Volume Title: In Pursuit of Leviathan: Technology, Institutions, Productivity, and Profits in American Whaling, 1816-1906

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Volume Publisher: University of Chicago Press

Volume ISBN: 0-226-13789-9

Volume URL: http://www.nber.org/books/davi97-1

Publication Date: January 1997

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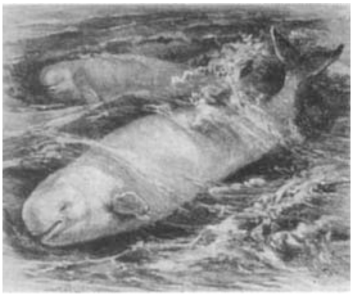
Chapter URL: http://www.nber.org/chapters/c8283

Chapter pages in book: (p. 297 - 341)

8 Productivity



During the nineteenth century the New Bedford whaling industry changed dramatically: in size, in the composition of its capital stock, in the structure of output, in the distribution of effort among various whaling grounds, in the sources of labor supply, in the organization and techniques of production, and, no doubt, in other ways as well. Changes were made by whalemen in response to such developments as the discovery of new hunting grounds and shifts in the supplies of inputs and demands for outputs. Managers acted to cope with new problems and to exploit the new opportunities thereby created. How great were the challenges posed to the industry? In what ways did it respond? What degrees of success were achieved?

The importance of the problems facing whalemen and of the managerial responses can be established only if it is possible to measure their effects on some index of performance. The significance of the opening of the Western Arctic, for example, could be judged in terms of the impact of Arctic hunting on the productivity of the industry and on its profits. Chapter 11 focuses on profits. Here we measure differences in productivity among whaling voyages and compute the effects of the principal factors believed to have influenced productivity.

If information were available with respect to the amounts and the qualities of all inputs, there would be no productivity differences among voyages at all, except for those due to disembodied technical change—that is, technical change not embodied in capital, including human capital. There would be only output differences, which would be fully explicable in terms of the various inputs and their qualities—once again, with the exception of productivity differences resulting from disembodied technical change. In fact, however, the information needed to make a full and entirely satisfactory accounting of the causes of output differences among firms is never available, and evidence with respect to whaling is no exception. The productivity measurements carried out here refer to the productivity of undifferentiated labor and undifferentiated capital, combined, and to no other inputs. The measurements are analyzed by means of multiple regression analysis; variables reflecting the volumes of other inputs (natural resources—the whales), the qualities of inputs, and technological differences among voyages are entered on the right-hand side of the regression, with the object of explaining differences in productivity among voyages in these terms.

Recent work on the theory of index numbers has shown that outputs, inputs, and productivity can be measured as effectively by using index numbers as by fitting econometric functions. Such index numbers have been used in the analysis of time-series, cross-section, and panel data; they have been applied to firm, industry, and country data; and, of course, they have been used in multiproduct and multifactor circumstances. They can be assembled from evidence on prices, outputs, and inputs, and they are relatively simple to compute. The index used in this chapter—representing a translog production function—has a clear intuitive meaning. It consists of the difference between translog multilateral output and input indexes. The output and input indexes, in turn, are also simple. The aggregated outputs (inputs) of a given whaling voyage are compared with the aggregated outputs (inputs) of the representative voyage, where the representative voyage is the average voyage. The exact form of the productivity index is

$$\ln\lambda_{kn} = \frac{1}{2}\sum_i (R_i^k + \overline{R}_i)(\ln Y_i^k - \overline{\ln Y_i}) - \frac{1}{2}\sum_n (W_n^k + \overline{W}_n)(\ln X_n^k - \overline{\ln X_n}).$$

In the equation, $\ln\lambda_{kn}$ is the productivity index (voyage specific); the R are the shares of total revenue attributable to the three individual outputs; the Y are quantities of the individual outputs; and W are factor shares in income; the X are quantities of factor inputs; the $\overline{R}$, $\overline{\ln Y}$, $\overline{W}$, and $\overline{\ln X}$ are average values across all voyages. Three outputs (sperm oil; whale oil, including blackfish and walrus oil; and baleen) and two inputs (labor and capital—man-months and vessel ton-months) are distinguished.[1]

Although the index is very nearly ideal for our purposes, it is not entirely without problems. First, in principle the method can be applied only in cases in which there are no scale economies, and New Bedford whaling may not meet this requirement. As the results of the regression will show, large vessels were slightly more productive than small ones. The advantage to large vessels was not great, however, and it held over only a very limited size range. It is highly unlikely that the limited scale economies in whaling (if they existed) seriously compromise our use of the index.

Second, since the index is cast in log form, it cannot accept zero values. For

1. The index was taken from Caves, Christensen, and Diewert 1982b. See also Heien 1983; Caves, Christensen, and Diewert 1982a; Diewert 1976; Nishimizu and Robinson 1984; Barnett, Offenbacher, and Spindt 1984; Denny and Fuss 1983.

inputs that requirement poses no problem: no voyage took place without both a crew and a vessel. That is not the case for outputs. Some voyages returned with sperm oil only, some with whale oil and baleen, and some with all three products.[2] The problem might have been dealt with by treating the industry as three separate industries, consisting of specialists in sperm whaling, specialists in baleen whaling, and generalists, hunting all kinds of whales. That did not seem to be the proper method. While it is true that some voyages began as sperm-whaling or baleen-whaling voyages—and some ended as they began—most whalemen would take whatever whales they found, especially on the way home with stowage space aboard. Furthermore, as prices changed, vessels would shift from an emphasis on one type of whale to an emphasis on another. The reality seems to have been a single fleet, rather than three separate fleets; and it called for a single analysis, rather than three separate analyses. The analysis did recognize that specialization took place, by including on the right side of the regression equation variables taking account of it.

We treated the industry as one industry, and we handled the problem of missing outputs in a practical, if inelegant, way commonly adopted in such circumstances. We assumed that the vessels, in fact, had small amounts of the nonexistent outputs, and replaced the zeros in the data set with these amounts. Values smaller than the base of natural logs produced absurd results, but a value as small as ten—a very small amount, compared with average voyage outputs—yielded reasonable results (Davis, Gallman, and Hutchins 1989, 114–15). We therefore substituted ten barrels or pounds for any smaller reported value.

Finally, the analysis deals only with voyages from which vessels returned safely to port. Voyages that ended with the sinking of the vessel or its abandonment or sale or condemnation in a foreign port were ignored. It is not clear how, in such circumstances, productivity should be conceptualized and measured, nor is it clear what could be learned about whaling productivity by considering these cases. There are about 380 such voyages, of a total of 4,731 in the data set.

We made no adjustments to productivity for the loss of men or whaleboats and other gear, or for damage to the vessel short of complete loss. These events were regarded as normal incidents of a whaling voyage, part of the flow of capital and labor expended in the process of production. Were comprehensive records of unusual losses available, they could be integrated into the analysis. Unfortunately, while there is much information of this type (see chapters 10 and 11), it is not comprehensive and it does not lend itself to simple quantitative expression.

We are now in a position to consider the developments that history and the-

2. In eighty-nine instances voyages ended with no output of any kind—the vessels came home clean, as the whalemen said. Every one of these voyages, however, was aborted, typically because the captain became sick or died. The median length of clean voyages was one month. These were not true whaling voyages, and we ignored them for present purposes.

ory suggest influenced whaling productivity, and the decisions made by agents in their attempts to exploit or to offset the effects of these developments.

8.1 Developments beyond the Control of Managers

8.1.1 Supplies of Whales

The drift of the industry productivity index across time—falling as the industry expanded and rising very slightly as it contracted (see figure 1.1)—the persistent search for new hunting grounds, contemporary complaints, and even the structure of output, all suggest that as the industry expanded there may have been pressures on the stocks of whales. Whale numbers may have been so hunted down that the search became ever more costly and less rewarding. The evidence assembled in chapter 4 is not consistent with this view, but neither is it quite powerful enough to settle the issue. There is enough uncertainty to warrant running additional tests.

To do so, we assembled annual indexes of hunting pressures on the whale populations of the four major grounds—the Atlantic (including Hudson Bay and Davis Strait), the Pacific, the Indian, and the Western Arctic. Pressure index numbers germane to the relevant date and destination were attached to each voyage. For example, a vessel that hunted in the Pacific was assigned sperm and baleen pressure index numbers relevant to the Pacific and to the date of the voyage. If excessive hunting reduced productivity, the regression coefficients of these indexes should have negative signs. Another hunting-pressure index, combining sperm and baleen whales, was used in a second set of regressions.

Details of the construction of the indexes are in appendix 8A. The indexes are clearly imperfect. For example, vessels destined for the Pacific often hunted in other oceans as well. Moreover, problems of whale scarcity, if they arose at all, probably affected specific grounds within an ocean, rather than the entire ocean. Unfortunately, there is no way to remove these imperfections. The indexes represent the best approach to the issue of whale scarcity that we were able to develop. Despite their crudity it is almost certainly the case that, if shortages of whales occasioned by overhunting lowered the productivity of the New Bedford fleet, the signs on the regression coefficients of these indexes would record the fact.

8.1.2 Competition among Whaling Vessels

There is a second possible effect of hunting on measured productivity. Even if whale stocks were not being depleted, increased hunting might have led to lower productivity simply because of greater competition among vessels. One vessel coming on a pod of sperm whales might be able to take all the largest whales by itself; approaching 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 might do so. Still, it seems useful to distinguish analytically between the two cases: hunting pressures on the whale populations, on the one hand, and competition among whaling vessels, on the other.

To that end a second index, reflecting whaling competition in each month and in each hunting ground, was constructed. The index number for any given ground and month is a ratio. The numerator is the number of vessel tons hunting in that ground in that month. The denominator is the number of whales (all species combined) living there before intensive hunting began, per one hundred square miles. Thus the index measures the number of vessel tons per whale per one hundred square miles of hunting ground. We assumed that each vessel hunted the ground its agent had specified, and that the competition index for the median month of a voyage adequately represents the competition faced by the vessel on that voyage. Appendix 8B gives more details of the construction of the index. The limitations of the hunting-pressure indexes (described above) are shared by the competition index.

Competition could not have been all bad. Not infrequently, two whalers

The boats of four whaling vessels attack a pod of sperm whales off the coast of Hawaii in 1833. The artist shows the stroke and harpooner's oars of each boat on the port side, which was contrary to normal (invariable?) practice.

Colored aquatint, 1838, reproduced courtesy of the Old Dartmouth Historical Society–New Bedford Whaling Museum.

chose to hunt in concert, implying that, within limits, increased competition actually promoted greater productivity. Beyond these limits, however, it is reasonable to suppose that competition would lead to a lessening of measured productivity. We therefore entered the index in quadratic form. We expected that the coefficient on the index would carry a positive sign, the coefficient on the index squared, a negative. We expected that the effects of the negative element would overbalance the effects of the positive element at a relatively low level of competition. For example, although it was not uncommon for two vessels to hunt together, we know of no instances in which more than two did so. This strongly suggests that the benefits of cooperative behavior did not extend beyond two vessels.

From the point of view of the individual captain or agent, the effects of these two factors (hunting pressures and hunting competition), if they had any effects at all, were not consequences of managerial decisions. They were exogenous factors, so far as individual firms were concerned.

