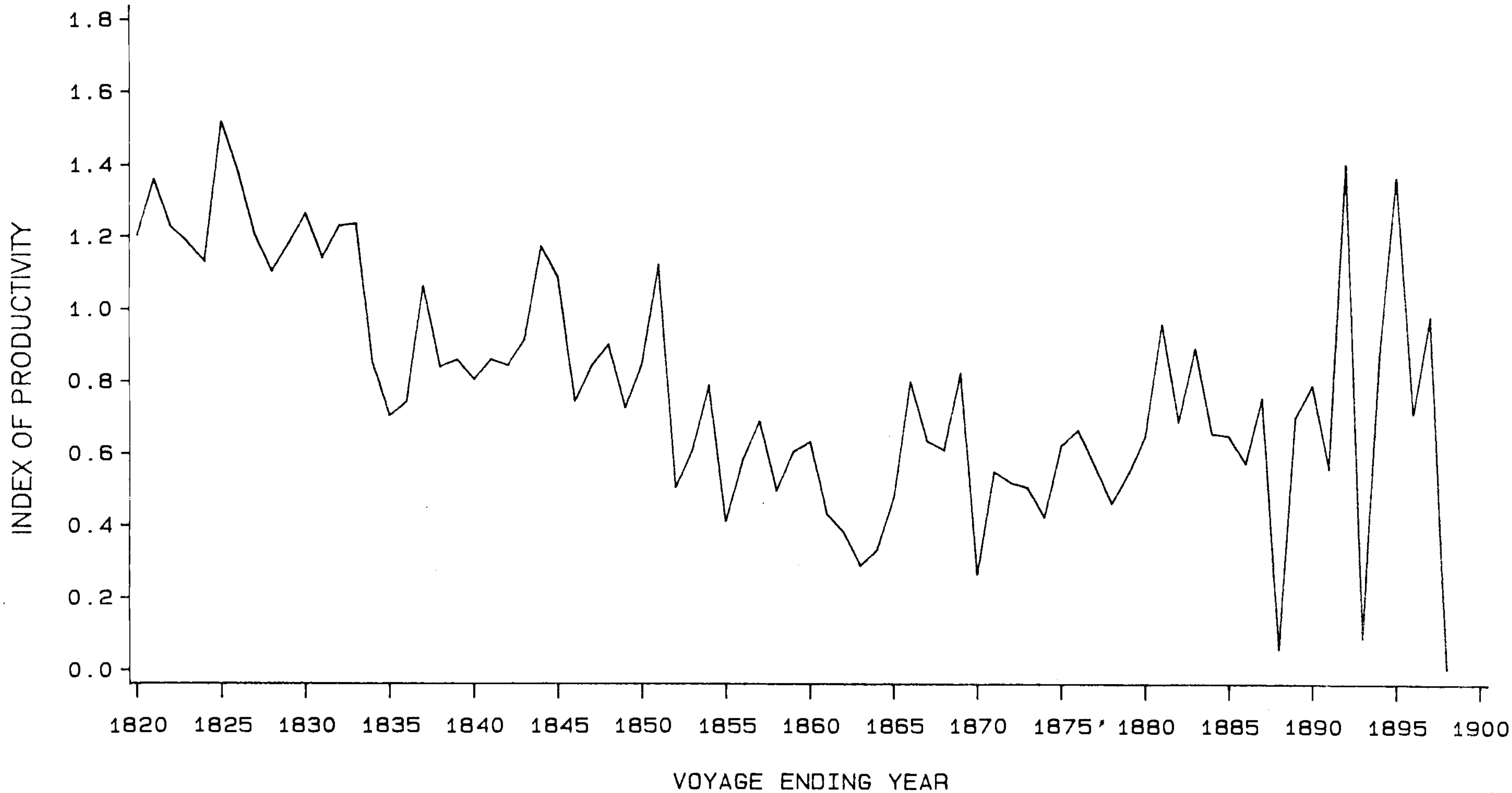
Three outputs -- sperm oil, whale oil, and baleen -- and two inputs -- labor and capital (man months and ton months) -- are distinguished.[24]

The sources of the evidence and our estimating decisions have been discussed in Section (3), above.

(5) Influences on Productivity

The productivity index for the whole New Bedford industry declines from 1820 -- when the industry was still very small -- to the mid 1830's, when the industry was quite large. During the period of its maturity (1835 onward), New Bedford whaling exhibited less pronounced changes in productivity. Plotted, the productivity index describes a profile like that of a dinner plate: it declines, gradually flattens out, and finally rises again (see the chart). Although a trend line fitted to the index in the years of maturity exhibits little movement, the industry was by no means quiescent in the period. It changed dramatically in size, in the composition of its capital stock, in the structure of its output, in the relative importance of the hunting grounds it visited, in the sources of its labor supply, in the ways in which production was organized, in its techniques of production, and, no doubt, in other ways as well. The changes reflected responses to shifts in the environment in which the New Bedford whalers operated, and represented the efforts of whaling men to cope with new problems and to exploit new opportunities. The central concern of this paper is with the estimation of the direction in which, and the strength with which, each of these influences pressed productivity. We want to understand the forces affecting the industry and the ways in which its entrepreneurs and managers responded to them. The following subsections consider the factors that influenced productivity and attempt to capture them in a series of variables that can be used in the regression analysis.

INDEX OF TOTAL FACTOR PRODUCTIVITY,
NEW BEDFORD WHALING VOYAGES ENDING IN THE YEARS 1820–1898



SOURCES: SEE TEXT. THE INDEX NUMBERS ARE UNWEIGHTED MEANS OF VOYAGE PRODUCTIVITY CALCULATIONS, THE LATTER COMPUTED FROM A CAVES–CHRISTENSEN–DIEWERT TYPE FORMULA REPRODUCED IN THE TEXT. GIVEN THE NATURE OF THESE DATA, UNWEIGHTED MEANS ARE UNLIKELY TO DIFFER MUCH FROM WEIGHTED MEANS. THE CALCULATIONS WERE MADE FROM THE DATA USED IN THE REGRESSION ANALYSIS DESCRIBED IN THE TEXT.

(a) Whale Stocks

The drift of the industry productivity index across time, the persistent search for new hunting grounds, contemporary complaints, and even the structure of output, all suggest that, as the industry expanded, there were pressures on the stock of whales. The evidence on stocks before large-scale hunting began, on the procreative capacities of the whales, and on the amount of hunting conducted in the nineteenth century suggests that there was no global problem, no general ecological disaster resulting from American whaling in the 19th century.[25] Depletion of some hunting grounds, and possibly some species of whales, however, might have required whalers to seek out new grounds, the search raising costs and reducing the productivity of capital and labor.

To test this proposition we developed annual indexes of hunting pressures on the whale populations of the four hunting grounds. Pressure index numbers reflecting hunting dates and destinations were attached to each voyage. Thus a vessel that hunted in the Pacific had assigned to it sperm and baleen pressure index numbers relevant to the Pacific and to the dates of the voyage. If excessive hunting was reducing the productivity of whaling capital and labor, the regression coefficients of these indexes should have negative signs. (Details are contained in Appendix 1.)

(b) Vessel Competition

There is a second possible effect of hunting on measured productivity. Even if whale stocks were not being depleted, increased hunting might lead to lower productivity simply because of greater competition among vessels. One vessel coming upon a pod of sperm whales might be able to take all the largest whales by itself; however, if it approached the pod in company with

other vessels, it would be less likely to come away with as many barrels of oil. The one case slides over into the other, of course. One vessel alone would be unable completely to destroy a pod, but three or four vessels might do so. Still, it appears useful to distinguish analytically between the two cases. To that end a second index reflecting whaling competition in each year and in each hunting ground was constructed. The index number for any given ground and year is a ratio: the numerator is the number of vessel tons leaving for the hunting ground two years previously, divided by 300 (to convert the tons to "standardized vessels"). The denominator is the number of whales (all species combined) in the ground before intensive hunting began, per 100 square miles in the hunting ground. Thus the index can be interpreted as the number of standard sized vessels per whale per 100 square miles per hunting ground. Since the index is designed to measure competition in the ground, it could be expected to carry a negative coefficient in the regression, if competition affected productivity unfavorably. (Appendix 1 provides more details of the construction of the index.)

(c) Specialization

The degree to which whalers specialized in a particular type of whale varied from vessel to vessel and voyage to voyage. In an effort to see how far specialization mattered we included dummy variables indicative of the degree and type of specialization. Specifically, we divided voyages into three groups (of roughly equal size): those in which sperm oil contributed at least ninety percent of the value of output, those in which whale oil and baleen contributed at least ninety percent of the value of output, and all others. This device also helps to deal with a technical problem. All productivity indexes have trouble dealing effectively with output mixes far removed from the mean mix and the superlative index is no exception. The specialization dummies segregate voyages in which the degree of specialization was pronounced and permit the regression to standardize for them (the issue is discussed further below).

(d) Hunting Grounds

The search for whales carried New Bedford whalers from the Atlantic to the Indian and Pacific oceans, and finally to that bonanza ground, the western Arctic. One would expect to find productivity varying initially from ground to ground, the differences disappearing as the fleet adjusted its hunting activities. In the case of the Arctic, however, equilibrium was probably not achieved before the New Bedford whalers began abandoning their home port for the west coast port of San Francisco. Furthermore, the Arctic was by far the most dangerous ground, exhibiting much higher rates of vessel loss than the other grounds. Thus, even if whalemen, owners, and agents were risk neutral, it should have taken higher rates of gain, gross, to attract whalers to the Arctic. Therefore, since the analysis excludes vessels that were lost while whaling, one would expect that vessels hunting in the Arctic would appear to be more productive than vessels that avoided that ground. As among other grounds, differences might be slight, with the new grounds of the Indian and Pacific oceans perhaps displaying modestly higher average productivities than the Atlantic.

One word of warning: Although acknowledged mixed voyages (i.e., voyages reported to have been to the Pacific and Arctic, for example) are excluded from the regression data set, to some extent all voyages to any ground but the Atlantic were mixed. That is, even if the vessel was sent to hunt in the Arctic, Indian, or Pacific Ocean, it was forced to pass through other grounds, and captains seldom passed up a chance to catch a whale. Moreover, if weather or catch proved discouraging captains frequently steered to adjacent grounds for short periods of time. Thus the assignment of ground should not be thought to have precluded the possibility that the vessel hunted at least a little in other grounds.

(e) Rig Types

As time passed hunting grounds shifted, and so did the way vessels were rigged. There had never been more than one or two of the smaller vessels -- brigs, sloops, and schooners -- in the Pacific and Indian oceans, and there was none at all in the western Arctic, but by the middle of the period they had all but disappeared from the Atlantic as well. Over the first half of the period barks gradually eroded the dominant position previously held by ships in all grounds, but they really came into their own in the western Arctic, where the relative ease of handling and of launching the two stern boats were matters of great importance.

