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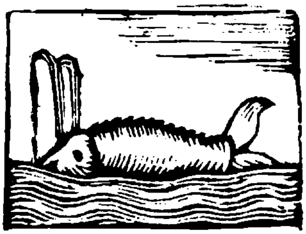

This work began as a study of the relationships among technological innovation, productivity change, and profits, in the context of a competitive industry experiencing rapid shifts in the markets for its inputs and outputs. The focus is the nineteenth-century New Bedford whaling industry. Whaling was chosen because the natural resource (whales) was equally available to all competitors—both domestic and foreign. Since there were no property rights carrying with them implicit rents, the analytical task of sorting out the relationships among technology, productivity, and profits was simplified. The nineteenth century encompassed most of the last stage of the industry—the pelagic stage—before the advent of modern whaling. During this period the American fleet rose to world leadership and then collapsed—posing important historical and analytical issues. New Bedford was chosen because it sent out about one-half of American whaling voyages.

The study has shown that, although the choice of industry simplified the problem of identifying technical change and assessing its impact, it certainly did not solve it. It has been necessary to consider changes in the markets for labor and capital and for oil and bone, to say nothing of the quality of the entrepreneurial input that directed and combined capital and labor.

There was a substantial American whaling industry in the years before the Revolution. By 1814 two wars and a prohibitive British tariff had virtually destroyed it. In 1815 the industry began to rebuild itself, and over the years 1816–20 its agents directed each year more than half a hundred whalers aggregating almost twenty thousand tons, with an average annual catch valued at about $750,000 (in 1880 dollars).

Twenty-five years later, American agents directed 672 vessels valued at $21 million (1880 prices), and the industry employed 16,600 seamen. In 1860 the annual value of the industry's output reached almost $8 million, which made it larger than 583 of the nation's 631 manufacturing industries. That value, according to the census, resulted from the sale of 2,695,000 gallons of sperm oil, 7,413,000 gallons of whale oil, and 3,196,000 pounds of bone—with New Bedford contributing more than one-half (U.S. Census Office 1866, 550; 1865, 733–42).

The expansion was not limited to vessels, men, and product; it was geographic as well. At the time of the Revolution, American whalers operated over most of the Atlantic—as far north as Baffin Bay, east to the coast of Africa, and as far south as Patagonia. In 1791 the *Rebecca* followed the British *Emilia* around Cape Horn and into the Pacific. By the mid-1830s American whalemen had pushed the industry's Pacific boundaries first into the center of that ocean and then to the coast of Japan; in the Indian Ocean they had hunted as far north as the Red Sea. During the next fifteen years Pacific operations expanded into the Gulf of Alaska and the Sea of Okhotsk, and in 1848 the first American whalers entered the Western Arctic.

By that time captains and crewmen were well acquainted with sperm, right, gray, and humpback whales, and they had begun to speak rhapsodically about the western bowheads encountered in the North Pacific and Western Arctic. The Americans, for all their whaling prowess, however, had not managed to capture a significant number of the fast-swimming rorquals—blues, seis, minkes, and finners—that were to be the foundation of modern whaling.

Midcentury marked the zenith of the American effort. Although the industry recovered slightly from the depredations of the Confederate raiders *Alabama* and *Shenandoah,* the contraction that began in the mid-1850s continued almost unabated until the industry was wound up in the 1920s.[1] By the beginning of the twentieth century, the value of whaling output was less than 10 percent of its earlier peak. Between 1901 and 1905 the forty-odd remaining vessels—aggregating about ten thousand tons—returned an annual average of about 600,000 gallons of sperm oil, 95,000 gallons of whale oil, and 100,000 pounds of bone.

What, then, was the relationship between technology and productivity change in this evolving industry? What caused its rapid increase in output, and what caused its equally rapid contraction? The standard account points to increasing demand for oil and bone as the engine of expansion and to decreasing demand coupled with an exhaustion of whale stocks—the result of overhunting—as the causes of contraction. Since it was the American, not the world, industry that declined, it has also been suggested that the failure of this nation's whaling entrepreneurs to capitalize on the new techniques and markets exploited by the Norwegians was a factor.