8.1.3 Competition for Labor

As chapter 5 shows, the structure of the whaling labor force changed in the period 1840–66. The fraction of unskilled greenhands in a typical crew rose, as did the fraction of illiterate seamen. The quality of the crew could be said to have declined. At the same time the wage rates ashore for common and skilled workers rose, compared with the returns to whaling crewmen. It is reasonable to conclude from this evidence that opportunities ashore were improving relative to opportunities afloat and that the best men were being bid out of the whaling labor pool. The results of such developments would surely tend to lower the productivity of whaling. In fact, the standard literature assigns an important role in the decline of the American fleet to the declining quality of crewmen.[3] The evidence presented in chapters 5 and 7 has suggested that, coincident with shifts in the quality of crews, technical innovations were adopted that seem to have reduced the need for skilled crews.

How should one interpret these changes? Did the competition of opportunities ashore lead to less skilled crews, which in turn led to the adoption of new

3. Charles Nordhoff's account can be interpreted to mean that the share of greenhands in whaling crews rose with the duration of voyages. It became difficult to recruit for long voyages and more difficult to retain the crew; desertion became a serious problem. According to Nordhoff (1895, chaps. 1, 2, and pp. 234–36, 245) experienced seamen were more likely to desert than were greenhands, since they had options not open to greenhands (e.g., the merchant marine). See also chapter 5 above. A study of the records of whaling vessels suggests that deserting greenhands did have other opportunities. They could always sign on with a whaler heading home, since whalers seem persistently to have been filling berths emptied by desertion or death. This is the way Herman Melville came home, after two desertions from whalers. Note also that greenhands did not remain greenhands. Deserting after a year on a whaler, the former greenhand now had experience. Melville started as a greenhand and ended in the exalted position of boatsteerer. Nonetheless, Nordhoff's story is not his alone. See Hohman 1928, 66. It may be that the variable *voyage length,* discussed below, picks up some of the productivity effects of problems in recruiting and holding crew members, when the length of the typical voyage increased.

vessel and rigging designs? Or did shifts in technique directly produce changes in the structure of the typical crew, without the intermediation of changes in wage rates ashore?

The importance of opportunities ashore can be tested by introducing wage-rate series for shore occupations on the right-hand side of the regression equation. If the best men were being bid away from whaling, with deleterious effects on productivity, the coefficients on these variables should be negative. The direct relationships among wage rates ashore, the skill mix of the typical crew, and productivity can be tested for the brief period 1840–58 and 1866, the only period for which relevant data are available. If opportunities ashore were indeed of primary importance, while technical changes represented an attempt to cope with the problem created by changes in relative wages, one would still expect to find negative coefficients on wage rates ashore—evidence that the best crewmen were drawn to jobs ashore and that the productivity of the fleet dropped accordingly. The coefficients on the indexes of deterioration in crew quality, on the other hand, might be positive, reflecting the relative success in any given year of vessels that had adopted the new techniques. The two sets of variables might pick up two different aspects of important developments—the wage-rate series measuring the influences of competition in the labor market on trends in whaling productivity, and the quality indexes measuring the differences in the cross-section between vessels that did and did not adopt the new techniques.

8.2 Managerial Decisions

Managers made five kinds of choices that could influence productivity: they chose the crew, the grounds in which to hunt, the types of whales to be hunted, the duration of the voyage, and the technical characteristics of the vessel. Decisions about the crew have been briefly discussed; the choice of captain will be taken up in chapter 10. The other decisions are discussed next.

8.2.1 Hunting Grounds

The vessel registrations of New Bedford list fifty separate hunting grounds as destinations. It would be possible to study the effects of managerial choices among hunting grounds by entering fifty dummy variables—one for each ground—in the productivity regression.

That is not a sensible procedure. A vessel sailing for the northwest coast of the United States was unlikely to confine its attentions to this ground alone, even if the hunting there were good, certainly not if the hunting proved poor. It is safer to treat such a reported destination as an indication that the vessel was set to hunt the Pacific. The captain might not follow the agent's instructions precisely. He might, for example, slip over to the Indian Ocean, or even up into the Western Arctic; and surely he would take any opportunity to capture whales as he passed through the Atlantic on his way to the Pacific. Nonetheless, the agent's order to hunt some part of the Pacific is a fair indicator that the vessel would spend most of its time in that ocean.

There is a second reason for ignoring the detail and distinguishing as destinations only major bodies of water—the Pacific, the Atlantic (including Hudson Bay and Davis Strait), the Indian, the Western Arctic. Some agents reported, for example, that their vessels would hunt the Sea of Japan or the Northwest Coast; most did not. They noted simply that a vessel would hunt the Pacific. Since most destination information is of this type, it is better to define the hunting-ground dummies at this level.

In the regression the Pacific—the most common destination—is used as the basis of comparison. Dummies are entered for the Atlantic, Indian, and Western Arctic. Vessels reporting that they were headed, for example, for the Indian Ocean, the Pacific, and the Western Arctic—that is, some combination of grounds—are necessarily excluded. The numbers so excluded are not large, and the effects of their exclusion are unlikely to be important.[4]

Before the fact it seemed reasonable to suppose that the regression would yield a positive sign on the Western Arctic dummy, a negative sign on the Atlantic, and a very small coefficient of either sign on the Indian. Productivity might be expected initially to vary from ground to ground, the differences disappearing as the fleet adjusted its activities to exploit effectively newly discovered grounds. The Pacific, Indian, and Western Arctic were the newer grounds; on that basis alone they might be expected to yield, on average, higher levels of productivity throughout the period. This is particularly true of the Western Arctic, which was discovered very late (1848).

8.2.2 Specialization

Specialization in a particular type of whale varied from vessel to vessel and voyage to voyage. In an effort to see how far it mattered, a set of dummy variables indicating the degree and type of specialization is included on the right side of the regression. Voyages are divided into three groups (of roughly equal size): those in which sperm oil contributed at least 90 percent of the value of output, those in which whale oil and baleen contributed at least 90 percent, and all others. (The all-other group is the comparison base.)

8.2.3 Voyage Duration

As the nineteenth century wore on, whaling voyages from New Bedford grew longer. One explanation for this development is that they were hunting more distant grounds. Within each ocean the duration of voyages increased also, and the reason may be the invention and diffusion of new institutional arrangements. As the whaling fleet expanded, ports in the Azores, Western Australia, Panama, Hawaii, and California began to specialize in servicing it. They

4. There are 194 of these mixed-ground voyages out of a total of 4,731 voyages in the data set. In another 71 cases we do not know the hunting ground.

provided repair facilities, provisions, a convenient system for shipping oil and bone back home, a place to fill out a cargo, and replacement crewmen. By the early 1830s a vessel could sail to the Pacific and plan to stay there several years. Once the Western Arctic was opened and transcontinental railroads were in place, many vessels owned and registered in New Bedford made San Francisco a second home port.

Did these new arrangements contribute importantly to productivity improvement? Unfortunately, there is no perfect quantitative index to stand for the opening and expansion of refitting and reprovisioning ports. The best available measure of the extent to which a vessel used these facilities might be the duration of the voyage, since the development of port facilities made it possible for whalers to stay longer at sea.[5] Of course, the length of the voyage might pick up other characteristics of the venture, as well: unsuccessful captains may have stayed out longer, in hopes of recouping; longer voyages probably led to higher desertion rates, and desertion may have reduced productivity (see chapter 5). The interpretation of the sign and coefficient of this variable is therefore not straightforward. Since the length of the voyage figures in the computation of productivity (labor input is man-months; vessel input is ton-months), the variable entered on the right-hand side of the equation is the square of the length of the voyage.

8.2.4 Technical Characteristics of the Vessel and Whalecraft

The whaling agent made many choices that had to do with the technical characteristics of his vessel: the rig, the size, and the age of the vessel, whether it was constructed for whaling or was a refitted merchantman, and the types of whalecraft to be put aboard.

Rig. The rig choices have been described in chapter 6. In numbers the ship was the principal whaling vessel, although the bark became more important as time passed. The brig, schooner, and sloop were unimportant, particularly during the high tide of New Bedford whaling. For purposes of the regression analysis, vessels are divided into two classes, *ships* and *all others:* we created a dummy variable with a value of one if the vessel was a ship and a value of zero if it was not. Since ships were the most common whalers, it would be reasonable to suppose that they were also the most productive, and so a positive coefficient on the ship dummy could be expected.

5. Some of the sources on which the data set is based distinguish product shipped home from product carried home by the vessel. Were this information complete in the years in which it is available, which it is apparently not, and were it available for all years covered by the data set, which it is not, it would serve to signal one use made of the facilities of these ports and could be entered into the regression analysis. Although the data are not adequate for that purpose, they are good enough to show that the vessels that shipped product home stayed at sea longer than vessels that did not ship product home. See chapter 7.

Size. Over time the sizes of ships and barks increased. This was associated in part with the growing importance of the more distant hunting grounds, but probably also with increasing voyage length within each ground. The variable measuring size is entered in squared form (tonnage squared), because size also figures in the calculation of the productivity index.

Mode of Entry into the Fleet. Some whalers were built expressly for whaling; more were transferred into the fleet from the merchant marine. The regressions distinguish the mode of entry. We expected to find that vessels built for whaling were more productive than those that transferred in, ceteris paribus.

Technical Characteristics. Since there were important changes in vessel design and rigging, some after 1849 and more after 1869, we distinguish vessels by period of construction. We expected vessels built in the second half of the century to have been more productive than those built in the first half (ceteris paribus, of course), and we expected whalers built after 1869 to have been more productive than those built before 1870.

Rerigging. In the second half of the century, a number of vessels were rerigged; generally, ships were rerigged as barks. Barks were easier to sail with few hands and were deemed to be more maneuverable than ships. These advantages were particularly important in the Western Arctic, a ground that was opened to whaling in the middle of the century. It seems reasonable to suppose that rerigged vessels were more productive. This proposition is tested by entering a dummy for rerigged vessels. The test is imperfect, of course, since it compares rerigged vessels with all others, rather than with the prior experience of the vessels that were rerigged.

Age. The age of the vessel (entered as age and age squared) 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 pick up 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 coefficients should record this influence as well as the influence of capital consumption. One should expect to find a positive sign on the coefficient for age, as poor vessels were screened out, and a negative sign on the coefficient for age squared, as wear and tear reduced even an efficient vessel's effectiveness.

In a further attempt to understand the influence of the deterioration of a vessel's productive capacity on an agent's choices, the last voyage of each vessel is identified. If poor performance led to condemnation or transfer to another activity, the variable should have a negative sign.

Whalecraft. Whalecraft consists of the implements used in capturing whales. The chief inventions were introduced in the brief period from 1848 to 1865, and were widely diffused by 1870. In an attempt to provide a measure of their importance, outfitting books were searched for data on whalecraft. Unfortunately, few are still extant. More important, the outfits do not exhibit enough voyage-to-voyage variation—particularly when time is held constant—to produce good statistical results.[6] The outfitting books do show that the diffusion of new techniques took place quickly. Consequently, the adoption of the new body of techniques can be reasonably proxied by a time dummy. The date 1 January 1870 is selected for this purpose—observations of voyages sailing in the years 1870 and later take the value one, while those of voyages sailing in earlier years take the value zero.

Time. Time (represented as the voyage's year of departure minus 1820) is entered simply as a detrender. The regression model is sufficiently complete that we did not expect the time variable to have a large or significant coefficient.