In the regression, barks, brigs, sloops, and schooners are grouped together. It should be kept in mind however that the three smaller classes represented only a tiny fraction of the total. Thus the comparison is really between ships and barks (excluding all but barks does not affect any result).

The performance of this somewhat heterogeneous group was compared with the performance of ships. The expectation as to sign is somewhat ambiguous. Ships dominated in the Atlantic, Indian, and Pacific grounds in most years, but barks were more important in the Arctic and ultimately pushed their competitors from the other grounds as well. On net for all grounds and all years the coefficient on the ship dummy was thought likely to be positive.

(f) Vessel Size

The shift toward ships and toward more distant grounds was associated with an increase in the size of whalers, but vessel size also rose independently of these developments. That is, standardizing for rig and hunting ground, vessel size increased. The shift seems not to have been a pure scale phenomenon.[26] Tonnage was entered (squared, since tonnage also appears in the formula used to estimate productivity) as an independent variable. Given the shift toward larger vessels, we expected a positive sign on the coefficient of this variable.

(g) Mode of Entry into the Fleet

Some vessels were built for whaling, others transferred into the fleet from the merchant marine, and still others, vessels that had originally entered by one of these two routes, were rerigged (ships were often rerigged as barks, particularly to hunt the Arctic). Ceteris paribus, one would expect vessels built for the fleet to be most productive. Whether one should expect this result to emerge from the statistical analysis, however, is not so clear. In the flush times of New Bedford whaling, particularly when the Arctic was opened, many vessels were quickly transferred into the whaling fleet and many ships were rerigged as barks to fit them for Arctic hunting. It took longer to design and build vessels to exploit this rich ground, and, by the time these entrants were in service, some of the "first arrival" gains had almost certainly evaporated. Transferred and rerigged vessels may, then, exhibit unusually high productivity levels, for market as opposed to technical reasons.

(h) Age of Vessel

The age of the vessel (entered as age and age squared) also captures the effects of more than a single set of forces. Elements of wear and tear that influenced productivity, a technical characteristic that one might hope to capture in the age variable, are confounded with the consequences of qualitative differences among vessels. Effective vessels were presumably survivors; ineffective vessels were transferred by their owners to other activities, were condemned at an early age, or were destroyed in service. The regression should pick up this influence as well as capital consumption. Thus one could expect to find a positive sign on the coefficient for age, as poor vessels were screened out with advancing age, and a negative sign on the coefficient for age squared, as wear and tear reduced even an efficient vessel's effectiveness.

As a second device for uncovering the influence of the deterioration of a vessel's productive capacity, the last voyage of each vessel was identified. If poor productivity performances eventually led to condemnation or to transfer to other activities, the variable should have a negative sign.

(i) Innovations

Although they were not equally important, three types of technical innovations were widely adopted in the whaling fleet between the 1820's and the 1880's. The first reflected improvements in maritime technology in general; the other two were associated with improvements in whaling narrowly defined. Although the years between 1820 and 1845 have been viewed by some specialists as technologically unprogressive, the period was, in fact, marked by substantial technical progress. There was a series of advances that were first tested in the merchant fleet and then borrowed by the builders of whaling vessels. These advances included, in addition to the substantial gains realized by improvements in the techniques of ship construction, "patented rigging, deck machinery, and fittings. Such things as geared capstans and windlasses, iron strapped blocks, geared steering,...geared winches, new mast and spar ironwork...rod rigging and turnbuckles, screw- or lever-operated, were [also] introduced."[27] In addition the number of sails was increased (the top sail, for example, was divided into an upper and a lower half) for ease in handling.[28]

The second set of innovations was in vessel design: barks were specifically designed for whaling. These new vessels were first built in the vicinity of New Bedford in the mid-1850's. They were constructed with raking stems and with sharper lines than the usual whalers. "The hull design of these vessels had much in common with that of the clippers. Their sailing qualities were disguised by the heavy appearance of the hull, above water, which was emphasized by the deck houses and the whale boats carried on strong davits [another innovation] or on skids above the deck. These American whalers were built of wood, copper sheathed below the waterline. . . ."[29] They were, in fact, medium clippers, "sharp floored and easy bilged to make them roll down when 'cutting out' a whale."[30]

The third group of innovations was in "whalecraft," the implements employed to capture and kill the whale -- harpoons, lances, whale guns of various types.[31] According to Scammon (see Appendix 2) in a period of twenty years these innovations had as revolutionary an impact on whaling as had all the vessel design changes that took place between the 17th and the late 19th centuries. The successful inventions were made in the relatively short period, 1848-1865, and were widely diffused by the mid-1870's. The most significant of the group, the darting gun, was invented last (1865), and did not begin to diffuse rapidly until the early 1870's. (See Appendix 2.)

Unfortunately, the Dias data do not indicate the equipment carried on the various whaling voyages. The period during which the innovations diffused is clear, however, as well as the fact that they diffused very widely. In the regression, therefore, a dummy was entered to distinguish voyages sailing before January 1, 1870, by which date the chief design and whalecraft innovations had been made and most had been widely diffused. If these new techniques had affected productivity favorably, the coefficient on the variable would be positive.

(j) <u>Competition for Labor</u>

A frequently told story attributes the collapse of the American whaling fleet to the qualitative deterioration of the vessel crews as the best labor was bid away by improving onshore opportunities. Real wage rates ashore certainly were rising through a substantial part of this period and our preliminary analysis of whaling lays suggests that the return to whalemen may not have been keeping pace. The pool of seamen available to man the whalers may very well have deteriorated, with unfavorable consequences for whaling productivity. With measures of labor quality this proposition could be tested directly, and we hope to be able to do so in future. At present, however, we must settle for an indirect test, employing wage rate data, alone. We first entered wage indexes of common and skilled labor on shore as independent variables.[32] Since the two proved to be collinear, we re-ran the regression, using only one wage series at a time. The choice between the two mattered little: The results are virtually identical, whether the common or the skilled index is employed. The coefficient should be negative if the New Bedford whaling industry really did have a labor problem.

(k) Time at Sea

As the fleet moved into more distant waters, the organization of hunting was revised to cope with the problems raised by the greater distances. Resupply and transshipment points were developed; by using these bases, a vessel could hunt for longer periods and catch more than it could bring home itself. Organized resupply and transshipment were important institutional innovations. To capture their influence on productivity, the interval at sea (actually, the square of the interval) was entered as an independent variable in the regression equation. Unfortunately, the variable also picks up other influences, including, for example, the bad luck (or poor performance) that kept a vessel long at sea before an adequate cargo was obtained. If the first influence -- the innovation of the transshipment point -- predominated, the coefficient on this variable should have a positive sign; otherwise, it should have a negative sign.

(l) Measurement Errors

The "tonnage" for most vessels in the data set refers to old admeasurement tonnage; in a few cases, however, it refers to new admeasurement tonnage (see footnote 16). A dummy was introduced to deal with the problem. The coefficient of this dummy should have a negative sign.

(m) Time

Finally, time was entered as an independent variable. As will be evident, the technology variable -- which is a time dummy -- leaves something to be desired and might pick up any of a variety of time-dependent processes other than technical change. While the comprehensiveness of the model, both theoretically and empirically reduces the chances of such an eventuality, we decided to reduce them further by entering time as a device for detrending (the issue is taken up further below). The analysis is limited to voyages leaving New Bedford in 1820 or later. The time variable is, therefore, the year the vessel sailed from New Bedford minus 1820.

(6) Statistical Results

(a) General Considerations

The general New Bedford data set contains evidence on over 4100 whaling voyages in the period 1790-1906, but this paper is concerned with only some of them. First, since the industry was unduly affected by political and military events during the early period, the years before 1820 have been excluded (reducing the universe to fewer than 3,900 voyages). Second, a number of incomplete observations were dropped. As a result, the regression analysis is based on fewer than 2400 observations, confined to the period 1820-1896. The sample is a very large one, but is it representative? If it is representative, of what is it representative? of New Bedford voyages? of east coast voyages? Unlike many other Northeastern ports, New Bedford engaged in diversified whaling. It sent vessels to every hunting ground, and the port was regarded as representative of the east coast ports taken together. The sample, however, was certainly not randomly drawn from all of the east coast voyages. Indeed, it was not even randomly drawn from the list of New Bedford voyages.

To test the extent to which the sample resembles the universe of New Bedford voyages, 1820-1896, we compared average sample and universe values for each of the outputs, the data on crew numbers, vessel tonnage, and average voyage time, by hunting ground. On the whole, we found that the sample over-represents successful voyages.

To test whether this feature of the sample made the regression results unrepresentative of the behavior of the entire New Bedford fleet, we re-ran the regression analysis on the relatively unsuccessful voyages alone, i.e., on the 1000 voyages with the lowest levels of productivity. In all but five cases (intercepts and independent variables), the coefficient signs were the same for the full sample and for the sample of unsuccessful voyages. In three of the remaining five cases, the interpretation of the variable was left essentially unchanged, despite the sign change (e.g., low significance levels; very small coefficients). We concluded, therefore, that although some features of the full sample may make it imperfectly representative for some purposes, nonetheless the regression results do adequately describe New Bedford whaling. Although we cannot demonstrate the matter rigorously, we also believe that the regressions capture the nature of east coast whaling as a whole.

(b) The Model

The results of the first regression (#1) appear in Table 10. The equation explains almost half of the productivity variance, a level of explanatory power that is excellent for a pooled cross section-time series data set, particularly given the nature of this industry. It is well known that the variation between the performances of one vessel and another could be extremely wide and that whalemen attributed such variations in some considerable measure to luck. The Dias data also show that certain vessels -- and probably certain agents and captains -- typically performed above standard, and others, typically below. Even in these cases, however, performance varied from one voyage to the next. No attempt has yet been made to sort these matters out and to see how far the quality of the vessels, agents, and captains differed one from the other (although these are feasible projects). The regression equation leaves luck out of account and deals only indirectly with the quality of captain and crew. Not all of the variables conform precisely to the theoretical requirements. With these matters in mind the degree of explanatory success attained by the equation seems very high.[33]

(b-1) Strong Priors

We had strong expectations as to the signs on the coefficients of six of the variables in the equation. Specifically, we expected positive signs on the vessel size variable, on the Arctic dummy, and on the technological date dummy, while we expected negative signs on the wage series and on the tonnage measurement and last voyage dummies. In every case the signs are as expected, while the coefficients are large and, in all cases but one, significantly different from zero at the one percent level.[34]

(b-2) Weak Priors

We had expected productivity in the Indian and Pacific oceans to exceed productivity in the Atlantic, and the regression confirms our expectations. The Pacific, the ocean to which most voyages were made, proves to have been, on average, a more productive hunting ground than the Indian Ocean, but not by a wide margin. Per our expectations, ships were more productive, on average, than other vessels.