It does not take a study of technology or productivity to show that changes in demand were important. Despite the increase in the American output of sperm oil from an annual average of 723,000 gallons in 1816–20 to an annual

1. The voyage of the *John R. Manta* in 1925 was the "last successful whaling voyage from New Bedford" (Hegarty 1959, 47).

average of 4,627,000 gallons in 1836–40, the real price of sperm oil increased over the period from $0.61 to $0.93 per gallon. For whale oil the increase from an annual average of 820,000 gallons in 1816–20 to 7,875,000 gallons in 1846–50 was accompanied by a price increase from $0.33 to $0.45. For whalebone, too, increased prices accompanied increased outputs: the annual average output of 50,000 pounds in 1816–20 sold for $0.08 a pound, that of 3,394,400 in 1851–55 for $0.42.

Similarly, the 79 percent fall in the American average annual output of sperm oil, from 2,560,000 to 536,000 gallons, between 1856–60 and 1901–5 coincided with a 54 percent decline in its real price—from $1.39 to $0.64—and the collapse of the whale oil market, a 97 percent fall in output between 1861–65 and 1901–5, was accompanied by a 31 percent decline in price.

These movements are consistent with developments in the market for the industry's final products. During the Golden Age the tripling of the nation's population raised domestic-lighting demand, foreign demand increased, and the rapid growth of the manufacturing sector caused a large increase in the demand for lubricants. As knowledge of its strength and flexibility spread, whalebone demand increased as well.

The industry's decline coincided, first, with the development of new illuminants and lubricants such as manufactured gas and lard oil, second, with the discovery of petroleum, and finally, with the innovation of fractional distillation. Petroleum provided a substitute for sperm and whale oil as illuminants; distillation reduced the price of the substitute (kerosene) and produced a steady flow of inexpensive substitutes for whale-based lubricants as by-products of the refining process. The skyrocketing demand for whalebone—real prices increased almost fifteenfold between 1854 and 1904—was due to women's fashions (which called for wasp-waisted corsets) and to manufacturers' desire for a material that was both strong and flexible.[2] Whalebone alone prolonged the life of the American industry for at least fifteen years, despite the near total collapse of the markets for oil.

Demand forces, however, do not tell the entire story. Output of sperm oil fell by 44 percent between 1836–40 and 1856–60, despite a price increase of 64 percent. In the case of whale oil, output fell by almost two-thirds in the fifteen years after 1846–50, in the face of a near 170 percent increase in real prices.

For a complete explanation of the industry's response to changes in its economic environment, it is necessary to explore supply responses in addition to shifts in demand. In particular the relationships among changes in the stocks of whales, the evolution of factor (particularly labor) prices, and the invention and innovation of new technologies must be examined. The productivity regressions provide an analytical vehicle that can be used to begin such an examination. (See table 8.2.)

Although measured productivity was subject to violent year-to-year fluctua-

2. The whalebone price increase was also importantly due to the decline in supply.

tions, over time a moving average of the productivity index for the New Bedford fleet makes a pattern similar to that of a jump rope held at one end by a ten-year-old girl and at the other by her six-year-old brother. The index averaged about 1.2 in the decade 1820–30, fell sharply (to about 0.9) over the next five years, levelled off over the next fifteen, and then gradually declined (to about 0.4) between 1850 and the end of the Civil War. Thereafter, as the industry continued to contract, the trend in productivity was reversed. Between the mid-1860s and the end of the century, it more than doubled—reaching, by the mid-1890s, the level of 1835–50.