8.3 Multivariate Analysis

The Voyages Data Set contains evidence on 4,731 whaling voyages in 1789–1927, but this chapter is not concerned with all of them. Before 1821 the industry was unduly influenced by political and military events; after 1897 it consisted of only a handful of firms. Observations before 1821 and after 1897 are therefore excluded from the statistical analysis of this chapter. Voyages that ended in the loss of the vessel (about 380) and voyages that yielded no output (89) are also excluded, as are voyages for which the evidence is incomplete. As a result of these restrictions the largest data set figuring in the regressions contains 2,935 observations.

This is a very large data set, by any standards. Is it also representative? If so, of what? New Bedford? All the East Coast ports? All the American ports? Unlike many other American whaling ports, New Bedford engaged in diversified whaling (see chapter 1). It sent vessels to every hunting ground and was regarded at the time as representative of American ports, taken together. The sample, however, was not drawn randomly from all American voyages. Indeed, it was not even drawn randomly from New Bedford voyages.

To test the extent to which the sample resembles the universe of New Bedford voyages, 1821–97, we compared average sample and universe values for each of the outputs, vessel tonnage, and length of voyage. The data appear in table 8.1, panel A. The mean tonnage of vessels making sample voyages is about the same as the mean tonnage of vessels making universe voyages. Sample voyages were one month longer than universe voyages, but also

6. See Davis, Gallman, and Hutchins 1989, 131–33, 142–47, where the outfitting data are considered at length.

Table 8.1 **Characteristics of the Voyages in the Productivity Sample and of the Voyages Composing the Universe of New Bedford Whaling Voyages, 1821–97**

A. Outputs and Inputs

	Universe[a]	N	Sample (N = 2,935)
Average output of			
Sperm oil (barrels)	764.6	3,373	769.8
Whale oil (barrels)	978.3	3,373	995.2
Baleen (pounds)	8,400.8	3,373	8,798.2
Average inputs			
Vessel size (tons)	306.3	3,428	310.1
Interval at sea (months)	31.7	3,435	32.7
Average real value of catch ($)	47,800.9	3,373	49,667.1
Average value of catch per ton-month ($)	4.923	—[b]	4.898

B. Distribution of Voyages among Hunting Grounds[c] (%)

	Universe	Sample
Atlantic	32.4	30.4
Indian	13.0	13.8
Pacific	47.8	48.6
Western Arctic	6.8	7.2
Total	100.0	100.0

Sources: Voyages and Productivity data sets.

[a]The universe consists of voyages beginning in 1821 through 1897 and ending with the return of the vessels to New Bedford, voyages for which there is information concerning at least one of the variables listed in this table.

[b]The average vessel size, interval at sea, and real value of the catch were computed from universes of different sizes.

[c]Only voyages to one of these four grounds are reported (Hudson Bay and Davis Strait are included with the Atlantic).

brought back somewhat more product. The value of real output per ton-month was almost identical for sample and universe voyages. This is an important point, since it suggests that productivity levels of sample voyages, on average, are representative of the universe,

Panel B contains a second comparison: universe and sample are distributed among the four major hunting grounds. The sample contains, proportionately, somewhat fewer voyages to the Atlantic and somewhat more to the other grounds than does the universe, but the differences are not great.

These are not sophisticated tests, but perhaps no sophisticated tests are called for. The sample is very large, compared with the universe, and its known relevant characteristics appear to mirror those of the universe. In what follows, the sample is treated as representative of New Bedford whaling, 1821–97; it is probable that the sample also represents all East Coast whaling.

Table 8.2 Productivity in New Bedford Whaling, Sailing Years 1821–97

	Dependent Variable: Total Factor Productivity		
	(1)	(2)	(3)
Statistical properties			
F	96.5	100.2	99.7
Adjusted R^2	.428	.426	.430
Dependent mean	.699	.699	.699
Durbin-Watson D	1.781	1.786	1.774
Observations	2,935	2,935	2,935
Parameter estimates			
Intercept	2.5016*	2.7227*	2.1248*
Hunting pressure[a]			
On baleens	0.0013**	0.0021*	—
On sperms	−0.0008**	−0.0003	—
On all whales	—	—	0.0001
Competition index[a]	0.0003*	−0.000008	0.0003*
Competition index squared	-1.125×10^{-7}*	—	-1.128×10^{-7}*
Real common wage rate ashore	−0.0048*	−0.0055*	−0.0050*
Ratio, skilled/common wage rate ashore	−1.3001*	−1.4320*	−0.9093*
Ships (compared to other rigs)	0.1524*	0.1559*	0.1489*
Vessel tons squared	8.846×10^{-7}*	8.854×10^{-7}*	8.723×10^{-7}*
Ground (compared to Pacific)			
Atlantic	−0.1339*	−0.0949**	−0.0723**
Indian	0.0870***	0.0962***	0.1397*
Western Arctic	0.3523*	0.3780*	0.3491*
Mode of entry to fleet (compared to built before 1850)			
Built as whaler 1850–69	−0.0155	−0.0142	0.0083
Built as whaler 1870–96	−0.1079	−0.1080	−0.0753
Built as merchantman 1850–96	0.1414**	0.1450**	0.1435**
Technological dummy	0.3642*	0.3658*	0.3459*
Vessel rerigged	0.0826**	0.0856**	0.0891*
Vessel age	−0.00005	−0.00010	0.00009
Vessel age squared	−0.00003	−0.00003	−0.00003
Last voyage	0.0244	0.0299	0.0205
Specialization			
In baleens	0.0937*	0.0958*	0.1119*
In sperms	−0.6165*	−0.6175*	−0.6280*
Voyage length (months) squared	−0.0002*	−0.0002*	−0.0002*
Time (years since 1820)	−0.0011	−0.0008	−0.0024

Sources: Most of the data were taken from the Voyages and Productivity data sets, which are described in chapter 3 and in this chapter. The appendices to this chapter describe the hunting-pressure and competition indexes and the sources of these data series.

The common wage-rate series was computed from David and Solar 1977, data on page 59 divided by data on page 16. The skilled wage-rate index was derived by multiplying the series on page 59 of David and Solar by the skill ratios on page 307 of Williamson and Lindert (1980) and then dividing by the price index on page 16 of David and Solar.

Notes: The wage rates ashore associated with each voyage are the wage rates in effect in the year the voyage began.

(continued)

Table 8.2 (continued)

The residuals were examined for evidence of heteroscedasticity. None was found. Nevertheless, we ran a second test, regressing the residuals against the squares of the independent variables. The resulting F-statistic was .398, and the adjusted R^2 was -0.0047. One coefficient variable was significantly different from zero at the 10 percent level; none of the others achieved significance at even this level. We therefore assumed that the regressions are not heteroscedastic. The issue is not very important in any case; heteroscedasticity affects only the t values. Our sample is so large that, even if the regression is treated as no more than descriptive of the sample, the description holds for more than 60 percent of the New Bedford whaling industry (sample = 2,935 voyages; universe = 4,731 voyages).

There is a modest amount of collinearity, as one would expect from the long array of variables, several of which relate to time, or appear in quadratic form. Of the 253 paired relationships among the intercept and the independent varibles of the second regression, 37 exhibit correlations of .20 or greater. Notice, however, that both the F- and t-statistics of this regression are excellent, and that the signs and values of the coefficients are quite stable, from one formulation of the model to the next (this table), and from one period to the next (compare this table with tables 8.5 and 8.6). These results would be unlikely to occur if multicollinearity were an important problem.

The t-statistics were adjusted to allow for the large size of the sample. Adjusted t = coefficient/adjusted standard error. Adjusted standard error = standard error multiplied by (population size minus sample size) divided by (population size minus one). (See, for example, Freund and Walpole 1987, 278–80, "finite sample correction factor for standard deviation when sample size is greater than 5 percent of the population size.")

We thank David Guilkey, James Murphy, and Michael Salemi for econometric advice.

[a]For a description of the ways in which the hunting-pressure and competition indexes are entered into the regression, see appendixes 8A and 8B.

*Significant at the 1 percent level.

**Significant at the 5 percent level.

***Significant at the 10 percent level.

The results of the first set of regressions appear in table 8.2. Each of the equations explains over four-tenths of the productivity variance, a level of explanatory power that is excellent for a pooled cross-section time-series data set, particularly in view of the role of luck in this industry. The F values are very high, and most of the coefficient signs and values yield sensible interpretations. There is considerable stability in the coefficients from one regression formulation to the next. Levels of significance are exceptionally high. There is not much to choose among the three regressions. Before discussing the coefficients, it may be useful to consider another test of the power of the equations.

Average productivity in the New Bedford whaling industry dropped sharply from the 1820s to the 1860s and then rose mildly to the 1890s (see figure 1.1 and table 1.3). How far do the equations shown in table 8.2 explain this pattern of falling and rising productivity? A test of the following form was run: First a regression was estimated with productivity as the dependent variable and dummies standing for the decades of the 1820s (the comparison base), 1830s, 1840s, and so forth as independent variables. The equation was then reestimated, including the decadal dummies and all of the independent variables of the regression equations (except time, whose place was taken by the decadal dummies).[7] The changes in the coefficients of the dummies between the first and second runs measure the extent to which the comprehensive equation ex-

7. The test was suggested by Robert Evenson, to whom we give our thanks.

plains the pattern of productivity change across time. The results obtained from the first equation in table 8.2 (the other two equations yield similar values) are shown in table 8.3.

The comprehensive equation explains between 12 and 100 percent of the deviations in productivity among the decades. In fact, however, the performance is better than these figures suggest. Only 12 percent of the drop between the 1820s and the 1830s is explained; but notice that the productivity curve described in the second column of figures is much flatter, between the 1830s and the 1880s, than is the curve described by the first column. This characteristic of the second column can be exhibited most clearly in the decrements (or increments) in the coefficients between the 1830s and each of the subsequent decades (table 8.4). Notice that the equation explains between 65 and 100 percent of the changes between the 1830s and subsequent decades.

It appears, then, that the equations in table 8.2 account for only a small part of the drop in productivity between the 1820s and the 1830s, the early years of the industry, but are much more successful in explaining the movements of productivity in the mature industry.

Table 8.3 Coefficients of Dummies

	Coefficients		
Decade	Simple Equation (s)	Complex Equation (c)	% Explained by Complex Equation $((s - c)/s) \times 100$
1830s	−.284	−.249	12
1840s	−.390	−.245	37
1850s	−.574	−.351	39
1860s	−.738	−.342	54
1870s	−.728	−.274	62
1880s	−.736	−.317	57
1890s	−.652	+.134	100

Table 8.4 Changes in Coefficients of Dummies

	Changes in Coefficients from 1830s		
Decade	Simple Equation	Complex Equation	% Explained by Complex Equation
1840s	−.106	+.004	100
1850s	−.290	−.102	65
1860s	−.454	−.092	80
1870s	−.444	−.025	94
1880s	−.452	−.068	85
1890s	−.368	+.383	100

What do the equations tell us about productivity in New Bedford whaling? The specifications of the three regressions differ only slightly. In the first and third the competition index appears in quadratic form; in the second, the squared term is dropped. The first and second regressions include separate hunting-pressure indexes for baleen and sperm whales; the third employs an index that is intended to measure hunting pressures on all whale populations taken together.