(b-3) Tests of Hypotheses in the Literature

Contemporary comment and the subsequent literature on whaling suggest that productivity may have been adversely affected by over-hunting, on the one hand, and heavy competition among whalers, on the other. Our study of data on whale stocks, the procreative capacities of whales, and the level of hunting in the nineteenth century led us to doubt that over-hunting was a major problem;[35] the possibility that competition may have reduced productivity seemed more likely to us, a priori.

In the cases of the hunting pressure indexes, our guesses are shown to have been correct. Both indexes carry small coefficients of the wrong sign, one not significantly different from zero at conventional levels of significance. The coefficient of the competition variable has the sign that a reading of the literature would lead one to expect, but it is very small, as is the t value associated with it.[36]

(b-4) Complex Variables

Three sets of variables capture the effects of more than one influence, which made the signs and values of the coefficients of the variables difficult to predict. The favorable influence of the transsshipment innovation was apparently overborne by the unfavorable influence of long, unsuccessful hunts (the coefficient on voyage length is negative). The large catches associated with the opening of the Arctic appear to have formed the measured effect of mode of entry on productivity. The regression shows no significant productivity difference between transfers and vessels built for the fleet. Rerigged vessels, however, exhibit a modest but significant advantage, an advantage that presumably reflects as much the date of their entry to the fleet as any underlying technical superiority.

Finally, the age variables no doubt reflect the experience of successful survivors, but it is clear that the unfavorable effects of aging also figure in the results. The measured level of productivity turns down at about the age of fifty, if the coefficients on age and age squared are to be believed. That figure would probably not have surprised whaling men of the nineteenth century, who were accustomed to vessels that lasted much longer than this in the whaling trade.[37] It may be that, properly refitted, an old vessel was, indeed, only very modestly inferior to what it had been when new. Certainly there is some suggestion of this idea in the literature, and these results appear to add additional support.

(b-5) <u>No Priors</u>

Time was entered as a detrending variable, while the specialization indexes were incorporated in our effort to cope with an undesirable feature of the productivity index. The coefficient on time is very small -- even allowing for the number of years covered by the equation -- and is not significantly different from zero (the t value is very small). There is the suggestion here that the equation is comprehensive, leaving no role for time, but we return to this point below.

Both of the specialization dummies carry negative coefficients, the one for sperm whalers a very large one. Since there is no good reason to believe that sperm whalers were, indeed, at so dramatic a disadvantage, the strong suggestion is that the productivity index, even with missing values supplied (see above), understates the productivity of specialist vessels. The specialist variables correct for this feature of the index, however, so that the regression results should not be unduly influenced by the problem.

(c) Interaction Terms

In two respects it appeared before the fact that the model could be improved by introducing interaction terms. Specifically, the advantages of the bark were said to be pronounced only in the Arctic, while ships were believed to have important advantages in the Indian and Pacific oceans. The matter could be explored by interacting the vessel type and hunting ground dummy variables. Furthermore, the institutional advantage of the refitting and transshipment port were exploited only by vessels sailing to the Indian, Pacific, and Arctic Oceans. Interacting voyage length and hunting ground might, then, reveal the favorable consequences of this institutional innovation, consequences that are not exhibited in the coefficient of the voyage duration variable of the first equation.

In fact, these procedures throw no new light on the problem of whaling productivity. The signs on the voyage duration - hunting ground interactions are all negative. We are unable to separate out the favorable effects of the institutional innovations. The vessel type-hunting ground interactions have the correct signs, but the differences among them are not large. Little additional is learned from them.

(d) Technical Changes and Labor Quality: Some Further Thoughts

While the regression analysis unfolds reasonably and seems to reveal important aspects of forces at work on U.S. whaling productivity, some of the variables are less than perfect and pose interpretive problems. Two sets of these variables -- measuring technical changes and labor quality -- deserve further attention.

New technology did diffuse very rapidly, so that the use of a time dummy to proxy technical changes is certainly reasonable. (See Appendix 2.) The fact remains, however, that the dummy is only an indirect indicator of technical change, and could be picking up the effects of some other time-dependent process. It would be helpful to have direct evidence of the tools and methods employed by the whalers in our sample.

Most whalers had an outfitting book that listed the gear aboard the vessel at the beginning of each voyage. One part of the book was devoted to "whalecraft," the implements used to capture the whale. As we have indicated, among the three sets of technical changes those that appear to have had the greatest impacts on productivity were innovations in whalecraft. Whales were frequently lost because a harpoon failed to hold or because the whale smashed the attacking boat before the boatheader was able to dispatch it. Innovations were devised to make the harpoon more secure and the lance, more deadly. The two-flued harpoon was partly replaced by the more secure one-flued harpoon, and that device was, in turn, replaced by the toggle iron. Boatheaders shifted from common lances, to steel lances, to bomb lances shot from guns, to the deadly darting gun. (See Appendix 2.)

Some outfitting lists have survived and we have managed to assemble seventy-five that can be used to establish the gear that was actually aboard the vessels in the sample. Unfortunately, however, the range of experience depicted in these lists is very narrow: there is, for example, little usable evidence on the darting gun. Thus the comparisons that can be drawn depend on very little hard evidence:

	n	Average Productivity Index
vessels with toggle irons	69	.655
vessels w/o toggle irons	6	.481
vessels with bomb lances	68	.649
vessels w/o bomb lances	7	.567

The mean productivity of the voyages using advanced gear was greater than the mean productivity of the rest, but the sample sizes are small and the differences between the sample means are not significant (student's t). We also ran various regressions in which the technological date dummy was replaced by dummies relating to the use of toggle irons and whale guns. Not surprisingly, none was very illuminating. The regression in Table 11 is characteristic.

It will be observed that only one of the technological variables has the right sign, and neither carries a coefficient significantly different from zero at a conventionally acceptable level. In view of the very limited number of vessels outfitted with the earlier technology, and in the absence of evidence on the darting gun, the regression results cannot be taken to be a very serious challenge to the view that improved whalecraft technology did, indeed, raise whaling productivity. Settling the matter definitively will require the acquisition of more outfitting books; but if, as we believe, the new technology did diffuse very rapidly, even more outfitting evidence may not make it possible to distinguish the effects of technical change from other time-dependent processes.[38]

The wage variables were introduced into the regressions to test an hypothesis drawn from the whaling literature: as wage rates ashore went up, the best men were bid out of whaling, the quality of crews deteriorated, and productivity fell. Our modeling of this hypothesis seems straight-forward enough, linking, as it does, the underlying cause (higher wage rates ashore) with the ultimate consequence (lower productivity). We also believe, as we indicated above, that wage rates ashore rose relative to the earnings of whalemen. The middle step in the argument, however, is by-passed: the deterioration of the quality of crews. Did crews really decline in quality? We are presently exploring this question by collecting signatures and marks as well as stations from the crew lists. While this task is as yet incomplete, the data assembled so far strongly suggest that both literacy and the skill level among crewmen fell markedly, in the 1840's and 1850's. If the analysis confirms these conjectures we should be able to conclude that the testimony of the whaling literature and of the coefficients on the wage variables in the regressions is correct: the quality of whaling crews did decline, as time passed.

The wage series pose a second problem. We know that the productivity index for the fleet as a whole declined from 1820 to the 1860's, while the wage rate ashore rose. The strong negative association between the wage series and the vessel productivity series may, therefore, describe only the numerical relations between two trends that, in fact, have no true theoretical connection. The latter proposition could be tested by differencing or detrending the data. Such a procedure is not appropriate in the present case, however. The hypothesis in the literature is, in fact, an hypothesis relating to trends. That is, the argument is not that a rise in wages ashore in year 1 reduced the quality of whaling seaman in year 1, and that a decline in wages ashore in year 2 raised the quality of seamen in that year. The argument is that a persistent, strong increase in the wage rate ashore led to the deterioration of whaling crews.

Nonetheless, we did attempt a species of detrending, above and beyond that attempted in equation #1. First, we restricted the regression to voyages departing after 1833 -- a period that saw productivity first fall and then rise, finally re-achieving in the 1890's the levels attained sixty years before. Second, in order to allow for the remaining long-term variations in productivity, we entered time and time squared variables. The regression appears in Table 12.

It will be observed that the common wage coefficient retains a large negative value and is significantly different from zero at better than the one percent level. The correlations between the coefficients of the two time variables and the common wage coefficient are also very small (-.082 and -.035). The wage series appears to be capturing something other than time. The suggestion that the quality of whalemen deteriorated, as opportunities ashore improved, and that the decline in the quality of crews tended to lower productivity, <u>ceteris</u> <u>paribus</u>, is strengthened.[39]

Two other features of the regression are worthy of notice. First, the signs, coefficient values, and significance levels of most of the variables are very similar to those in Table 10, which is reassuring, since it suggests that we have identified stable relationships. The significance levels are also very high, across the board.

Second, one might have supposed, before the fact, that the introduction of time squared might displace the technological dummy -- a dummy that divides the observations at January 1, 1870. The reason for this expectation is that productivity turned up late in the period (see the chart), so that one could expect time squared to carry a positive coefficient, which it does. Notice, however, that the technological dummy retains a large coefficient, significantly different from zero at the one percent level. The correlation matrix also shows clearly that the technological dummy is not simply a version of time squared. The correlation between the coefficients on the technological dummy and time squared is only 0.0144.

(7) Conclusions

After 1820 a series of changes in the economic environment pressured whaling agents to change their ways. The rapid growth of the demand for lubricants and illuminants led agents to send their captains farther and farther from home in search of whale and sperm oil. The whalemen opened rich grounds in the South Atlantic, the Indian Ocean, and the Pacific. The subsequent change in the structure of demand for whaling products -- a change that favored whale bone over sperm and whale oil -- sent captains to the North Pacific in search of right whales. One of them was venturesome enough to push through the Bering Strait into the Bering Sea, where he found a profusion of the greatest of the bone whales, the bowhead. He was quickly followed by many other captains.

These shifts in demand and in hunting grounds, coupled with emerging labor problems, led the agents to re-organize the industry. In place of the fourteen-month voyage to Davis Strait and the Atlantic, typical of the early nineteenth century, voyages of two, three, and even four or more years to the Indian Ocean, the Pacific and the Western Arctic had become common by mid-century. Different vessel types (ships in the Pacific; barks in the Arctic) and new designs of each type (clipper style, with heavy use of power winches) were adopted. The new designs came in part from unspecialized builders for the merchant marine, and in part from ship architects specializing in whalers. Longer voyages meant the adoption of larger vessels of each type and the development of re-supply and trans-shipment points in Hawaii and Panama. In the whale boats, the whaling gun replaced the hand-held lance, and toward the end, the darting gun, the most effective American whalecraft innovation, was widely adopted. The agents responded to the economic and technical stimuli. They reacted quickly and effectively. For example, when the writing was on the wall -- when the Arctic had become the most profitable hunting ground, when steamers proved the most effective whalers, and when the transcontinental rail lines were in place -- they abandoned New Bedford and reberthed their vessels in San Francisco.