The regression analysis provides insights into the sources of the movements in the index. Four results stand out. First, while there may have been overhunting of some whales in some grounds (of right whales in the North Pacific, for example), there is no evidence that American whaling contracted because of a serious shortage of whales. An increase in the hunting-pressure index appears to have no large, unfavorable impact on productivity. Collateral evidence indicates that Americans did hunt the Pacific gray whale almost to the point of extinction, but the massacres in the Baja calving grounds occurred after whaling had begun its long-term decline, and grays were never an important part of the American effort. Furthermore, Americans made no serious inroads into sperm-whale or humpback stocks, and the industry had been long in decline before the hunting of bowheads had a substantial impact on bowhead numbers.

Second, whaling productivity was adversely affected by the competition for labor from shore-based industry. The negative relationships between productivity and both the common wage ashore and the ratio of skilled to common wages are strong. As the internal economy developed, the increased demand for workers pushed wages up, and many of the best crewmen were bid away from the sea. Throughout the nineteenth century, cheap labor was a key to profitable whaling. The British had been successful as long as they could draw on the Shetland Islanders, whose opportunity cost was almost nil; the Norwegians became successful not only because of their willingness to innovate new technologies and open new markets, but also because of the supply of cheap domestic labor—the product of Norway's rapid rate of population growth and slow rate of industrialization.

Third, it is clear that the industry's entrepreneurs and managers made significant contributions to productivity (see chapter 10). In the case of agents, the choice of vessels (the early substitution of ships for brigs, barks, and schooners, and later the substitution of barks for ships), the substitution of larger for smaller vessels, and the decision to shift operations from the Atlantic to the Pacific, Indian, and Western Arctic, all contributed to increased productivity. A good captain also made an important difference in a voyage's success.

The agents' and captains' efforts would not have been sufficient to sustain productivity in the face of the siren call of the manufacturing sector had it not been for the potential productivity of new technologies, both process and institutional.

Process technology is captured in several variables. The improvement in general vessel design is picked up in the "mode of entry to the fleet." By the early 1850s hulls had been largely redesigned, there had been a "revolution aloft" with greater numbers of smaller, flat, canvas sails replacing the very large and heavy hemp sails, and the first steps had been taken in the science of naval architecture. The impact of these changes can be seen in the near 20 percent productivity differential between merchant ships built before 1850 and those built after.

Rerigged vessels—almost always ships rerigged as barks—proved more productive than the vessels that remained rigged as they were built. The development of an efficient winch reduced the labor required to raise the lateen sail on the mizzen and made it feasible to operate barks of upwards of four hundred tons. Given equal size, barks had always tended to be more productive than ships. They had more clearance for the aft boats, and they were easier for shipkeepers to handle when the majority of the crew were in the boats. With the opening of the Western Arctic (and later with the reopening of the grounds in Hudson Bay and Davis Strait), the greater maneuverability of barks made them substantially more productive than ships.

The regressions do not indicate, however, that vessels built especially for whaling were more productive than others. The finding is surprising, and there is no obvious explanation for it.

The crew-quality variables also appear to pick up some of the effects of technical progress, particularly the innovations aloft in sails and rigging and in the design of the steering mechanism. In the regressions, productivity is positively associated with the fraction of the crew that was illiterate and with the fraction that was unskilled. It appears that the new sail plans and steering mechanisms allowed the substitution of mates and illiterate greenhands for skilled and semi-skilled seamen, whose wages were relatively high. The statistical results should not be interpreted to mean that less-qualified seamen *caused* higher productivity. Rather, the skill mix of whaling crews reflected the technical characteristics of the vessels. Vessels with advanced technical configurations—thus more productive vessels—could be managed by crews with relatively large numbers of unskilled seamen. The high productivity of those vessels reflected their technical characteristics, not the low quality of their seamen.

The positive sign on the technological dummy probably reflects chiefly the effects of improvements in whalecraft. Better charts and better vessel design may also figure in this result, although the latter should be captured in the vessel-design variables. By 1870 the toggle iron had effectively replaced the two-flued iron; virtually all vessels carried steel lances and whale guns that delivered explosive lances. Many vessels, especially those in the Western Arctic, carried darting guns. These innovations greatly increased the probability that a whale, once harpooned, would be killed and recovered. Fewer lost whales meant increased productivity, the same number of attacks yielding oil and bone from more whales.