To begin with the stocks of whales, the signs on the index of hunting pressure on baleens are positive. There is no indication that hunting baleens led to lower productivity, a finding that confirms the impression conveyed by the evidence of chapter 4 that American whaling did not collapse for lack of baleen whales.

The story with respect to sperm whales is less clear. In the first model the sign on the sperm hunting-pressure index is negative, and the significance level is high: the equation indicates that hunting pressures on sperm whales *did* lead to lower productivity levels. The effect was apparently not large. In the period between the opening of each ground (after 1819) and the highest level of hunting pressure, the effect of hunting was to lower the productivity index by .041 in the Atlantic, .010 in the Indian, and .130 in the Pacific.[8] Compared with the dependent mean, .699, only the effect in the Pacific is substantial enough to warrant special attention. Even in this case, the implicit decline in productivity was about 0.5 percent per year (that is, one two-hundredth of the productivity level) across the period of expansion in the Pacific. Furthermore, the results with respect to the pressures on sperms are not stable. For example, in the second equation displayed in table 8.2, which differs in only one respect from the first, the coefficient on the sperm-whale hunting-pressure index drops to only four-tenths of that in the first; and the t value shows that the second-equation coefficient is not significantly different from zero. In view of the enormous size of the sample, t values should perhaps receive little attention. If the regression is regarded as no more than descriptive, it is descriptive of more than 60 percent of the industry. The instability of the coefficient on the variable, however, does raise questions about the impact of the hunting of sperm whales on productivity. It does not seem probable that hunting pressures contributed in an important way to the decline of productivity and the eventual demise of the whaling fleet. This conclusion is supported by the third equation, where the sign on the combined hunting-pressure index is positive. There is no support to be drawn from this regression for the assertion that whaling productivity fell as a consequence of overhunting.

The competition indexes provide little support for the argument that crowding on the hunting grounds seriously affected productivity. The quadratic form of the index was entered in the first and third equations, the index alone, in the

8. These numbers were calculated by applying the coefficients in the table to the relevant hunting-pressure index values. For the hunting-pressure indexes see appendix 8A.

second. The significance levels on the variables in the first and third regressions are good, but the coefficients are very small. These results suggest that negative consequences must have appeared only at very high levels of crowding, and that even in these instances they must have been minute. The squared form of the index was dropped from the second equation. The sign on the index alone is indeed negative, but the coefficient is so small that the effects of crowding could not have been important. For example, if this coefficient is applied to conditions in the Western Arctic, it appears that the increase in crowding in that ground between January 1850 and March 1853—the month when the competition index hits its apogee—caused productivity to fall by 0.2.[9] There is no other instance in which the degree of crowding changed so much. If competition ever affected productivity unfavorably, it must have done so in this period.[10] The findings are clear: the negative consequences of competition were negligible.[11]

Unlike hunting pressures and competition, the series of wage rates ashore yield the expected results; the coefficients are large, given the range within which the wage series moved (86 points, for the common wage, between 1820 and 1896; .52, for the ratio of the skilled to the common wage); they have the expected sign; and they are significantly different from zero at an appropriate level.[12] It appears that competition for labor from activities ashore did indeed bid away the best whalemen, with unfavorable consequences for productivity. That argument is admittedly indirect, and more evidence must be assembled before its conclusions can be enthusiastically embraced.

As to the choices made by whaling agents, it seems that their preference for ships and their tendency to adopt larger vessels as time passed were sensible. Ships were substantially more productive than other vessels; within limits, larger vessels were more productive than smaller ones. (Given the tonnage range within which most whalers lay—the interquartile range of vessels was 151 tons and of voyages only 121 tons—size was not of overwhelming importance.) Their decision to shift—during the heyday of New Bedford whaling—from the Atlantic, to the Indian, to the Pacific, and finally to the Western Arctic also is shown to be well motivated, if the pursuit of high productivity was sensible. (The profit consequences of these changes are considered in chapter 11.)

9. The competition index in January 1850 in the Western Arctic was 4.1; in March 1853 it was 213.1. See appendix 8B.

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

11. This conclusion does not rule out the possibility that competition or overhunting affected productivity on more narrowly defined hunting grounds (for example, the Baja calving grounds). If such developments had been important to the whaling fleet, however, their impact would surely also be observable in the statistical results for the larger hunting grounds identified by the regression equations in table 8.2.

12. The skilled wage rate is expressed as a ratio to the common wage rate in order to avoid problems of multicollinearity.

Several of the variables bear on the impacts of technology. The effects of changes in vessel design are presumably captured chiefly by the variables listed under the heading "mode of entry into the fleet." The statistical results based on these variables show that vessels built as merchantmen after 1849 and then transferred into the whaling fleet were substantially more productive (the advantage is about 20 percent of the dependent mean) than vessels built before 1850 and then transferred into the whaling fleet; this is the expected result, given that the designs of merchantmen improved dramatically after 1850 (see chapter 7). What is surprising is that the two variables representing vessels built as whalers after 1849 have coefficients of the wrong sign in two of the regressions and the wrong value in all three. Vessels built after 1870 are shown to be less productive than those built between 1850 and 1870. In two of the three regressions, both groups—those built after 1870 and those built between 1850 and 1870—are less productive than vessels built before 1850. The significance levels are very poor, but even if we accept the implication that these coefficients are not different from zero, they indicate that vessels built after 1849 were *no less* productive than the ones built before 1850—small comfort, given that the literature says they were much better designed.

Vessels built before 1850 were hunting, on the whole, during a more favorable period than vessels built after 1849, since average productivity was higher before than after 1849. Is it possible that the unexpected results described above reflect this phenomenon? That is, could the results reflect the circumstances of the years after 1849, rather than the quality of the vessels built then? The regression is comprehensive enough that the average productivity levels peculiar to the periods before 1850 and after 1849 should not influence the results obtained on variables recording the years vessels were built. For example, the regression clearly shows that merchantmen built after 1849 were much more productive than those built before 1850. Nonetheless, on the chance that the results are affected by the periods of time during which these various groups of whalers were hunting, the regression was rerun for the period from 1870 onward. That specification yields, in effect, a cross-section regression. The results (not shown) improved a little, but not much. The signs on the two dummies representing vessels built as whalers in the periods 1850–69 and 1870–96 are now positive, a good result; the coefficient on the dummy representing the later period is larger, by a wide margin, than the one on the dummy representing the earlier period, an even better result: the vessels with the more advanced technology, per chapter 7, were more productive than those with the less advanced technology. Unfortunately, the t values are very small.[13] Further-

13. Notice that in this regression, as distinct from the previous one, the vessels built as whalers are being compared with older vessels (converted merchantmen) operating contemporaneously with them. Presumably the age variables in the regression pick up the unfavorable effects of age, so that the comparison remains legitimate. The comparison vessels are not only older, however; they are also survivors. The regression does not adjust for this characteristic, so that in this respect the comparison is biased *against* a finding of high productivity for vessels built as whalers.

more, the dummies representing vessels built expressly for whaling have smaller coefficients than the one representing vessels built as merchantmen and subsequently converted. These results, obviously, are counterintuitive, and we have no explanation for them.

The technological dummy is designed to measure the effect of improvements in whalecraft, although it may also pick up some part of the improvement properly attributed to vessel design. The variable works very well. The coefficient is large, of the right sign, and stable from one regression formulation to the next; the significance level is high.

A final technological variable relates to rerigging, chiefly the rerigging of ships as barks. Rerigged vessels are shown to have a productivity advantage. Their superiority might have been due to the relative speed (as compared with construction) with which they could be produced. When the Western Arctic opened, rerigged vessels could be thrown quickly into that ground and could scoop off the first-arrival gains. This factor may be the source of the positive coefficient on the rerigged variable, although one would think that the Arctic-ground dummy would capture this effect. The earlier discussion of the very limited consequences of crowding in the Western Arctic also suggests that first-arrival gains were not quickly dissipated. If first arrival is not the correct explanation, then rerigging represents the introduction of improved technology, and the results of the new technology were clearly favorable.

The findings with respect to the remaining choice variables are mixed. The coefficients on the age variables are very small and are not significantly different from zero. Apparently, old vessels performed as well, or nearly as well, as new ones. How far these results reflect selection bias is anybody's guess, but presumably the survivors were the vessels that had been most successful.

The coefficient on the last-voyage dummy suggests that vessels were withdrawn from whaling for reasons other than poor productivity on the last voyage. The last-voyage variable has the wrong sign, the coefficient is very small, and according to the t value the coefficient is not significantly different from zero.

Specialists in baleen hunting appear to have done better, ceteris paribus, than both the specialists in sperm whaling and the nonspecialists. Why were baleen specialists more productive? Most of the factors that differentiate baleen from sperm specialists figure in variables that have already been considered; the sources of the remaining differences are unknown.

The sign on voyage length is wrong, if voyage length is taken to be only an index of the impact of the innovation of the reprovisioning port. The variable also seems to pick up the bad luck or lack of skill that kept some vessels long at sea. Given the sign of the coefficient, the lack of luck or skill seems to have had the greater effect (see note 3), but the effect was not large. For example, given the sizes of the coefficients, a twenty-four-month difference in voyage length was associated with a difference in productivity of only 12 or 13 percent of the dependent mean.

Finally, the coefficients on the detrending variable, time, are small. According to the *t* values, they are not significantly different from zero. Ignoring the *t* values, the equations indicate that, ceteris paribus, productivity declined by between 0.1 and 0.3 percent per year, between 1821 and 1896. Since there is little left to be explained by the portmanteau variable time, it appears that the equation is reasonably complete.

8.4 Tests of the Multivariate Analysis

The regression analysis unfolds reasonably and seems to reveal important aspects of forces at work on U.S. whaling productivity. Still, some of the variables are less than perfect and pose interpretive problems. Two sets—those bearing on labor quality and on techniques of production—deserve further attention.

The productivity index for the fleet as a whole declined from 1821 to the 1860s, while the wage rate ashore rose. The strong negative association between the wage series and the productivity series may describe only the numerical relations between two trends that have no true theoretical connection. This proposition can be tested by differencing or detrending the data. The procedure has already been carried out in the regressions in table 8.2, where time serves as detrender. A second and stronger effort is described in the equation in table 8.5. Notice that the data set is restricted to the period 1834–96, a period during which productivity dropped and then rose, reaching again in the mid-1890s the level of the mid-1830s. Time appears once again as a detrender, but now in the form of time and time squared. If in the first equation the relations between the trends in the wage rate and the productivity series down to the mid-1850s alone produced the sign and coefficient on the wage-rate series, one would think that, in the new formulation, the wage-rate series would no longer exhibit the same characteristics. In fact, however, it does. The ratio of the skilled to the common wage rate is not significant at as high a level as before, but it is very close to being significant at the 10 percent level. The common wage-rate series retains a large negative value—slightly larger than before—and is significantly different from zero at better than the 1 percent level. The correlations between the coefficients of the two time variables and the common wage coefficient are also very small (-0.082 and -0.035). The wage series appears to be capturing something other than time. The conclusions that (1) the quality of whalemen deteriorated as opportunities ashore improved and (2) the decline in the quality of crews tended to lower productivity, ceteris paribus, are strengthened.