These changes in environment and the reactions to them by the agents affected productivity in ways nicely captured in the regression appearing in Table 10. The clearest and most powerful environmental change was the deterioration in the quality of labor, occasioned by competition ashore. According to the coefficient on the common wage variable, productivity fell .006 points for every point the real wage ashore went up. Since the real common wage ashore rose by 52 points between 1820 and 1860 and another 34 points between 1860 and 1895, the effect was a strong one. Thus, if we press these results as far as we can -- perhaps harder than they should be -- the common wage variable "accounts" for a decline of .504 in the productivity index across the full period. Given a dependent mean of .733, this is a very powerful effect, indeed.

The changing quality of labor may also be hidden in a second variable, the one concerned with voyage length. This paper had been completed to this point in its present form when we encountered Charles Nordhoff's little book, Whaling and Fishing.[40] Nordhoff's account strongly suggests that the quality of crews deteriorated as voyage length went up. Except when whales were actually under attack, whaling was immensely boring, particularly for seamen accustomed to the constant activity of a merchantman, or a naval vessel, or even a fishing smack. As voyages increased in length, the boredom became unbearable and the rate of desertion increased dramatically, a point made by many students of the industry. Nordhoff claims that the problem became so serious that recruiters began to by-pass seamen and recruit the greenest of green hands. These hands, since they had not had the experience of merchant service, might be less likely to be unfavorably affected by the tedium of the voyage, but also their prospects on desertion were dim. A seaman could desert and easily pick up another vessel. Not so a green hand who had nothing but his brief whaling experience.

Whether or not Nordhoff is right as to the recruitment practices of agents, the variable "voyage length" may pick up the unfavorable consequence of the rising desertion rate, in addition to the factors previously discussed. Indeed, it may well be that this factor is the most important one influencing the coefficient on the variable "voyage length."

The reactions of agents to these -- and other -- environmental changes are also captured nicely in the regression. There are, first, the shifts in hunting ground, the movement first into the Pacific, with its vast supplies of sperm whales, and then into the Western Arctic, in pursuit of the bowhead. These changes can be though of as the results of a persistent search for better hunting grounds, the agents adjusting activities in ways that raised productivity. There is also, however, another aspect of them:

they reflect the changing structure of demand. The drive into the Pacific in the 20's, 30's and 40's was motivated by the high price of sperm oil; the drive into the Western Arctic after 1848, by the market for baleen.

All of the preceding discussion of the regression, while it is concerned with productivity change, leaves technical considerations aside. This point is an important one. The principal environmental influences on productivity and some of the chief actions taken by agents to raise productivity had nothing to do with technology. That point is worth stressing. Nonetheless, agents also manipulated technological variables and the results they obtained show up in the coefficients of the regression in Table 10.

Thus the adoption of ships, as opposed to other rig types, increased productivity (ceteris paribus) by a substantial amount (coefficient of +0.11, as compared with a dependent mean of +0.733), presumably reflecting the advantage of ships in the Indian and Pacific Ocean hunting grounds, the grounds that were most important throughout the full period. The choice to re-rig to bark specification with the opening of the Arctic also is shown to have been an important factor promoting higher productivity (coefficient of +0.09), while the adoption of improved vessel design and, perhaps more important, better whale craft, had an enormous effect, according to the regression (+0.310). The change in vessel size was also favorable, although of a smaller order of importance. For example, the rise in average ship size between 1821-35 and 1871-75 improved productivity only +0.006, according to the regression coefficient.

The regression, then, effectively describes the chief influences bearing on whaling productivity, including the activities of agents. A substantial part -- a little over half -- of the variance is left unexplained, however. The place to seek for further enlightenment is surely among the human actors in this drama. How far did the identity of the agent matter? Presumably there were good agents and bad ones. How far did the quality of the agent determine the result of the voyage? The same question may be asked with respect to the captain. Did crews regularly break up after each voyage, or were some crews kept together to sail a second and a third time? If so, were such crews more effective? All of these queries can be treated with the data set detailed in this paper and all will be the subject of our attention in the months ahead.

Footnotes

1. For a criticism of this approach, see Edward Ames and Nathan Rosenberg, "The Enfield Arsenal in Theory and History," The Economic Journal, Vol LXXVIII, No. 312, Dec. 1968.

2. See, for example, the papers of Matthew Howland, held by Baker Library of the Graduate School of Business, Harvard University. Howland was an agent who kept a particularly firm grip on the activities of his captains.

3. Robert Owen Decker, Whaling Industry of New London (York, 1973), 119.

4. Ibid., 19.

5. Alexander Starbuck, History of the American Whale Fishery (Waltham, MA, 1878), 57. Starbuck's History was first published in Part IV of the Report of the U.S. Commission on Fish and Fisheries (Washington, D.C., 1878).

6. Walter S. Tower, A History of the American Whale Fishery (Philadelphia, 1907), Table I, 129. For the first year for which he has tonnage statistics, Tower lists the tonnage of the U.S. fleet at 4,129. At the end of the war it was 1,168. The maximum value reached during this period was 12,339 (1804).

7. Edgar Winfield Martin, The Standard of Living in 1860 (Chicago, 1942), 95.

8. Louis S. Russell, A Heritage of Light (Toronto, 1968), 58.

9. Tower, op. cit., 126, Table III.

10. Ibid., 127, Table IV. Until 1862 Tower's whale oil statistics include data on "other fish oil."

11. Ibid., 126, 127, Tables III and IV.

12. Ralph S. Kuykendall, The Hawaiian Kingdom, Vol. I, 1778-1854, Foundation and Transformation (Honolulu, 1968), 309.

13. Joseph Dias, MSS, The New Bedford Whaling Fleet, 1790-1906, on deposit at Baker Library, Graduate School of Business, Harvard University. See Anonymous, "The New Bedford Whaling Fleet, 1790-1906," Bulletin of the Business History Society 6 (December 1932), 9-14, for a discussion of the manuscript. A.B.C. Whipple (Tall Ships and Great Captains (New York, 1951), 179-185) says that Joseph Diaz (sic), Jr. (then only twenty-eight years old) was captain of the Pocahontas in 1850, when that vessel was rammed and nearly sunk by a large whale in the south Atlantic.

14. Starbuck, op. cit.; Hegarty, Returns of Whaling Vessels Sailing from American Ports (New Bedford, 1959).

15. Federal Writers' Project, Works Progress Administration of Massachusetts, Whaling Masters (New Bedford, 1938). Where Dias disagrees with Starbuck or Hegarty or Whaling Masters, we accepted Dias, unless there was very good reason to prefer the other. Hegarty's records for the late nineteenth century and early twentieth century are more complete than Dias's; we therefore filled out our data set with Hegarty's data. The Dias records for the period before 1876 are also probably incomplete (perhaps ten to fifteen percent) but less seriously so, and we made no effort to complete them. It should be said that matters of completeness are not easily settled. The ports of Dartmouth, Fairhaven, Mattapoisett, and New Bedford were within a few miles of each other and whether a vessel belonged to one or the other of these ports on any given voyage was not always easily settled. For example, Dias lists some voyages as beginning from New Bedford, which Whaling Masters attributes to Fairhaven, across the Acushnet River from New Bedford, and vice versa. This type of disagreement appears to be of a random nature and should have absolutely no importance to the statistical estimates described in this paper.

16. The official procedure for measuring vessels changed in 1865. In most cases Dias recorded the tonnage of the vessel when it entered the fleet, and, since most entered before 1865, the tonnages of most of the vessels in our data set are "old" tonnages. In virtually every one of those few cases where Dias chose to report "new" tonnage, we were able to adjust to the "old" standard by consulting Starbuck. A few cases remain, however, of vessels that were built or transferred from the merchant marine into the whaling fleet after 1865. The "old" tonnages of these vessels are unknown, and while we have developed formulae for translating "new" into "old" tonnages that work quite well for many purposes (Davis, Gallman, and Hutchins, "The Structure...," op. cit., footnote 10), we decided that they are not sufficiently exact for the purposes of this paper. We therefore left the capacities of these few vessels expressed in "new" tons and recognized the problem in the regression analysis by entering a dummy variable.

17. Rough estimates derived from Elmo Paul Hohman, The American Whalemen (New York, London, Toronto, 1928), 315 and 325, assuming that the provisioning described on p. 325 for sperm whalers was to cover twenty-nine months, and for right whalers, twenty-three months (see p. 327, 1843). The estimates were carried to other years than 1844 on the basis of the Warren and Pearson food price index (Historical Statistics of the United States, 1789-1945).

18. We took our data from port records, held by the National Archives, and from the New Bedford Public Library's collection of the Whalemen's Shipping Papers. The two sources overlap. Where they gave contradictory accounts, we used the larger of the two values. We did not make use of the records of the New Bedford Port Society, since they appear to be less comprehensive than the records of the other two sources.

19. We thank Douglas W. Caves, V. Kerry Smith, Richard Hydell, and David Guilkey, all of whom discussed these indexes with us.

20. Douglas W. Caves, Laurits R. Christensen, and W. Erwin Diewert, "Multilateral Comparisons of Output, Input, and Productivity Using Superlative Index Numbers," The Economic Journal, 92 (March 1982), 73-86.

21. The possibilities for specialization were greater than this statement suggests. Among baleens, bowheads were taken in the Arctic; grays and humpbacks, in temperate and tropical waters. Bowheads produced large amounts of high quality baleen (whale bone); grays and humpbacks, much less, per whale, and of lower quality.

22. Nonetheless, the possible significance of output mix -- degrees of specialization -- is explored in the regression analysis described below.

23. Davis, Gallman, and Hutchins, "The Structure...," op. cit.

24. Whale oil includes oil taken from blackfish and walruses.

25. Davis, Gallman, and Hutchins, "The Decline of U.S. Whaling: Was the Stock of Whales Running Out?" Manuscript.

26. See L.E. Davis, R.E. Gallman, and T.D. Hutchins, "Technology, Productivity, and Profit: British-American Whaling Competition in the North Atlantic, 1819-1848," presented to the Congress of the International Economic History Association, Berne, August 1986. Since the productivity formula assumes no scale economies, this point is an important one. It should be said that, while the size of whalers increased, the range through which the increase occurred was quite limited. The typical ship, for example, ran between 300 and 350 tons, although some were as much as 500 tons.