One institutional innovation, although not affecting the trend, did affect the level of productivity of the American fleet. The Americans early adopted the lay system of payment. Every member of the ship's company from captain to cabin boy signed on, not for a wage or piece rate, but for a predetermined percentage of the value of the product returned. The system had a positive impact not only on profitability, transferring a part of the risk from entrepreneur to crewman, but also on productivity. Nineteenth-century whaling was a cooperative enterprise. A boat's crew had to work closely together, if a whale was to be successfully taken, and a vessel's crew had to work together, if a carcass was to be efficiently reduced to oil. The lay system rewarded cooperative, not individual, effort.

If the lay system affected only the level of the index, two other institutional innovations affected its time path. As whalers ranged farther and farther from New Bedford, the time lost travelling to and from the whaling grounds increased. In order to overcome the transport capacity constraint imposed by the size of the whaling vessel, agents began to use distant ports—Honolulu, Lahaina, Sydney, San Francisco, Port Louis—as transshipment points. A whaler could leave New Bedford, travel to the North Pacific or Western Arctic, hunt for a season, offload at Lahaina, and return to the hunt for a second season. Sometimes the process was repeated three or four times. In the decade 1816–25, before agents had begun to transship the catch, a typical Pacific voyage lasted slightly more than twenty-four months; fifty years later the figure had almost doubled.

Finally, the American whaleman benefitted from the government's decision to socialize exploration, hydrography, and ocean cartography. In the late 1830s Congress financed a five-year effort to explore and survey the Pacific coast and the South Seas and, fifteen years later, a similar venture designed to explore "and reconnaisance—the courses of navigation used by whalers in the regions of Behring's Straits; also such parts of the China Seas, Straits of Gaspar, and Java Sea as lie directly in the route of vessels proceeding to and from China" (*WSL* 3 August 1852). Both expeditions ended with the publication and widespread dissemination of accounts of their findings and maps of the regions.

Also at midcentury the navy's Hydrographic Office, under the direction of Matthew Fontaine Maury, began systematically to collect information on winds, ocean currents, magnetic deflections, and weather. Drawing on the reports filed by a substantial fraction of the nation's sea and whaling captains, Maury constructed a series of maps that spelled out the best routes for sailing ships to follow at various times of the year on all standard voyages. The work resulted in major reductions in average voyage lengths for American sailing vessels and greater productivity for American whalers.

Clearly, one major explanation of the demise of the American industry was the decline of the markets for sperm and whale oil beginning in the 1850s, and, three decades later, of the market for bone as well. New technologies were developed and innovated, and they appear to have reversed the downward slide

She struck where the white and fleecy waves
Looked soft as carded wool,
But the cruel rocks, they gored her sides
Like the horns of an angry bull.
The Wreck of the Hesperus, Longfellow

Wrecks ended the careers of many New Bedford vessels. The *Citizen,* a Sag Harbor whaler, was transferred into the California trade and then brought back east to join the New Bedford whaling fleet. On her next voyage—her first out of New Bedford—the whaler was lost with six of her crew. A seventh died later from injuries sustained in the wreck.

Drawing reproduced from *The Arctic Whaleman,* by Lewis Holmes, 1857, courtesy of the Old Dartmouth Historical Society–New Bedford Whaling Museum.

in measured productivity and somewhat prolonged the life of the industry. They were not, however, sufficient to save it.

Within a decade of the time that the American industry began to decline in the 1850s, in and off Finnmark—Norway's most northern province—Svend Foyn began an enterprise that launched modern whaling. The new enterprise differed in the products it produced, in the technology it employed, and in the species of whales it caught.