Two other features of this 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 8.2—which is reassuring, since it suggests that the identified relationships are stable. Moreover, the significance levels are high across the board. Second, since productivity began to increase late in the pe-

Table 8.5 Productivity in New Bedford Whaling, Sailing Years 1834–96

	Dependent Variable: Total Factor Productivity
Statistical properties	
F	70.3
Adjusted R^2	.388
Dependent mean	.634
Durbin-Watson D	1.789
Observations	2,628
Parameter estimates	
Intercept	1.888*
Hunting pressure	
On baleens	0.0011***
On sperms	0.00003
Competition index	0.0003**
Competition index squared	-9.704×10^{-8}**
Real common wage rate ashore	−0.0052*
Ratio, skilled/common wage rate ashore	−0.5174
Ships (compared to other rigs)	0.1202*
Vessel tons squared	0.000001*
Ground (compared to Pacific)	
Atlantic	−0.1147**
Indian	0.1932*
Western Arctic	0.3766*
Mode of entry to fleet (compared to built before 1850)	
Built as whaler 1850–69	−0.0204
Built as whaler 1870–96	−0.1109
Built as merchantman 1850–96	−0.1091***
Technological dummy	0.1725*
Vessel rerigged	0.0796**
Vessel age	0.0025
Vessel age squared	−0.00007***
Last voyage	0.0299
Specialization	
In baleens	0.1206*
In sperms	−0.615*
Voyage length (months) squared	−0.0002*
Time (years since 1820)	−0.0192*
Time squared	0.0003*

Note: See table 8.2.

*Significant at the 1 percent level.
**Significant at the 5 percent level.
***Significant at the 10 percent level.

riod (see figure 1.1), one might have supposed before the fact that the introduction of time squared would displace the technological dummy—a dummy that divides the observations at 1 January 1870. In fact, it does not. The technological dummy retains a large coefficient, although not as large as before. It is significantly different from zero at the 1 percent level.

The wage variables were introduced to test a hypothesis drawn from the whaling literature: as wage rates ashore went up, the best men were bid out of whaling, the quality of the crews deteriorated, and productivity fell. The modeling of this hypothesis in table 8.2 is straightforward enough, linking, as it does, the underlying cause (higher wage rates ashore) with the ultimate consequence (lower productivity in whaling). There are also indications that wage rates ashore rose relative to the earnings of whalemen (see chapter 5). The middle step in the traditional argument—the deterioration in the quality of crews—is, however, bypassed in this analysis. Did crews really decline in quality? Yes, they did. For a limited stretch of years—1840–58 and 1866—there are quality indexes at the voyage level. With these data it is possible to look directly at the links between crew quality and productivity.

Table 8.6 reports the results of three regressions that do so. The first is virtually identical to the first equation in table 8.2. It omits (necessarily) the technological variable, but—except that it is fit to only 1,112 voyages beginning in the years 1840–58 and 1866—it is otherwise unchanged. Notice that, with a few notable exceptions, the results of the two equations are very similar. The relationships are stable.

The second equation in table 8.6 is almost the same as the first, except that direct indexes of labor quality—the percentage of the crew that is illiterate, the percentage of the crew consisting of greenhands—are substituted for the wage rates ashore. The results are not what might have been expected. The coefficients on these variables are very small, and the larger carries the wrong sign; neither is significantly different from zero at a conventionally acceptable level. The suggestion is that the decline in labor quality had no effect on productivity.

The third equation incorporates both the wage rates ashore and the two indexes of crew quality. The wage-rate variables again carry reasonably large coefficients, they have the correct signs, and they are significant at a demanding level.[14] The two quality indexes have larger coefficients than before, but they are of the wrong sign if these variables are to be interpreted as indexes of the quality of labor. If instead they are regarded as indicators of the adoption of new technology, the signs are correct. Perhaps the wage series capture the effects of the tendency for opportunities ashore to advance faster than those afloat and, therefore, for the best men to be bid away from whaling. That leaves

14. For example, the real common wage rate ashore rose from a level of sixty-eight in 1842 to ninety-one in 1857, a twenty-three-point gain. Multiplying the coefficient of the real wage-rate index by thirty-eight yields a very large value, compared with the dependent mean, .695.

Table 8.6 Productivity in New Bedford Whaling, Sailing Years 1840–58 and 1866

	Dependent Variable: Total Factor Productivity		
	(1)	(2)	(3)
Statistical properties			
F	67.9	62.0	59.4
Adjusted R^2	.558	.557	.569
Dependent mean	.719	.695	.695
Durbin-Watson D	1.936	1.908	1.941
Observations	1,112	1,021	1,021
Parameter estimates			
Intercept	2.5123*	1.2129*	2.5263*
Hunting pressure			
On baleens	−0.00009	−0.00140**	-9.05×10^{-7}
On sperms	−0.00070	0.00001	−0.00060
Competition index	0.0003	0.0003	0.0003
Competition index squared	-9.266×10^{-8}	-1.161×10^{-7}	-9.774×10^{-8}***
Real common wage rate ashore	−0.0128*	—	−0.0135*
Ratio, skilled/common wage rate ashore	−0.3618	—	−0.3990
% of crew illiterate	—	0.1478	0.2106
% of crew greenhands	—	−0.0138	0.1128
Ships (compared to other rigs)	0.1275*	0.1337*	0.1325*
Vessel tons squared	0.000001*	0.000001*	0.000001*
Ground (compared to Pacific)			
Atlantic	−0.6143*	−0.5549*	−0.5443*
Indian	−0.0600	−0.0618	−0.0455
Western Arctic	0.1066	0.1045	0.1369
Mode of entry to fleet (compared to built before 1850)			
Built as whaler after 1849	−0.0553	−0.0378	−0.0687
Built as merchantman after 1849	−0.2951**	−0.2062	−0.2976**
Vessel rerigged	0.0951***	0.1043**	0.1006***
Vessel age	−0.0050	−0.0032	−0.0068
Vessel age squared	0.00007	0.00003	0.00010
Last voyage	−0.0400	−0.0617	−0.0170
Specialization			
In baleens	0.0056	0.0111	0.0060
In sperms	−0.6606*	−0.6889*	−0.6882*
Voyage length (months) squared	−0.0003*	−0.0003*	−0.0003*
Time (years since 1820)	0.0051	−0.0021	0.0040

Sources: Most of the data come from the works cited in the notes to table 8.2. The information on illiteracy and greenhands comes from the Stations and Lays Data Set.

*Significant at the 1 percent level.

**Significant at the 5 percent level.

***Significant at the 10 percent level.

the quality indexes to pick up the favorable effects of adopting new methods. That is, the wage series bear on the changes across time in the ability of whaling to compete for men, while the quality indexes refer mainly to the differences in the cross-section between vessels that had adopted the new methods (and could therefore ship crews composed mainly of unskilled greenhands) and those that had not. At least this explanation makes the most sense of the strong statistical results reported in table 8.6.

The other measures of new technology, the two dummies representing vessels built after 1849, do not perform well in these regressions. That may be simply because few new vessels of the designated types had yet appeared on the scene in these years. The labor-quality indexes perform better, probably because they capture cases in which the new technology was introduced by reworking old vessels. The two vessel-construction dummies do not reflect such changes, of course. The rerigging variable probably does, and that variable performs very well.

In summary, after 1820 shifts 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. Whalemen opened rich grounds in the South Atlantic, the Indian Ocean, and the Pacific. The subsequent shift in the structure of demand—favoring whalebone over sperm and whale oil—sent captains to the North Pacific in search of right whales. One was venturesome enough to push through the Bering Strait into the Bering Sea, where he found a profusion of the greatest of the whalebone whales, the bowhead. He was quickly followed by many others.

These changes in demand and in hunting grounds, coupled with emerging labor problems, led agents to reorganize 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 became common. Different vessel types (ships in the Pacific and the Indian Ocean, barks in the Western 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, in part from architects who specialized in whalers. The designs made it possible to save on experienced labor, an increasingly scarce input.

Longer voyages led agents to adopt larger vessels and to utilize the developing resupply and transshipment points in the Azores, Hawaii, Panama, and the West Coast of the United States. In the whaleboats the whaling gun replaced the handheld lance; toward the end the darting gun, the most effective American whalecraft innovation, was widely adopted.

These changes in environment and agents' reactions to them are given quantitative expression in the regressions exhibited in this chapter. The findings call for no extended summary. The most interesting results show that productivity was not adversely affected by overhunting or crowding on the hunting grounds.

Of particular interest is the finding—well recognized in the whaling literature—that, as time passed, labor problems emerged and that they were, in all likelihood, a result of relatively favorable alternative opportunities ashore. Perhaps in response to this development, new vessel designs that saved on experienced labor were introduced, and seem to have had favorable effects on productivity. Innovations in whalecraft, concentrated in a relatively short period, were also effective.

The account rendered in this chapter considers the decisions of agents that bore on productivity. It does not take up the agents themselves, nor does it treat the captains. These subjects—including their relationship with productivity—are discussed in chapter 10.

Appendix 8A

Derivation of the Hunting-Pressure Indexes

The hunting-pressure indexes were constructed to allow us to test the propositions that (1) whales were hunted so intensively in the nineteenth century that they became scarce—or wary—and (2) as a result of hunting, the capture of the typical whale called for the expenditure of more labor and capital than had previously been necessary (i.e., productivity in whaling declined).

We began with Tower's estimates (1907, 126) of the volume of whale oil, sperm oil, and whalebone brought into the United States by American whalers in the years 1805–1905. From 1805 through 1837 the oil figures are expressed in gallons, thereafter in barrels. We converted the earlier figures into values expressed in barrels by dividing Tower's gallon estimates by 31.5. (A typical barrel of oil contained 31.5 gallons.)

Our plan was to estimate, on the basis of the oil imports, the numbers of whales killed. Toward the end of the period, however, baleen whalers frequently took only the bone from captured whales, and the aggregate whale oil imports after about 1886 are therefore not good indicators of the numbers of whales killed. Consequently, we derived a second whale oil series, based on bone imports, and intended to measure the oil that could have been extracted from the baleens killed, had they all been tried out. The second series rested on the assumption that one barrel of oil could have been extracted from a baleen whale for each fourteen pounds of bone taken. The figure was based on a study of oil and bone imports in the 1860s, 1870s, and early 1880s, before the ratio began to move up dramatically. In these years the ratio varied widely from year to year but showed no trend. We took the largest value for these years, that for 1868, and assumed that any larger figure in a later year indicated that blubber was being discarded. After 1886 all of the ratios are larger, and therefore we replaced the oil imports of those years by new estimates. The estimates unfortunately do not exhibit the degree of variation from year to year that the true figures before 1886 do. It is also possible that the level of the estimates is too low, but we do not think it is. In the years after 1886, bowheads probably came to dominate the baleens being taken, and the ratio of bone to oil in bowheads was larger than for other baleens. Consequently, employing the peak figure of 1868 as the basis for our estimates is reasonable enough.

The two final oil series—sperm and whale—were then used to estimate the numbers of whales killed by Americans to obtain this oil. The estimating coefficients were taken from chapter 4. Specifically, we assumed that, on average, 33.6 barrels of oil could be recovered from a sperm whale, and that, in addition to the whales taken, another 10 percent were killed but lost. The number of sperm whales killed to obtain the oil imported each year was computed as the product of the number of barrels imported and the fraction .032738 (1.1/33.6), rounded to a whole number. Notice that the procedure makes no allowance for variations from year to year in the average sizes of whales taken, or for long-term trends in size. There is no way in which the former variations can be taken into account, and chapter 4 suggests that long-term changes in size were not pronounced. The same procedures were used in the case of baleen whales, except that the average baleen was estimated to contain seventy-three barrels of oil and the estimating coefficient is .0150684.