27. Howard I. Chapelle, The Search for Speed Under Sail: 1700-1850 (New York: W.W. Norton, 1967), p. 279.

28. Gordon Grant, Ships Under Sail: An Outline of the Development of the Sailing Vessel (New York: Garden City Publishing Company, 1930), p. 24.

29. B.W. Bath, "The Clipper's Day," in Joseph Jobe (ed.), The Great Age of Sail (London: Patrick Stephens, Ltd., 1967), 205-206.

30. Howard I. Chapelle, The History of American Sailing Ships (New York: W.W. Norton, 1935).

31. Thomas G. Lytle, Harpoons and Other Whalecraft (New Bedford, 1984).

32. The wage rate indexes entered the regression with a lag. That is, a voyage beginning in year n was associated with wage rate index numbers for year n-1. The common wage rate series was computed from Paul A. David and Peter Solar, "A Bicentenary Contribution to the History of the Cost of Living in America," Research Economic History, vol. 2, 1977, data on p. 59 divided by data on p. 16. The skilled wage rate index was derived by multiplying the series on p. 59 of David and Solar by the skill ratios on p. 307 of Jeffrey G. Williamson and Peter H. Lindert, American Inequality (New York, London, Toronto, Sydney, San Francisco, 1980) and then dividing by the price index on p. 16 of David and Solar.

33. The superlative index is said to represent outliers badly, which could distort our results. To test to see how large were the effects of outliers, we dropped the 240 voyages (about 10 percent of all voyages) with the highest productivities, and the 240 voyages with the lowest productivities and ran the regression on this restricted data set. The results were not markedly different.

34. As to size, compare the coefficients to the dependent mean. Bear in mind that the vessel size variable is the square of vessel tonnage and the coefficient on the common wage rate variable refers to each point of the index number. The concluding section of the paper treats these issues in more detail.

35. Davis, Gallman, and Hutchins, "The Decline of U.S. Whaling...," op. cit.

36. The possibility that the variable, voyage length, was capturing over-hunting and competition led us to drop the variable in one run, to see if the signs, coefficients, and significance levels of the pressure and competition indexes changed dramatically. They did not.

37. For example, the Charles Morgan served eighty years as a whaler, the Rousseau, eighty-seven, the Maria, ninety. The Canton was lost in its seventy-sixth year. Albert Cook Church, Whale Ships and Whaling (New York, 1938, reissued in 1960), 19, 20.

38. Unfortunately, there may be little more evidence to exploit. We have collected data from virtually all the outfitting books at the New Bedford Public Library, the New Bedford Whaling Museum, and the G.W. Blunt White Library at Mystic. There may be more evidence in vessel logs and agents' papers.

39. The t value on the ratio of the skilled to common wage indexes drops to a low value, however, and the correlations between this coefficient and the time coefficients become large. These are quite unimportant matters, however, compared with the results with respect to the common wage series.

40. New York, 1895.

Appendix 1

Whale Stock Pressure Indexes

General Procedures

We began by assembling Frost's data on the initial stock of mature female sperm whales for each of the oceans in which sperm whales are found: the Atlantic (Frost's Divisions 1 and 2), Indian (Divisions 3-5), and Pacific (Divisions 6-9).[1] We then used the parameters from Frost's sperm whale model (pp. 254-256, especially 257-260) to estimate the maximum sustainable yield in each ocean. Next we distributed the U.S. catch of sperm oil among the three oceans on the basis of the New Bedford catch, which we derived from the Dias-Hegarty data set, described in the text. We converted the catch into numbers of whales killed, following Starbuck's procedure, and computed four-year moving averages.[2] These averages, dated to the year following (e.g., 1816-19 = 1820). were expressed as ratios of the maximum sustainable yield relevant to the particular hunting ground. The ratios, which reflect relative pressures on whale stocks (differing by year and by ground), were then associated with the voyage data. Thus, a vessel leaving New Bedford in 1820 to hunt in the Pacific would have an associated "pressure index" of 1820 (reflecting average hunting 1816-19) for the Pacific Ocean. We used four-year averages so that the indexes would reflect the hunting pressures over an extended period, but there is nothing sacrosanct about the number four. It could easily have been a larger or a smaller number.

There are many things wrong with the sperm hunting "pressure index," but it is clearly the best option open to us, and we think that it is a satisfactory proxy for the relative degree of sperm population depletion, by hunting ground and by year.[3] Similar procedures were followed in the case of baleens.

Maximum Sustainable Yield

In order to produce indexes of the pressure placed on whale stocks by U.S. hunting in the nineteenth century, we were obliged to estimate the maximum sustainable yields of the sperm whale populations inhabiting the Atlantic, Pacific, and Indian oceans (a separate estimate for each population) and the baleen whale populations inhabiting the Bering Strait and Okhotsk Sea (taken together), and the Atlantic, Pacific, and Indian oceans (taken together). The absolute levels of these estimates matter not at all; all that matter are the relative levels among hunting grounds and years for each of the two broad whale types. (Even relative levels between the two broad whale types do not matter.) Since the initial population numbers establish these relative differences, we could have adopted procedures producing only rough estimates of the true maximum sustainable yields. Our actual methods, while entirely adequate, were probably too elaborate for the purpose.

According to Frost, the natural rate of mortality of sperm whales is about 0.133 for the first two years of life and 0.05 thereafter (p. 257 -- but see, also, Allen, pp. 9, 10).[4] We assumed a static population with an unchanging number of births each year. Given Frost's death rate data, and the assumption of numerical equality between the sexes at each age, we were able to estimate the age-sex structure of the population. Frost says that the sperm whale population models assume females reach the age of sexual maturity at between 8.5 and 10 years (p. 257). We chose 10 years, which implies an average pregnancy rate of .22 in the stationary population (a figure .03 higher than the one used by Frost). Since the maximum pregnancy rate is .25, according to Frost, the implied ratio of net increase to the sexually mature female population is .03 (assuming that the structures of the stationary and maximum yield populations are the same).

The maximum sustainable yield is achieved at various female population levels, depending upon the form in which the yield is to be obtained (i.e. in females alone, or in males alone, or in females and males combined, or in weight) (Frost, p. 260). We assumed that the yield was to be taken in females alone, and therefore computed the yield against a mature female population 60 percent of the original level (Frost, p. 260).

Without any doubt, our sperm M.S.Y. estimates are too low. One could make a good case that the Frost "net pregnancy rate" of 0.06 should have been used in place of our derived 0.03, and that we should have computed the yield on the assumption that it was to be taken disproportionately in the form of males. Moving to these assumptions would have produced much larger M.S.Y. estimates and much lower indexes of hunting pressure on the sperm whale stocks. But it would not have altered the relative levels of the indexes from year to year or from hunting ground to hunting ground.

The regression requires that there be a pressure index for each hunting ground for each type of whale. Since there are virtually no sperm whales in the Arctic, we were obliged to produce a synthetic value for this type of whale for this ocean. We used the average value of the indexes for all other oceans. The coefficient on this index for the Arctic has no substantive meaning.

We used the same mortality rates and population structure in the estimating procedures for baleens. We assumed a maximum pregnancy rate of .50 (e.g., Burton, p. 86) and an age of sexual maturity of 10.5. Both these estimates may be too high (e.g., see Matthews, p. 84), but the errors tend to offset and, in the event, they seem to have offset very well.[5] At least it is true that the crude birth rate implied by our simple model is almost identical with the crude birth rate observed by D. W. Rice and A. A. Wolman among the California gray whales during the recovery of this group from over-hunting.[6] The implied crude death rate, however, while at the level of the average for sperm whales (Allen, p. 10), is about two percentage points below the death rate found by Rice and Wolman among the grays. The difference may reflect the fact that smaller whales, such as the grays, have higher mortality rates than larger ones (Allen, p. 9), presumably in part because they suffer the depredations of the killer whales, while the larger types do not. It is also possible that our mortality estimate is too low and that, as a result, our estimated M.S.Y. level is too high. Once again it is worth remarking that for our purposes such an error matters not at all, as long as the relative levels of the hunting pressure index numbers among years and hunting grounds are correct. Whether they are depends not on the M.S.Y. estimates but on the estimates of the initial population levels.

Estimates of Whales Killed

The estimates of the numbers of whales killed were based on the quantity of sperm and baleen oil brought back by hunters, following procedures established by Alexander Starbuck. That technique works well for sperm whales, and for baleen whales through the 1870's. After 1880 the ratio of oil to baleen brought back drops sharply. Whalers were probably abandoning blubber, a rational response to the dramatically changing relative prices of baleen and oil. For the years after 1878, therefore, the estimate of the number of whales killed was based on the amount of baleen brought back. To produce the estimate it was necessary to infer from the baleen returned the amount of oil that could have been obtained from the whales that produced the baleen. This estimate (3.49 gallons per pound of bone) was derived from the returns of U.S. hunting in the period immediately preceding the 1880's.

Competition Index

The number of exploitable sperm whales in each hunting ground (Atlantic, Pacific, and Indian) was taken from Frost. We defined the Atlantic as Frost's divisions 1 and 2, the Indian, 3, 4, and 5, and the Pacific, 6, 7, 8, and 9. We then converted exploitable whale stocks to total whale stocks, per James Scharff.[7] Gray whales were allocated to the Pacific, bowheads, to the western Arctic and to the North Atlantic, per Frost (pp. 266-267). We accepted Allen's estimates (p. 19) of the number of humpbacks and rights in the North Pacific, and the latter were allocated to the Arctic.[8] Frost's estimates of the number of humpbacks and rights in the Southern Hemisphere (converted from exploitable to total numbers, per Scharff) were divided among the Atlantic, Pacific, and Indian oceans in proportion to the number of sperm whales in these oceans.

Whales are not of equal size or equal value, but we made no attempt to adjust for these matters. On the whole, baleens were bigger, but yielded less valuable output, ton for ton, than sperm whales. Summing up without weighting is a reasonable enough procedure.

Hunting voyages differed in duration, from time to time, hunting ground to hunting ground, and voyage to voyage. Again, we made no effort to introduce these subtleties into our index numbers. We assumed that a vessel arriving in New Bedford from the Pacific, in, say, 1830 was affected during its whaling voyage by the amount of competition from vessels leaving for the Pacific in 1828. Thus if the vessel had hunted in the Pacific and had returned to New Bedford in 1830, it was assigned the "competition index number" for 1828. We were unable to allow for competition offered by vessels other than those sailing from New Bedford.