The number of whales was then distributed among hunting grounds in proportion to the New Bedford catch (Voyages Data Set).

Next we added in the British catch for the years up to the mid-1840s. The British were important hunters in this period, but the British fleet fell away to virtually nothing in the 1840s and did not recover until the end of the century. It is essential that estimates of British hunting be included in the early years, but some of the figures we were able to put together are quite weak, and that point must be borne in mind.

The data for the British northern fleet (the Atlantic, Hudson Bay, Davis Strait) are from Jackson (1978, 270), they refer to numbers of whales taken, and they are excellent. We assumed that all of these whales were baleens. For the Pacific and Indian Oceans combined, we estimated the catch on the basis of the tonnage of the British southern fleet (Jackson [136] interpolated to fill gaps) and the productivity of the northern fleet (whales/tonnage). The catch—which we assumed consisted exclusively of sperm whales—was divided between the Indian and Pacific Oceans on the basis of the New Bedford catch.

The estimates in the various grounds were then scaled, by dividing each by the number of whales originally in the ground. The estimates in table 8A.1, based on chapter 4, were used for this purpose.

Virtually no sperm whales were taken in the Western Arctic. There are two ways to handle the statistical problem thus posed, and we used both. First, we assumed that the ratio of sperms killed to sperms originally in the Western Arctic ground was equal to the average for the remaining three grounds. This assumption permits calculations to be made, although the results with respect

Table 8A.1 **Estimated Whale Populations before Intensive Hunting Began**

	Sperm	Baleen	Total
Atlantic	280,000	66,000	346,000
Pacific	1,574,000	255,000	1,829,000
Indian	502,000	42,000	544,000
Western Arctic	—	30,000	30,000

to sperms in the Western Arctic are meaningless. The second technique was to combine baleens and sperms and produce only one hunting-pressure index per ground, instead of two.

Next, four-year moving averages were run for each index, and then all the indexes were converted to relatives of the figure for the Pacific in 1855 (average of 1851–54). See table 8A.2.

Index numbers were associated with voyages in the following way. A vessel leaving for the Pacific in 1821, for example, was associated with three index numbers (sperm, baleen, combined), each of which is the average for the years 1817, 1818, 1819, and 1820. The assumption is that if previous hunting affected the productivity of a voyage unfavorably, it would be hunting over a period of years that counted, not just hunting in the year before the voyage began. How many years should be included is moot; four seems better than three; many more than four would become cumbersome.

Appendix 8B
Derivation of the Competition Indexes

The competition indexes were constructed for use in the regression analysis of productivity. The underlying assumption is that productivity was likely to be unfavorably affected by competition on the hunting ground, not because the stock of whales was being hunted down (a hypothesis tested using the hunting-pressure indexes), but because on a crowded hunting ground the prospective whale victim of vessel A might be taken instead by vessel B, thus diminishing A's productivity.

The form of the index for any year is, then, easily imagined. The index is computed by dividing the number of vessel tons on a given hunting ground by the ratio of the number of whales on the hunting ground to the square miles composing the hunting ground. The smaller the ratio in the denominator, ceteris paribus, the greater the competition for whales and the higher the index. Similarly, the larger the number of tons on the hunting ground, ceteris paribus, the greater the competition and the higher the index. Index numbers are attached to voyages, to measure the competition the vessels faced.

Table 8A.2 Indexes of Hunting Pressure on Stocks of Whales, by Ocean, 1820–1905 (Pacific 1855 = 100)

	A. Atlantic Ocean		
Index Year	Baleen	Sperm	All Whales
1820	23.241	6.253	35.774
1821	29.453	5.181	44.334
1822	38.413	8.163	58.334
1823	36.413	7.738	55.298
1824	40.460	14.067	63.443
1825	36.692	14.221	58.068
1826	33.597	20.790	56.011
1827	32.890	29.488	58.171
1828	29.555	26.296	52.199
1829	31.779	39.931	60.387
1830	35.309	33.845	63.249
1831	37.382	25.472	63.175
1832	38.596	25.293	64.859
1833	50.365	15.383	78.196
1834	60.325	16.923	93.111
1835	66.487	17.664	102.260
1836	65.722	26.126	104.251
1837	53.545	35.048	89.966
1838	45.770	41.438	81.098
1839	49.152	51.050	89.485
1840	46.948	51.919	86.625
1841	39.653	57.365	78.106
1842	28.773	54.470	61.370
1843	13.233	49.657	37.218
1844	6.062	40.810	23.651
1845	3.988	25.097	14.920
1846	2.250	16.697	9.344
1847[a]	—	—	—
1848	1.105	8.024	4.525
1849	0.464	7.920	3.564
1850	0.577	8.571	3.964
1851	0.536	5.961	2.951
1852	0.179	8.154	3.239
1853	0.119	6.176	2.429
1854	0.062	7.624	2.876
1855	0.529	16.403	6.758
1856	0.596	15.080	6.370
1857	0.788	17.591	7.566
1858	0.881	16.382	7.257
1859	0.793	11.839	5.470
1860	0.831	10.205	4.928
1861	0.638	7.108	3.517
1862	0.905	9.921	4.931
1863	0.679	8.063	3.926
1864	0.987	11.014	5.448
1865	2.188	19.250	10.189

Table 8A.2 (continued)

Index Year	A. Atlantic Ocean		
	Baleen	Sperm	All Whales
1866	3.331	22.633	13.072
1867	3.990	25.803	15.180
1868	4.546	34.129	19.025
1869	3.604	40.416	19.966
1870	2.459	40.563	18.370
1871	1.844	43.564	18.580
1872	1.305	34.394	14.451
1873	1.446	24.893	11.182
1874	1.570	25.142	11.451
1875	1.630	20.314	9.774
1876	1.575	28.782	12.790
1877	1.454	35.522	15.078
1878	1.693	42.070	17.816
1879	2.254	53.849	22.930
1880	2.221	53.034	22.584
1881	2.315	57.597	24.387
1882	2.474	52.503	22.755
1883	2.178	46.087	19.983
1884	2.862	50.884	22.723
1885	3.291	46.410	21.706
1886	3.311	44.147	20.906
1887	3.175	43.048	20.309
1888	2.455	35.275	16.431
1889	2.046	27.699	13.072
1890	1.095	24.003	10.351
1981	0.858	19.354	8.310
1892	0.762	17.405	7.459
1893	0.726	19.591	8.206
1894	1.393	25.297	11.254
1895	1.635	29.809	13.251
1896	1.582	33.135	14.391
1897	1.524	34.715	14.884
1898	1.193	30.380	12.823
1899	1.003	24.582	10.429
1900	1.262	20.823	9.430
1901	1.782	20.694	10.132
1902	1.442	24.276	10.951
1903	1.285	33.631	14.144
1904	0.937	36.599	14.728
1905	0.330	36.179	13.698

Index Year	B. Indian Ocean		
	Baleen	Sperm	All Whales
1820–28[a]	—	—	—
1829	0.000	0.000	0.000
1830	0.000	0.000	0.000

(continued)

Table 8A.2 (continued)

Index Year	B. Indian Ocean		
	Baleen	Sperm	All Whales
1831	0.108	0.112	0.157
1832[a]	—	—	—
1833	0.294	0.385	0.459
1834	0.294	0.385	0.459
1835	0.313	0.417	0.491
1836	0.522	0.912	0.904
1837	0.421	0.793	0.751
1838	1.080	1.595	1.757
1839	1.683	1.840	2.488
1840	3.170	2.560	4.334
1841	4.816	5.373	7.161
1842	5.201	6.740	8.097
1843	6.608	9.208	10.538
1844	6.830	10.127	11.130
1845	8.021	11.133	12.775
1846	9.209	12.042	14.379
1847	7.853	11.229	12.635
1848	7.192	10.670	11.722
1849	5.214	8.628	8.845
1850	3.429	8.891	7.067
1851	2.804	9.248	6.547
1852	1.999	10.024	6.002
1853	1.389	9.802	5.273
1854	1.397	9.377	5.117
1855	1.454	9.202	5.108
1856	1.079	8.146	4.303
1857	0.794	7.957	3.929
1858	0.536	6.559	3.114
1859	0.633	7.013	3.393
1860	1.042	7.652	4.072
1861	1.123	7.406	4.061
1862	1.141	7.221	4.008
1863	1.026	6.069	3.439
1864	0.603	5.866	2.915
1865	0.624	6.025	2.999
1866	0.445	5.260	2.513
1867	0.354	5.134	2.369
1868	0.337	4.379	2.057
1869	0.361	3.863	1.882
1870	0.462	4.106	2.082
1871	0.389	4.249	2.061
1872	0.487	4.404	2.224
1873	0.418	5.685	2.650
1874	0.330	6.147	2.737
1875	0.625	6.205	3.070
1876	0.560	6.101	2.962
1877	0.480	4.452	2.235

Table 8A.2 (continued)

	B. Indian Ocean		
Index Year	Baleen	Sperm	All Whales
1878–79[a]	—	—	—
1880	0.174	3.270	1.455
1881–85[a]	—	—	—
1886	0.000	0.132	0.051
1887	0.000	0.000	0.000
1888–1900[a]	—	—	—
1901	0.000	0.000	0.000
1902–4[a]	—	—	—
1905	0.118	0.000	0.124

	C. Pacific Ocean		
Index Year	Baleen	Sperm	All Whales
1820	0.939	45.266	19.414
1821	0.892	52.443	22.378
1822	1.166	58.746	25.165
1823	3.518	68.251	30.498
1824	7.804	90.102	42.105
1825	8.420	112.067	51.619
1826	7.497	114.345	52.030
1827	5.556	103.999	46.586
1828	1.269	105.814	44.842
1829	0.466	90.443	37.967
1830	0.410	98.804	41.419
1831	0.477	134.224	56.221
1832	2,614	142.043	60.726
1833	2.614	145.090	61.997
1834	5.547	155.210	67.924
1835	7.019	159.144	70.423
1836	5.935	171.511	74.945
1837	7.485	188.757	83.037
1838	7.450	207.202	90.704
1839	7.092	204.036	89.176
1840	14.312	192.269	88.483
1841	24.416	189.342	93.155
1842	39.154	182.399	98.857
1843	43.268	188.995	104.006
1844	49.300	199.862	112.053
1845	52.003	197.587	112.681
1846	55.378	197.847	114.758
1847	71.170	176.686	115.148
1848	88.342	160.694	118.498
1849	103.714	154.425	124.851
1850	111.298	131.021	119.519
1851	114.830	130.464	121.347
1852	120.588	118.651	119.781
1853	99.086	109.236	103.317

(continued)

Table 8A.2 (continued)

	C. Pacific Ocean		
Index Year	Baleen	Sperm	All Whales
1854	103.180	110.584	106.267
1855	100.000	100.000	100.001
1856	76.580	93.670	83.703
1857	84.936	93.665	88.575
1858	72.654	89.226	79.561
1859	59.172	92.360	73.005
1860	57.841	98.504	74.789
1861	53.056	98.215	71.878
1862	42.044	93.566	63.518
1863	38.735	88.082	59.302
1864	29.660	76.920	49.357
1865	22.944	68.227	41.817
1866	20.544	54.606	34.741
1867	17.924	45.913	29.589
1868	17.954	35.305	25.186
1869	16.332	26.791	20.691
1870	15.184	31.984	22.186
1871	16.345	37.004	24.956
1872	16.574	40.904	26.715
1873	14.315	41.435	25.618
1874	12.400	37.588	22.898
1875	11.215	31.238	19.561
1876	8.787	27.253	16.483
1877	9.061	26.582	16.364
1878	6.492	24.997	14.205
1879	6.377	26.193	14.636
1880	6.876	24.001	14.014
1881	7.707	21.106	13.292
1882	8.068	21.012	13.463
1883	7.416	20.548	12.889
1884	6.617	16.796	10.860
1885	6.526	14.533	9.863
1886	8.177	13.771	10.509
1887	9.244	12.267	10.504
1888	13.114	14.402	13.651
1889	13.309	16.380	14.589
1890	11.891	14.393	12.934
1891	11.556	11.514	11.539
1892	9.101	10.341	9.618
1893	9.477	7.851	8.799
1894	10.188	5.269	8.138
1895	9.716	5.542	7.977
1896	8.151	5.064	6.864
1897	6.779	5.018	6.045
1898	5.189	5.436	5.292
1899	5.194	7.199	6.030
1900	6.644	7.495	6.999

Table 8A.2 (continued)

Index Year	C. Pacific Ocean		
	Baleen	Sperm	All Whales
1901	5.819	8.873	7.092
1902	5.639	8.746	6.934
1903	3.934	7.164	5.280
1904	2.260	7.897	4.609
1905	2.458	7.567	4.587

Index Year	D. Western Arctic Ocean		
	Baleen	Sperm	All Whales
1820–48[a]	—	—	—
1849	0.000	0.000	0.000
1850	0.000	0.000	0.000
1851	0.000	0.000	0.000
1852	2.282	45.610	17.238
1853	3.878	41.738	29.294
1854	25.753	42.529	194.535
1855	49.077	41.868	370.730
1856	60.936	38.966	460.314
1857	70.376	39.738	531.627
1858	58.906	37.389	444.979
1859	52.740	37.071	398.404
1860	50.517	38.787	381.605
1861[a]	—	—	—
1862	44.114	36.903	333.238
1863	35.721	34.071	269.840
1864	28.740	31.266	217.102
1865	23.231	31.167	175.489
1866	15.401	27.500	116.337
1867	13.752	25.617	103.885
1868	17.296	24.604	130.657
1869	20.314	23.690	153.451
1870	25.138	25.551	189.890
1871	25.192	28.272	190.300
1872	22.720	26.567	171.627
1873[a]	—	—	—
1874	15.207	22.959	114.871
1875	8.034	19.252	60.692
1876	4.911	20.712	37.098
1877	5.823	22.185	43.987
1878	6.273	23.581	47.383
1879	6.995	27.543	52.837
1880	4.819	26.769	36.406
1881	3.996	27.272	30.186
1882	4.678	25.424	35.338
1883	4.646	23.003	35.096
1884	4.639	22.781	35.042
1885	3.073	20.406	23.212

(continued)

Table 8A.2 (continued)

Index Year	D. Western Arctic Ocean		
	Baleen	Sperm	All Whales
1886–91[a]	—	—	—
1892	0.000	0.000	0.000
1893–1904[a]	—	—	—
1905	0.000	0.000	0.000

[a]No New Bedford voyages set out for this hunting ground.

To compute the denominators it was necessary to make three assumptions, none of which is perfectly realistic: the size of each hunting ground and the number of whales in each hunting ground remained constant over time; whales of different species were sufficiently close in value that numbers of whales could be summed up without regard to species. The lack of perfect realism is unlikely to be important for present purposes. The object of the denominators is to distinguish hunting grounds, not periods of time. For this purpose the denominators appear to be adequate. The data from which the denominators were constructed and the denominators themselves are shown in table 8B.1.

The estimates of the numbers of whales are taken from chapter 4; the square miles in the hunting grounds were estimated using an atlas and information about the parts of each ocean or sea in which whales were typically hunted.

The numerators were constructed by estimating the number of tons of New Bedford whaling vessels in each ground in each month from January 1816 to December 1906, then blowing up these estimates to account for whaling vessels from other American ports. The Atlantic, Pacific, and Indian estimates were next increased to take into account British whaling in the years before 1846, and the Pacific and Western Arctic estimates to take into account Hawaiian whaling (1851–80).

When a New Bedford vessel's tonnage was missing, we estimated it on the basis of rigging: ship, 300 tons; bark, 250; brig, 150; schooner, 100; sloop, 100; rigging unknown, 200. When a date necessary to determine months at sea was missing—for example, the arrival date—we assumed the vessel was at sea for twenty months. If the sailing or arrival year was present but the month was missing, we assumed it was June.

We also assumed that New Bedford whalers destined for the Atlantic arrived there in the month they sailed, and left there in the month they returned to port; vessels destined for the Pacific or Indian Ocean arrived on the ground three months after they left port, and vacated the ground two months before they arrived home; vessels destined for the Western Arctic reached the ground six months after sailing from New Bedford, and got back seven months after leaving the Arctic. These estimates were made on the basis of the diaries of people

Table 8B.1 **Data Used to Construct Ratio of Whales to Area of Hunting Ground**

	Whales (millions)	Square Miles (millions)	Whales/ Square Mile
Atlantic	0.346	10.00	0.0346
Pacific	1.829	22.00	0.0831
Indian	0.544	7.00	0.0777
Western Arctic	0.030	2.17	0.0138

who sailed on whalers. The available reports are quite consistent. The time trend appears to be zero.

Some vessels started for the Pacific or Indian or Western Arctic, but obviously never got there: they were too short a time at sea. Competition indexes were not calculated for these vessels, and they were thus dropped from the productivity analysis. (For example, we assume that a ship going to the Pacific that spent less than five months at sea never got to the Pacific.)

The domestic blowup ratios were computed from data in Tower 1907, 121–25 (numbers of vessels, not tons). The form of the data prohibit the construction of separate ratios for individual hunting grounds; one ratio had to be applied to all grounds in each year. Tower cites Starbuck (1878), 1784–1839 (clearances); Clark (1887a), 1840–80 (probably also clearances); and the *WSL* (1843–1914), 1880–1906 (vessels in the fleet). The figures refer only to the U.S. fleet. The clearances data should ideally be averaged over some period of time, to approximate the situation of the fleet at sea, while the data from the *WSL* need not, in principle, be averaged. Something can be said for averaging, however, on the ground that sharp movements from one year to the next are unlikely properly to reflect shifts in competitive pressures from one year to the next. Table 8B.2 gives the raw figures, five-year moving averages, and rounded versions of both. The rounded average figures were used as blowup ratios.

The adjustments to take into account British whaling before 1845 were computed from data in Jackson 1978, 136, 270. We treated Jackson's "Northern Fleet" as an Atlantic fleet, and his "Southern Fleet" as a Pacific and Indian fleet, although some of these vessels were probably hunting the South Atlantic. British tons were roughly equivalent to American tons. (See chapter 12.) For the southern fleet Jackson has data only for the first three years of the decades of the 1820s and 1830s, and for 1841, 1842, and 1843. We interpolated (straight line) to obtain the missing values. Jackson has tons for the northern fleet (very much the larger of the two) for the years 1815 through 1834. We rounded to hundreds of tons and extrapolated down to 1842 on the number of vessels in the ground. For the northern fleet we extrapolated a disappearance rate from 1842 to 1845, for the southern fleet from 1843 to 1845. The British tonnage in the northern fleet was then added to the American Atlantic tonnage. The British tonnage in the southern fleet was divided between the Indian and

Table 8B.2 **Ratios of the Tonnage of the U.S. Whaling Fleet to the Tonnage of the New Bedford Whaling Fleet, 1816–1906**

	Raw	Average
1816	4.615	—
1817	4.462	—
1818	3.200	—
1819	3.850	—
1820	3.389	3.903
1821	3.385	3.657
1822	3.788	3.522
1823	2.846	3.452
1824	2.281	3.138
1825	2.576	2.975
1826	2.815	2.862
1827	2.500	2.603
1828	2.592	2.552
1829	3.143	2.725
1830	2.197	2.649
1831	2.446	2.576
1832	3.167	2.709
1833	3.162	2.823
1834	4.262	3.047
1835	2.952	3.198
1836	3.742	3.457
1837	3.588	3.540
1838	3.371	3.582
1839	3.378	3.405
1840	3.119	3.441
1841	3.075	3.306
1842	3.095	3.208
1843	3.100	3.152
1844	2.817	3.040
1845	2.862	2.990
1846	2.820	2.939
1847	2.811	2.882
1848	2.609	2.784
1849	2.432	2.707
1850	2.260	2.586
1851	2.193	2.461
1852	2.167	2.332
1853	2.080	2.226
1854	2.050	2.150
1855	2.010	2.100
1856	2.010	2.063
1857	1.951	2.027
1858	1.963	1.997
1859	1.927	1.972
1860	1.860	1.942
1861	1.732	1.887
1862	1.596	1.816
1863	1.600	1.743

Table 8B.2 (continued)

	Raw	Average
1864	1.492	1.660
1865	1.526	1.589
1866	1.573	1.557
1867	1.696	1.577
1868	1.785	1.614
1869	1.860	1.688
1870	1.795	1.742
1871	1.591	1.745
1872	1.476	1.701
1873	1.477	1.640
1874	1.434	1.554
1875	1.421	1.480
1876	1.371	1.436
1877	1.381	1.417
1878	1.392	1.400
1879	1.364	1.386
1880	1.375	1.376
1881	1.439	1.390
1882	1.450	1.404
1883	1.387	1.402
1884	1.548	1.439
1885	1.565	1.477
1886	1.610	1.512
1887	1.564	1.535
1888	1.568	1.570
1889	1.683	1.597
1890	1.796	1.644
1891	1.902	1.702
1892	1.917	1.773
1893	1.959	1.851
1894	2.020	1.929
1895	2.179	2.005
1896	2.026	2.032
1897	2.094	2.067
1898	2.250	2.125
1899	2.240	2.159
1900	1.920	2.108
1901	1.818	2.066
1902	1.625	1.972
1903	1.696	1.861
1904	1.680	1.749
1905	1.750	1.715
1906	1.750	1.701

Note: The text describes the construction of these ratios.

the Pacific in the same proportions as the American tonnage. We reduced the British tonnage in these two grounds by 25 percent, to allow for travel time. We made no allowances for the British fleet after 1845. The resulting estimates of British tonnage are given in table 8B.3.

We added data on vessels sailing from Honolulu, 1851–80, drawn from Hegarty 1959, 48–50. In those instances when only a sailing or an arrival date is given, we assumed the voyage took six months. If only the year is given, we assumed the voyage ran from April through September. For voyages to the Western Arctic, one month was deducted from the beginning and one from the end of the voyage, to account for travel time. In those few instances in which the prospective hunting ground is not given, all voyages leaving in the summer, fall, and winter were assumed to be Pacific voyages; spring voyages were assigned alternately to the Western Arctic and the Pacific. Our estimates of Honolulu tonnage are given in table 8B.4.