We assumed that the western Arctic encompassed about 2.17 million square miles (one-ninth of the Arctic Sea -- representing the Chukchi Sea -- the Bering Sea, the Sea of Okhotsk, and the Bering Strait); the Atlantic, about 10 million square miles (roughly one-third of the area of the Atlantic); the Pacific, about 22 million square miles (roughly one-third of the area of the Pacific); the Indian, about 7 million square miles (roughly one-quarter of the area of the Indian Ocean). These estimates rest on data from the Columbia Gazeteer of the World (New York, 1962) and maps showing whale migration routes in The Times Atlas of the World, Comprehensive Edition (New York, 1980).

Notes to Appendix 1

1. Sir Sydney Frost, The Whaling Question (San Francisco, 1979), 266-267. For a discussion of these estimates see Davis, Gallman, and Hutchins, "The Decline of U.S. Whaling...," op. cit.

2. Starbuck, op. cit., 661. The procedure leads to overestimates of the number of whales killed. See Davis, Gallman, and Hutchins "The Decline of U.S. Whaling...," op. cit.

3. The short-comings of the index:

(1) A more subtle index would allow the whale stock of each ground to decline, with hunting, and the fertility rate gradually to rise. But to carry through with such a model would require judgments as to the identity of the whales (by age and sex) captured each year. We opted for a simpler, more straight-forward calculation, which calls for fewer judgments about the nature of whale hunting.

(2) The procedure implicitly assumes that each ocean contains a single population group, whereas each contains more than one. But our hunting ground data do not permit us to draw distinctions so narrow.

(3) The division of the U.S. catch among hunting grounds on the basis of the New Bedford catch involves the assumption that New Bedford was typical of U.S. sperm whaling. It probably was, but we are unable to demonstrate that. If we had the data to do so, we would be able to work out a better method of division. Our procedure here is less than perfect, but it is the best we could produce.

(4) The use of an average annual catch in the index is readily defended, but there is no good defense for the selection of four years as against other possibilities, a point already made in the text.

(5) Vessels sailing, e.g., to the Pacific might kill whales in the Atlantic and the Indian Ocean, on the way to and from the Pacific. Thus New Bedford "Pacific" catches probably include whales from other oceans.

(6) Only U.S. hunting is accounted for. While the U.S. was far and away the leading hunter, other nations also participated in the hunt and accounted for between 20 and 25 percent of the total catch.

4. K. Radway Allen, Conservation and Management of Whales (Seattle and London, 1980).

5. Robert Burton, The Life and Death of Whales (Second Edition, New York, 1980); and L. Harrison Matthews, The Natural History of the Whale (New York, 1978).

6. Life History and Ecology of the Gray Whale, American Society of Mammologists, Special Publication 3, 1977.

7. James E. Scharff, "The International Management of Whales, Dolphins, and Porpoises: An Interdisciplinary Assessment," Part One, Ecology Law Quarterly. Vol. 6, 1977, 323. Scharff asserts that the ratio of the total population to the exploitable population was 2 to 1, in the case of sperm whales, and 1.5 to 1, in the case of baleens. Scharff uses these ratios to convert both current (i.e., disequilibrium) and initial (i.e., equilibrium) figures. One would expect the ratios to vary, from the first to the second case, but for present purposes the coefficients are adequate.

8. The geographic definition of the Arctic used here -- including all of the Bering Sea, as well as the Bering Strait -- is probably somewhat too broad. To compensate, we included in the region the North Pacific right whales, whose migration route takes them through the Bering Sea.

Appendix 2

The Diffusion of Whalecraft Innovations

"There has been as great a revolution in the mode of killing whales during the past twenty years, as there has been in the art of naval warfare; were it not for this, but few whalers would now be afloat..." Charles M. Scammon, The Marine Mammals of the North-Western Coast of America (San Francisco, 1874), p. 226.

Scammon refers to whalecraft innovations, which he believes produced effects in 20 years roughly equivalent to the changes in vessel design and other aspects of outfitting that took place in the period between the 17th and late 19th centuries. This appendix describes the principal innovations and investigates the speed of their adoption.[1]

The American style of whaling involved (1) a sailing vessel (later in the period some had auxiliary steam power) and (2) several small (28 to 30 feet by 6 feet), light whaling boats, from which the attack on the whale was made. The equipment in the boat and the attack on the whale depended somewhat on the type of whale involved and the place of the attack. Gray whales and humpbacks were typically taken in bays in shallow water, which required certain types of equipment (e.g., humpbacks sank when killed, so that boats had to carry gear to mark them and hold their bodies in place until, eventually, they rose again; bay hunting called for the use of anchors, useless in the open sea, where most hunting went on) and permitted the use of other gear that was not very effective in the rougher waters outside the bays (the Greener swivel harpoon gun, for example). Sperm whales were regarded as much more ferocious than rights, requiring special caution in the attack. Bowheads posed peculiar problems, since they could

-- and did -- seek escape from the hunters under the Arctic ice.

Despite these variations the fundamental character of the American system is clear. It can be described best if we consider the case of, say, a large bark hunting the Pacific. Slung from davits above the decks of the bark are four whaling boats; two or three spares are stored elsewhere. Men are in the cross-trees on watch for whales. When whales are sighted, the boats are lowered to give chase. Each boat carries six men, five oarsmen (three starboard and two port) and a steersman, called a boatheader. The boatheader of each boat is normally a mate. With all four boats on the sea, there are typically five or six men left to sail the vessel, keep lookout, and signal the movements of the whales to the boats.

Whale boats were sailed and sometimes rowed. If there was danger that the sounds of the oars would frighten the whale, they were paddled. The boat crew attempted to approach the whale closely; if possible, they would run the boat onto the whale's back, when the forward starboard oarsman -- known as the boatsteerer or harpooner -- would rise and thrust two harpoons into the whale. Boatsteerer and boatheader would then change places in the boat and, in the early days of whaling, the latter would slash at the whale with a sharp implement called a spade, in an effort to sever the tendons in the whale's flukes (tail) and to cripple him. This dangerous practice was later generally abandoned.

The purpose of the harpoon was to hook the whale and attach it by a line to the whaleboat. The weight of the line and the whaleboat were intended to tire the whale and permit him to be approached once again. The dispatching of the whale was then left to the boatheader, who killed it with a tool called a lance, originally a long, hand-held stabbing implement.

While the technique remained essentially unchanged, the implements were improved in important respects. The principal innovations were introduced between the late 1840's and the mid 1860's and they diffused during the period of decline of the American fleet.

The most important innovations in harpoons (called "irons" by whalemen) centered on the mode by which the implement was conveyed from the boat to the whale, and on the features of the head of the harpoon that affected its ability to hook the whale.

Most American harpoons were thrust or thrown -- darted, the whalers said -- by hand. The harpoon was attached to a cut sapling, with bark left on to improve the grip. The harpooner then thrust or threw the pole. If he was successful, the harpoon hooked the whale and the pole was detached and floated away.

Harpoon poles could not be thrown very far; thus attempts were made to shoot the harpoon from swivel guns and from rocket launchers that closely resembled the World War II bazooka. The swivel gun was invented at a very early date and figured importantly in the Scotch and English fisheries, but it never established itself in the American fisheries, except in the hunt for gray whales in the California bays. Success with the swivel depended upon calm seas (otherwise aim was thrown off) and sturdy boats, neither common in the American fisheries.[2]

The rocket launcher would seem to have been a more promising line. It was light and it did not have the kick of a swivel gun, an important matter for American whalemen, in view of the small, light boats in which they hunted. According to Lytle, notable whalemen from Scoresby to Rotch to Roys reported great success with various rocket launchers. Yet there appears to have been no rush among American whalemen to adopt this innovation and its general impact seems to have been negligible.

Innovations respecting the head of the harpoon were numerous and some were widely and rather quickly diffused. Although the variations on each style were great, there appear to have been only three basic styles of harpoon head: the two-flued, the one-flued, and the toggle. The terms are descriptive. The head of a two-flued harpoon was shaped like an arrow head, with sharp leading edges and dull following edges, the latter intended to lodge in the flesh of the whale. Sometimes, however, the two-flued harpoon pulled out. The one-flued harpoon -- with only one following edge -- was designed to minimize the chances that would happen, and was widely regarded as superior to its predecessor. The toggle iron had a head that turned on a pivet. When the harpoon was being thrown, the head was held in a fixed position -- sharp edges forward -- by a small, light piece of wood. When the head entered the whale, the wood broke, the head turned, and the whale was securely hooked.

The crucial innovation -- dated to 1848 -- appears to have been the toggle iron.[3] James Durfee, a leading New Bedford manufacturer of whalecraft, produced 22,133 harpoons between May 15, 1830, and October 29, 1844, all two-flued. Between October 29, 1844, and May 9, 1850, only two years after the invention of the toggle, he produced 7,526 two-flued harpoons and 265 toggle irons, while between May 9, 1850, and October 27, 1862, the numbers were almost equal: 20,462 two-flued versus 20,191 toggle. The outfitting books of the bark Ospray list 190 "common" irons and 50 toggle, in 1854; 40 two-flued, 10 one-flued, and 60 toggle, in 1866; and 10 two-flued, 11 one-flued, and 90 toggle, in 1880.[4] The bark Louisa carried all common irons in 1850; 130 common and 50 toggle, in 1853; 42 each of the one- and two-flued and 100 of the toggle, in 1856; 36 two-flued, 20 one-flued, and 100 toggle, in 1865; 10 two-flued, 3 one-flued, and 120 toggle, in 1874.[5] The bark Globe listed 36 toggle in 1869.[6] Scammon says that a first class whale ship on a Cape Horn voyage in the early 1870's should carry 15 two-flued and 150 toggle harpoons.[7]

The examples could readily be multiplied. The lessons seem clear. According to these records, the two-flued and toggle irons were the important designs, the one-flued having limited transitional significance. A clearer and firmer finding is that the toggle iron was adopted quickly, achieved equal importance with the two-flued iron in the 1850's, but did not clearly dominate the other forms until the 1870's, a quarter of a century after its innovation. Even then, outfit books typically called for a few common irons, in addition to the toggles.

Harpoons were made of iron, the shank of soft iron, to allow it to bend under pressure and, thus, to reduce the likelihood that the head would pull out of the whale. Hand lances, however, were to serve not as hooks, but as stabbing devices, easily thrust into the whale and easily withdrawn, so that subsequent thrusts could be made. The lance was typically made of tough wrought iron, mounted on a pole, but the head was frequently of steel. Lytle says steel was preferred -- for obvious reasons -- and that it completely displaced wrought iron, "...once steel was produced in quantity in this country...," a development presumably associated with a decline in the relative price of steel.[8] In fact, the timing is almost right. Relative steel prices fell particularly sharply after 1867. If the ratio of steel to wrought iron prices in 1867 is taken as the base of an index number series (100) the index fell to 71, in 1870, and 59, in 1875.[9] Outfitting lists immediately reflected the change: the lists for the Emily Morgan, 1842-1845, and the ships Julius Caesar, 1837, Magnolia, 1842, and

Francis Henrietta, 1843, mention no steel-headed lances, while those for the barks Globe, 1869, and Mary Frazier, 1876, mention no iron-headed hand lances.[10] Scammon's list for the early 1870's also contains no hand lances with iron heads.[11] The Ospray carried half common and half steel-headed lances in 1854, but its outfit had changed to all steel-headed lances by 1868.

There were other proposals to make the lance deadlier: heat it, electrify it, poison it. None of these plans came to much, for fairly obvious reasons: for example, crewmen reasoned (correctly) that if the poison killed the whale, it might kill them, too, when they handled their victim. The proposal to make the lance explosive, however, did come to something. Explosive devices were commonly innovated with new modes of delivering the lance to the whale, guns of various kinds.

The first set of guns consisted of shoulder guns, similar to shotguns, and they were intended to be managed by the boatheader. Unfortunately they produced a substantial kick, that frequently threw the boatheader to the bottom of the boat, sometimes broke his collar bone, and occasionally capsized the boat. Much inventive effort was directed toward dealing with these problems, and eventually the Allen gun -- usually called the Brand gun because C.C. Brand developed and promoted it -- achieved a wide acceptance. The progress of the shoulder gun is exhibited nicely in the outfitting lists of the bark Ospray: The lists for 1851 and 1854 show no whale guns, while those for 1866 and 1868 refer to three (fewer than one per boat), presumably all shoulder guns. The number rises to six at the end of the 1860's and the beginning of the 1870's, and remains at six in 1880, one per boat plus two spares. The bark Globe carried four in 1869, Scammon (early 1870's) calls for four on his Cape Horn whaler, and John

Williams, ca. 1880, allowed one gun per boat. The Lottie Beard, a resupply vessel, carried eight boxes of guns and lances, in 1886, while the order books of Frank E. Brown, a New Bedford seller of whaling implements, show the sale of 1,906 feathered lances -- i.e., lances for shoulder guns -- and only 921 long lances and unspecified lances -- presumably hand lances -- in 1877 and 1878. By the fall of 1899 and the spring of 1900, Brown listed only feathered lances and lances for darting guns (discussed below).[12]

The final whalecraft innovation of note combined in one instrument most of the important characteristics of harpoon and whaling gun. It consisted of a gun -- called a darting gun, or a Pierce gun, for its inventor -- mounted on the staff of a harpoon. When the harpoon was darted into the whale, a lever was depressed. The gun was fired and an explosive lance was driven deep into the whale. The Pierce gun could deliver an explosive lance more accurately than a shoulder gun. The location of the gun -- close to the whale when it went off -- meant that the lance was delivered with great power, without conveying a "kick" to harpooner or boat. Finally, the apparatus usually stopped the whale, preventing the long struggles common when a standard harpoon was placed. In the Arctic, where there was always danger that a harpooned whale would dive under the ice, this feature was particularly important.

The darting gun was probably the most effective piece of whalecraft introduced in the American fishery in the nineteenth century. It developed late, however. It was invented in 1865 and its diffusion did not begin on a large scale until the 1870's. The outfitting books of the bark Ospray in the late 1860's and early 1870's make no mention of darting guns, but two of them plus fifteen lances appear in 1880. None are on John Williams's list for ca. 1882, despite the fact that Williams had in mind an Arctic voyage, but Scammon (early 1870's) called for four -- one per boat -- and 50 darting gun bomb-lances. Clearly Scammon saw important uses for the darting gun, but did not conceive of its replacing all its predecessors: his list includes 35 steel-headed hand lances, four whaling guns, other than the darting guns, and 150 shoulder gun bomb-lances. The Frank E. Brown order books show a steady increase in the relative importance of the darting gun: the fraction of the total lances supplied by Brown that fit the darting gun rose from 7 percent, in 1877, to 9 per cent, in 1878, to 14 per cent, in 1879, to 41 per cent, in the fall of 1899 and the spring of 1900. A clearer indication of the change under way is that Brown sold only eight Brand shoulder guns in the period 1877 through 1879, while he disposed of 81 Pierce darting guns in the same years.[13]

In summary, the important whalecraft innovations were made in the period between 1848 and 1865, and they diffused in the 1850's through at least the 1880's. The order of adoption ran about as follows: toggle iron (1848-1870), steel-head lance (1845?-1870), shoulder gun (1855?-1880), darting gun (1865?-1885?). From the time when the diffusion of the toggle iron was clearly well under way to the time when the darting gun had made a substantial impact is an interval of about 30 years. The process began at about mid century and was over in the early 1880's.

Notes to Appendix 2

1. Much of the information on the innovations comes from Thomas G. Lytle, Harpoons and Other Whalecraft (New Bedford, 1984).

2. Ibid., Ch. 4, Ch. 6. The Florida was outfitted with a Greener Swivel gun and 20 irons in 1858 and Mrs. Williams describes the first mate shooting the gun from time to time, chiefly at fin whales and always from the deck of the Florida. She does not report that he hit anything with it. Harold Williams (ed), One Whaling Family (Boston, 1964). The book consists chiefly of the diary of Mrs. Williams, who went whaling with her husband and raised a family at sea.

3. Lytle, op. cit., p. 33.

4. New Bedford Whaling Museum, James Durfee, Mss. 56, Box 22, Series D, Sub-Series 13; Swift and Allen, Mss. 5, Box 37, Volume 85. Lytle (op. cit., p. 11) calls Durfee a typical New Bedford whalecraft maker.

5. Ibid., p. 16.

6. G. W. Blunt White Library, Mystic Seaport, Inc., Outfit Book of bark Globe, 3rd Voyage, 1869, New Bedford, VFM 425.

7. Scammon, op. cit., p. 316.

8. Lytle, op. cit., p. 133.

9. James M. Swank, History of the Manufacture of Iron in All Ages (Philadelphia, 1892), p. 514.

10. G. W. Blunt White Library, op.cit., Charles W. Morgan Papers, 1798-1861, Account book, 1842-1848, Coll. 27, Vol. 35 Emily Morgan, vol. 24, ship Magnolia, December 1842, ship Francis Henrietta, November 1843; Mary Frazier (bark), Memorandum of Whaler's Outfits, 1876, VFM 1461; Julius Caesar (ship) Papers, New London, coll. 167, Box 1/8.

11. Scammon, op. cit.

12. Swift and Allen, *op. cit.*; outfit book of bark *Globe*, *op. cit.*; Scammon, *op. cit.*; G.W. Blunt White Library, Mystic Seaport, Inc., John L. Williams, List ca. 1882 of Provisions Needed to Outfit a Whaling/Sealing Vessel for Sea, VFM 1430; Harvard University, Graduate School of Business Administration, George F. Baker Foundation, 1878-1886, schooner *Lottie Beard*, New Bedford, Mss. 252, and Order Book, Frank E. Brown, New Bedford Whaling Implements, 1877-1922, Mss. 252, Vol. I.

13. Swift and Allen, *op. cit.*; John L. Williams, *op. cit.*; Scammon, *op. cit.*; Frank E. Brown, *op. cit.*

TABLE 1

ANNUAL AVERAGE VESSEL TONNAGE:
USA AND NEW BEDFORD WHALING FLEETS
(1816-1905)

Years	Tonnage		Percent New Bedford of USA
	USA	New Bedford	
1816-1825	27775	9906	35.7
1826-1835	70352	35272	50.1
1836-1845	159788	64796	40.6
1846-1855	202143	94382	46.7
1856-1865	156129	93770	60.1
1866-1875	67602	53074	78.5
1876-1885	42967	33934	79.0
1886-1895	28380	7838	27.6
1896-1905	14311	3143	22.0
1816-1845	85971	36665	42.6
1846-1875	144719	80408	55.6
1876-1905	27968	14972	53.5
1816-1905	86694	44046	50.8

Sources

USA: Walter S. Tower, History of the American Whale Fishery (Philadelphia: University of Pennsylvania Press, 1907).

New Bedford: Davis, Gallman, Hutchins tape (see text).

TABLE 2

NEW BEDFORD WHALING FLEET
AVERAGE ANNUAL CATCH
(1816-1905)

Years	Sperm Oil (1000's of Gallons)	Whale Oil (1000's of Gallons)	Whale Bone (1000 lbs.)	Real Value* ($1000s)
1816-1825	352	466	11	360
1826-1835	1209	1200	80	1340
1836-1845	1867	2087	299	2591
1846-1855	1404	3322	1377	4256
1856-1865	1421	2483	828	4159
1866-1875	968	1320	440	2236
1876-1885	844	773	233	1797
1886-1895	344	87	78	632
1896-1905	224	11	10	195
1816-1845	1143	1251	130	1430
1846-1875	1264	2375	882	3550
1876-1905	471	290	107	875
1816-1905	959	1305	373	1952

*Real value expressed in $'s of 1880.

Source: Davis, Gallman, Hutchins tape. See text.

TABLE 3

VESSEL TONNAGE RETURNING BY GROUND
3369 NEW BEDFORD VOYAGES

Percentage of Returning Tonnage

Years	Atlantic	Indian	Pacific	Arctic
1816-1825	55.5	0.3	43.2	0.0
1826-1835	51.7	2.4	46.0	0.0
1836-1845	22.7	20.9	56.0	0.2
1846-1855	3.6	21.6	65.0	9.7
1856-1865	10.8	13.1	58.2	18.0
1866-1875	25.3	10.0	37.7	15.9
1876-1885	41.3	6.6	36.5	15.7
1886-1895	45.5	6.3	48.3	0.0
1896-1905	100.0	0.0	0.0	0.0
1816-1845	43.6	7.9	48.4	0.1
1846-1875	13.9	14.9	53.6	14.5
1876-1905	62.2	4.3	28.3	5.2
1816-1905	24.2	14.3	52.0	9.4

Source: Davis, Gallman, Hutchins tape. See text.

TABLE 4

AVERAGE VOYAGE LENGTHS IN MONTHS BY GROUND
NEW BEDFORD SHIPS AND BARKS

Years	Atlantic	Indian	Pacific	Arctic
Panel A: Ships				
1816-1825	12.2	--	24.2	--
1826-1835	12.2	14.8	33.3	--
1836-1845	20.7	24.9	36.3	21.0
1846-1855	26.9	33.7	37.5	34.8
1856-1865	20.5	41.0	43.6	41.3
1866-1875	22.0	42.0	47.2	46.9
1876-1885	36.3	40.5	37.6	8.8
1886-1895	37.6	--	33.6	--
1896-1905	--	--	--	--
1816-1905	17.0	32.1	37.6	38.9
Panel B: Barks				
1816-1825	12.3	--	32.0	--
1826-1835	12.6	23.0	30.3	--
1836-1845	18.7	22.4	35.5	21.0
1846-1855	24.0	34.0	37.6	38.1
1856-1865	23.7	40.3	44.4	42.4
1866-1875	27.6	41.4	45.2	52.1
1876-1885	32.9	38.8	33.4	16.2
1886-1895	32.6	35.7	34.7	--
1896-1905	28.3	--	--	--
1815-1905	26.4	36.1	39.8	36.2

Source: Davis, Gallman, Hutchins tape. See text.