The results of these calculations are represented in table 8B.5. The competition index itself is monthly; the table shows figures for July of each year.

Table 8B.3 **Tonnage of the British Whaling Fleet, 1820–45 (thousands of tons)**

	Northern Fleet	Southern Fleet
1820	50.5	19.8
1821	50.7	14.4
1822	38.1	11.4
1823	36.8	11.2
1824	35.0	11.0
1825	34.8	10.8
1826	30.4	10.6
1827	28.3	10.4
1828	28.7	10.2
1829	28.8	9.9
1830	29.4	9.7
1831	28.6	8.3
1832	26.4	12.1
1833	25.3	8.3
1834	25.0	7.9
1835	23.1	7.4
1836	19.8	7.0
1837	16.9	6.5
1838	12.7	6.1
1839	13.3	5.6
1840	10.1	5.2
1841	6.2	4.8
1842	5.9	1.8
1843	4.2	3.1
1844	2.0	2.0
1845	1.0	1.0

Source: Jackson 1978, 136, 270.

Table 8B.4 **Tonnage of the Honolulu Whaling Fleet, 1851–80**

Months	Western Arctic	Pacific
May–August 1851	325	0
September 1851–February 1852	0	0
March–May 1852	0	150
June–September 1852	274	150
October 1852–October 1853	0	0
November 1853–April 1854	0	550
May–September 1854	156	0
October 1854–April 1855	0	0
May–June 1855	139	0
July 1855	139	398
August 1855	604	398
September–October 1855	465	398
November 1855	465	490
December 1855	0	490
January–March 1856	0	92
April 1856	229	322
May 1856	545	230
June 1856	545	322
July–August 1856	745	322
September 1856	429	322
October 1856	429	92
November 1856–January 1857	0	92
February–March 1857	489	92
April 1857	489	167
May 1857	974	75
June–August 1857	1,174	75
September 1857	689	75
October 1857	229	0
November 1857	0	0
December 1857–January 1858	0	163
February 1858	317	163
March 1858	898	163
April 1858	898	673
May 1858	1,377	673
June 1858	2,007	759
July–August 1858	2,237	759
September 1858	1,661	759
October 1858	710	1,342
November 1858	163	1,342
December 1858–March 1859	163	1,772
April 1859	0	1,296
May 1859	550	1,590
June–August 1859	980	1,686
September 1859	700	1,686
October 1859	0	1,580
November 1859	0	2,127
December 1859–April 1860	0	2,291
May 1860	1,229	827

(continued)

Table 8B.4 (continued)

Months	Western Arctic	Pacific
June 1860	1,779	502
July–August 1860	2,039	887
September 1860	1,784	887
October 1860	294	887
November 1860	0	1,095
December 1860	0	1,522
January–February 1861	270	1,417
March 1861	596	1,617
April 1861	596	1,953
May 1861	596	1,799
June–August 1861	596	1,858
September 1861	596	1,603
October 1861	326	2,011
November 1861	0	2,461
December 1861–March 1862	0	1,446
April 1862	0	1,246
May 1862	536	280
June 1862	736	280
July–August 1862	1,006	280
September 1862	470	280
October 1862	200	0
November 1862	0	200
December 1862	0	300
January–April 1863	360	770
May 1863	1,267	750
June–August 1863	1,267	470
September–November 1863	326	470
December 1863	326	658
January–March 1864	686	658
April–May 1864	360	725
June–September 1864	1,386	725
October 1864	0	940
November–December 1864	0	658
January–March 1865	694	1,018
April 1865	694	548
May 1865	894	360
June–September 1865	1,164	255
October 1865	694	255
November 1865	368	255
December 1865	0	0
January–April 1866	326	0
May 1866	526	0
June 1866	894	0
July–August 1866	1,164	0
September 1866	964	0
October 1866	596	0
November 1866	0	0
December 1866	0	326

Table 8B.4 (continued)

Months	Western Arctic	Pacific
January–April 1867	368	326
May 1867	1,367	326
June–August 1867	1,367	0
September 1867	1,020	0
October 1867	750	0
November 1867	0	393
December 1867–February 1868	0	918
March 1868	453	918
April 1868	1,191	550
May–July 1868	1,538	157
August 1868	1,070	157
September 1868	815	157
October 1868	0	0
November 1868	0	157
December 1868	0	412
January 1869	1,298	412
February–March 1869	1,654	412
April 1869	1,654	592
May 1869	1,924	592
June 1869	1,924	978
July 1869	1,924	798
August 1869	1,924	978
September 1869	1,924	1,409
October 1869	1,191	1,155
November 1869	0	1,195
December 1869	0	1,151
January 1870	916	1,151
February 1870	916	1,406
March 1870	916	975
April 1870	1,617	926
May 1870	1,797	926
June 1870	1,797	544
July 1870	2,434	544
August–September 1870	2,865	544
October 1870	2,327	544
November 1870	356	386
December 1870	787	0
January 1871	787	255
February–March 1871	1,173	255
April 1871	817	525
May 1871	1,452	270
June–August 1871	1,066	270
September 1871	431	270
October–November 1871	0	0
December 1871–May 1872	431	188
June 1872	431	0
July–September 1872	718	0
October 1872	287	0

(continued)

Table 8B.4 (continued)

Months	Western Arctic	Pacific
November–December 1872	0	0
January 1873	431	0
February 1873	718	0
March 1873	718	86
April 1873	718	80
May–August 1873	804	80
September 1873	718	80
October 1873	0	0
November 1873	86	0
December 1873–February 1874	517	0
March 1874	431	0
April 1874	0	0
May–August 1874	280	0
September 1874–April 1875	0	0
May–August 1875	998	0
September 1875–April 1876	0	0
May–August 1876	818	0
September 1876–April 1877	0	0
May–August 1877	423	0
September 1877–April 1878	0	0
May–August 1878	423	0
September 1878–April 1879	0	0
May–August 1879	172	0
September 1879–April 1880	0	0
May 1880	188	0
June–August 1880	274	0
September 1880	86	0
October–December 1880	0	0

Source: Hegarty 1959, 48–50.

Table 8B.5 **Indexes of Competition (crowding) on the Whaling Grounds, 1820–1905 (Pacific, July 1855 = 100)**

Year	Atlantic	Indian	Pacific	Western Arctic
1820	158.34	7.43	17.53	0.00
1821	153.26	5.42	22.70	0.00
1822	109.38	4.29	33.06	0.00
1823	117.28	4.22	31.78	0.00
1824	116.19	4.14	13.38	0.00
1825	100.74	4.07	16.40	0.00
1826	95.72	3.99	27.00	0.00
1827	96.85	3.91	20.40	0.00
1828	104.63	3.84	27.96	0.00
1829	114.00	3.73	36.42	0.00
1830	111.17	3.65	34.82	0.00
1831	121.87	6.67	40.34	0.00
1832	131.96	5.22	59.68	0.00
1833	124.04	5.67	65.40	0.00
1834	129.50	6.18	68.34	0.00
1835	135.75	3.72	72.64	0.00
1836	160.96	8.23	81.05	0.00
1837	155.29	12.61	76.63	0.00
1838	98.92	13.77	79.42	0.00
1839	59.66	17.82	81.52	0.00
1840	59.04	17.06	101.92	0.00
1841	49.71	27.48	106.15	0.00
1842	37.51	32.86	108.41	0.00
1843	22.59	42.28	99.68	0.00
1844	10.56	21.15	99.35	0.00
1845	14.46	19.44	113.15	0.00
1846	12.96	18.85	109.70	0.00
1847	4.96	21.60	102.28	0.00
1848	3.62	22.69	97.97	0.00
1849	5.82	17.92	109.14	0.00
1850	4.31	21.33	95.94	20.94
1851	13.48	15.19	78.16	117.18
1852	23.99	17.38	105.80	257.77
1853	24.95	13.85	98.29	217.04
1854	17.36	12.11	99.23	191.09
1855	14.56	18.79	100.00	186.43
1856	12.27	21.19	98.73	192.57
1857	10.06	19.20	83.54	177.34
1858	5.61	18.66	98.27	192.05
1859	4.19	15.45	89.91	193.42
1860	19.32	19.80	79.10	170.66
1861	22.73	22.68	76.15	106.47
1862	33.99	15.78	56.41	39.45
1863	34.31	11.28	41.39	72.18
1864	38.22	7.69	29.65	105.41
1865	40.27	5.62	15.59	94.45
1866	42.34	5.27	24.25	127.77

(continued)

Table 8B.5 (continued)

Year	Atlantic	Indian	Pacific	Western Arctic
1867	44.94	7.09	29.60	112.47
1868	34.06	8.39	31.81	107.23
1869	31.18	12.71	32.62	100.15
1870	29.82	13.03	31.53	87.98
1871	19.58	12.71	24.39	56.74
1872	23.03	13.69	24.25	36.86
1873	18.30	10.22	22.29	38.65
1874	22.97	8.09	16.79	32.68
1875	37.98	3.97	16.62	25.31
1876	42.51	6.69	15.06	20.97
1877	48.87	6.81	14.52	22.63
1878	54.14	6.42	14.79	19.80
1879	49.99	2.58	16.53	15.09
1880	51.98	0.32	14.40	23.76
1881	50.04	0.43	12.22	16.76
1882	50.08	0.46	13.78	20.31
1883	36.53	0.00	15.71	22.23
1884	33.32	0.00	15.85	8.99
1885	25.31	0.00	17.47	6.65
1886	18.07	0.00	17.60	3.32
1887	14.04	0.91	17.16	0.00
1888	11.18	2.77	20.05	0.00
1889	11.60	1.97	17.17	0.00
1890	10.55	0.51	12.32	0.00
1891	15.72	0.00	12.69	0.00
1892	17.07	0.00	11.49	0.00
1893	16.50	0.00	10.46	0.00
1894	20.20	0.00	8.29	0.00
1895	20.33	0.00	9.33	0.00
1896	16.01	0.00	7.92	0.00
1897	13.22	0.00	7.95	0.00
1898	17.91	0.00	5.67	0.00
1899	16.95	0.00	4.55	0.00
1900	16.53	0.00	3.93	0.00
1901	14.50	0.00	3.72	0.00
1902	12.19	0.86	3.31	0.00
1903	13.82	0.00	4.15	0.00
1904	12.72	0.00	4.73	0.00
1905	16.35	0.00	3.63	4.27

Notes: An index number of 0.00 means that there were no whaling vessels in the ground. Only the month of July is represented in the table, but the indexes are computed for each month, and the index numbers vary within a year. For example, in 1855 the monthly numbers are:

Month	Atlantic	Indian	Pacific	Western Arctic
January	11.61	16.19	120.98	109.90
February	11.61	15.86	121.73	115.04

Table 8B.5 (continued)

Month	Atlantic	Indian	Pacific	Western Arctic
March	12.88	17.73	111.10	131.97
April	12.88	18.79	106.96	154.10
May	12.98	18.79	102.84	177.52
June	14.02	18.79	99.63	186.43
July	14.56	18.79	100.00	186.43
August	16.16	17.37	97.77	189.06
September	15.20	20.56	98.61	188.27
October	13.42	20.93	100.19	174.06
November	13.42	22.74	108.27	161.30
December	13.42	23.63	113.44	143.77