TABLE 5

VESSEL RIGGING TYPES
ANNUAL AVERAGES OF PERCENTAGE DISTRIBUTION
NEW BEDFORD FLEET

	Percentage of Total Tonnage		
Years	Ships	Barks	Other
1816-1825	87.0	5.2	7.8
1826-1835	87.5	9.8	2.8
1836-1845	83.4	15.0	1.6
1846-1855	75.2	23.9	0.1
1856-1865	56.5	42.8	0.6
1866-1875	34.3	64.0	1.8
1876-1885	25.6	67.6	6.8
1886-1895	23.1	65.0	11.9
1896-1905	0.0	73.3	26.6
1816-1845	85.1	12.4	2.5
1846-1875	59.0	40.1	0.9
1876-1905	23.4	67.5	9.1
1816-1905	62.2	35.5	2.4

Source: Davis, Gallman, Hutchins tape. See text.

Table 6

Annual Loss Rate[a]
New Bedford Fleet

	Ships	Barks	Other
1816-25	3.0	0.0	3.1
1826-35	1.5	2.7	17.4
1836-45	1.7	0.8	11.2
1846-55	3.0	3.8	7.9
1856-65	2.7	3.7	27.3
1866-75	3.5	5.4	8.0
1876-85	3.8	2.6	10.4
1886-95	0.0	0.5	1.8
1896-1905	---	3.1	4.7
Avg.[b]	2.6	3.5	8.7
Avg.[c]	2.4	2.8	10.2

Source: L.E. Davis, R.E. Gallman, T.D. Hutchins, "The Structure of the Capital Stock in Economic Growth and Decline," in Peter Kilby (ed.), Quantity and Quidity (Middletown, CT: 1987), p. 382.

[a]Number of vessels lost per vessel year of voyaging x 100.

[b]Vessel weights.

[c]Decade weights.

TABLE 7

AVERAGE CREW SIZE
NEW BEDFORD FLEET

	Average Crew Size		
Years	Ships	Barks	Other
1816-1825	20.9	14.3	14.0
1826-1835	23.4	19.8	14.8
1836-1845	26.3	22.7	16.8
1846-1855	29.1	25.8	18.3
1856-1865	30.0	27.1	20.1
1866-1875	30.9	27.4	17.7
1876-1885	31.1	27.8	18.3
1886-1895	33.0	28.4	16.5
1896-1905	--	26.4	17.0
1816-1905	27.5	26.5	17.1

Source: Davis, Gallman, Hutchins tape. See text.

TABLE 8

AVERAGE CATCH PER TON YEAR OF HUNTING
PHYSICAL QUANTITIES
NEW BEDFORD FLEET

	Sperm Oil (BBLS)			Whale Oil (BBLS)		
Years	Ships	Barks	Other	Ships	Barks	Other
1816-1825	1.2	2.1	1.7	4.3	0.1	3.2
1826-1835	1.4	1.8	2.2	3.2	1.8	0.4
1836-1845	1.1	1.1	1.7	1.8	1.7	0.3
1846-1855	0.6	0.8	0.5	1.7	1.0	0.2
1856-1865	0.5	0.8	1.3	1.1	0.7	0.7
1866-1875	0.7	0.9	1.3	1.1	0.7	11.8
1876-1885	0.9	1.0	1.6	1.0	1.5	0.4
1886-1895	1.0	1.4	2.9	0.3	0.4	0.2
1896-1905	--	3.6	3.5	--	0.1	0.1
1816-1845	1.2	1.7	1.9	3.1	1.2	1.3
1846-1875	0.6	0.8	1.0	1.3	0.8	0.5
1876-1905	1.0	2.0	2.7	0.7	0.7	0.2
1816-1905	0.9	1.0	2.0	1.9	1.0	0.5

	Bone (LBS)		
Years	Ships	Barks	Other
1816-1825	3.0	0.5	0.0
1826-1835	6.3	10.3	0.9
1836-1845	7.0	6.4	0.9
1846-1855	17.0	9.8	0.0
1856-1865	11.3	7.8	8.0
1866-1875	11.8	5.8	2.6
1876-1885	9.1	13.4	3.2
1886-1895	2.8	2.4	0.6
1896-1905	--	0.6	3.9
1816-1845	5.4	5.7	0.6
1846-1875	13.4	7.8	3.5
1876-1905	6.0	5.5	2.6
1816-1905	10.6	8.2	2.1

Source: Davis, Gallman, Hutchins tape. See text.

TABLE 9

AVERAGE PROFITS RATES (PERCENT)
NEW BEDFORD FLEET

Years	Ships	Barks	Other
1816-1825	40.5	22.6	30.5
1826-1835	54.8	54.1	28.9
1836-1845	39.7	34.5	21.1
1846-1855	38.3	32.1	LOSS
1856-1865	45.4	46.8	68.7
1866-1875	51.9	42.2	44.7
1876-1885	70.2	92.5	50.2
1886-1895	33.5	38.3	57.5
1896-1905	--	70.9	69.2
1816-1905	43.7	48.7	39.6

Source: L.E. Davis, R.E. Gallman, T.D. Hutchins, "The Structure of the Capital Stock in Economic Growth and Decline," in Peter Kilby (ed.), Quantity and Quiddity (Middleton, CT, 1987), data underlying Table 10.22.

TABLE 10
PRODUCTIVITY IN NEW BEFORD WHALING, 1820-1896
Regression #1

F = 103.1
Adj. R^2 = .478
Dependent Mean = .733
Observations = 2343

Productivity Depends on:

Variable	Parameter Estimate	Significance Level
Intercept	+2.2091	***
Vessel type: ships compared with all other vessels	+0.1055	***
Hunting ground:		
Atlantic	-0.1544	***
Indian	-0.0638	***
Western Arctic (compared with Pacific)	+0.1704	***
Time	-0.00039	
Mode of entry into the fleet:		
Built for fleet	-0.0298	
Rerigged (compared with vessels transferred into the fleet)	+0.0942	***
Hunting pressures:		
on baleens	+0.1070	***
on sperms	+0.0539	
Competition among whalers	-0.0037	
Technological dummy	+0.3103	***
Vessel size (tons squared)	+0.0000015	***
Voyage length (months squared)	-0.00029	***
Vessel age	+0.00421	***
Vessel age squared	-0.000089	***
Last voyage	-0.0762	***
Real common wage rate ashore	-0.0060	***
Ratio, skilled wage to real common wage	-0.5732	***
Specialization:		
in baleens	-0.0948	***
in sperms	-0.7005	***
Measurement dummy	-0.0314	

Notes to Table 10:

*** Significantly different from zero at the 1 percent level

Durbin-Watson D	1.823
1st order autocorrelation	0.086

Source: See text.

(a) The t statistics were adjusted to allow for the large size of the sample:

Adjusted t = coefficient/adjusted standard error

$$\text{Adjusted s.e.} = \text{s.e.} \times \sqrt{\frac{\text{Population - Sample Size}}{\text{Population - 1}}}$$

(b) The equation was also run in natural logs. The fit was poorer, while the results did not change substantially.

(c) A priori there is no strong reason to expect heteroskedasticity or, if it exists, to anticipate serious problems with it, in view of the enormous size of the sample compared with the universe. Nonetheless, since the data are panel data we tested for heteroskedasticity by regressing the variances of the error terms against the continuous explanatory variables, and the test turned up evidence of heteroskedasticity. We made corrections by dividing the dependent and independent variables by the standard errors of the residuals and ran the regression again. The significance levels did not deteriorate and the results did not change substantively.

TABLE 11
PRODUCTIVITY IN NEW BEDFORD WHALING, 1820-1896
Regression #2

F = 3.115
Adj R^2 = .3519
Dep Mean = 0.641431
Observations = 75

Productivity depends on:

Variable	Parameter Estimate	Significance Level
Intercept	+1.704420	
Vessel type: ships compared with all other vessels	+0.198935	
Hunting ground:		
Atlantic	-0.741689	**
Indian	+0.241176	
Western Arctic	+0.120425	
Time	+0.042115	
Mode of entry into the fleet:		
Built for fleet	-0.275912	***
Rerigged (compared with vessels transferred into the fleet)	+0.228511	
Hunting pressures:		
on baleens	+0.464618	**
on sperms	-0.209942	
Competition among whalers	+0.003333	
Whaling guns dummy	-0.141948	
Toggle irons dummy	+0.032362	
Vessel size (tons squared)	+0.00000145	
Voyage length (months squared)	-0.0005028	***
Vessel age	-0.016567	
Vesssel age squared	+0.000425	
Last voyage	-0.154950	
Real common wage ashore	-0.027653	**
Measurement dummy	+0.467091	

***Significant at the 1 percent level
** Significant at the 5 percent level

Source: See text.

TABLE 12
PRODUCTIVITY IN NEW BEDFORD WHALING, 1833-1896
Regression #3

F = 85.6
Adj R^2 = .465
Dependent Mean = .686
Obervations = 2144

Productivity depends on:

Variable	Parameter Estimate	Significance Level
Intercept	+1.7694	***
Vessel type: Ships compared with all other vessels	+0.1021	***
Hunting Ground:		
Atlantic	-0.1968	***
Indian	-0.0276	
Western Arctic (compared with Pacific)	+0.1069	***
Time	-0.00821	***
Time squared	+0.000259	***
Mode of entry into the fleet:		
Built for fleet	-0.02708	
Rerigged (compared with vessels transferred into the fleet)	+0.0999	***
Hunting pressures:		
On baleens	+0.1915	***
On sperms	+0.1555	*
Competition among whalers	+0.00112	
Technological dummy	+0.1485	***
Vessel size (tons squared)	+0.00000153	***
Voyage length (months squared)	-0.000278	***
Vessel age	+0.00628	***
Vessel age squared	-0.000120	***
Last voyage	-0.0981	***
Real common wage ashore	-0.0058	***
Ratio, real skilled wage ashore to real common wage ashore	-0.2111	
Specialization:		
In baleens	-0.0805	***
In sperms	-0.7044	***
Measurement dummy	-0.0338	

Notes to Table 12:

*** Significantly different from zero at 1 percent level.
** Significantly different from zero at 5 percent level.
* Significantly different from zero at 10 percent level.

Durbin-Watson D	1.862
1st order autocorrelation	0.067

See Table 10, note (a).

Source: See text.