With the demise of the lighting market, whalemen were left with a much smaller number of consumers—those who continued to need oil for lubrication; for the manufacture of soft soaps, jute, and textiles; for tanning; for tempering steel; and for tinning. Given the much reduced demand, it was difficult for a firm to survive if it gained no more than the 40 to 50 percent of the whale's oil that was found in the blubber. Foyn's factories retrieved more of the oil. In addition, the bones were ground for "guano"; when the oil had been boiled out, the remaining carcass—high in protein—was sold as cattle feed; the meat was canned and sold as canned beef or meat cakes; and even the glue water, the liquid left over from the boiling and bone-cleaning processes, was turned into a salable product—glue.

The technology innovated by Foyn was new. His was no longer a pelagic industry. Whales were hunted at sea, but processing was done at shore stations. In fact, it would have been impossible to render an entire whale on a nineteenth-century whaling vessel. Moreover, the hunt was no longer conducted from a sail- and oar-powered whaleboat, but from a much larger, iron-hulled, steam-powered killer boat armed with whaling cannon. Contrast Foyn's first killer boat, the *Spes et Fides*—almost ninety-five feet long, powered by a twenty-horsepower engine, capable of seven knots, and armed with seven whale guns—with the twenty-five- to twenty-eight-foot wooden boats that Americans used to attack whales. To complete the transition, in 1872 Foyn received a patent on a shell harpoon—a combination harpoon and grenade—that killed the whale instantly and could be fired from a gun mounted on the bow of the killer boat.

Although Foyn probably never saw a whale he didn't like, the new technology permitted him to hunt the fast-swimming rorquals that had theretofore escaped the whalemen's harpoons. He was thus able to benefit from a sudden increase in the economic supply of whales, a supply initially located within a day's sail of his factory.

The Norwegians did their best to keep their techniques secret, but the technology was certainly known to the Germans and the Scots, and it is unlikely that the same information was not also available to potential American entrepreneurs. Over the decade 1863–72, when Foyn perfected his hunting techniques, an American, Thomas Welcome Roys, was also working on a new technology that would allow him to hunt rorquals successfully. During those ten years his record for catching them was almost identical to Foyn's, but Roys lost most of his catch: the whales sank.

Why didn't New Bedford whaling entrepreneurs innovate the Norwegian techniques and move into the new industry? Distance may have precluded operations in Finnmark or Spitsbergen, but Iceland was not much farther from New Bedford than it was from Sandefjord, the principal Norwegian whaling port, and Newfoundland was certainly closer. Is whaling an example of American entrepreneurial failure?

Several factors appear to explain the American decision not to pursue the new opportunities, and none involves the quality of New Bedford entrepreneurship. In the first place the new system of whaling made the entire American capital stock—both physical and human—completely obsolete. Wooden vessels could play no role, and not only was there no use for the stockpiles of whaleboats, harpoons, and lances, but not even the recently acquired darting guns had a place on the modern whaler. Since the whales hunted were not the sperms, rights, grays, and bowheads of Melville's time, all the specialized knowledge about hunting grounds, migration patterns, and whale behavior that captains and agents had gained over the previous decades was no longer of any value. The same was true of the skills that had been developed to attack and kill those animals. Successful entry into modern whaling would have required an entire new capital stock.

In the second place the Americans had benefitted from the nation's comparative advantage in the design and manufacture of wooden sailing vessels. They had no such advantage in the case of iron-hulled steamships; in fact, the nation's comparative disadvantage would almost certainly have forced whalemen to turn to Britain for killer ships. Clearly they had no edge over actual Norwegian, or potential British, competitors.

In the final analysis, however, it was the matter of opportunity costs that doomed the American enterprise. The whales belonged to anyone who could successfully hunt them, but capital, labor, and entrepreneurial ability all had some national ties. American agents had employed men from distant places—for example, from the Cape Verde Islands and the islands of the South Seas—but untrained Americans still made up part of the crews, and almost all of the officers came from New England. Labor had always been relatively expensive in this country; after 1840 it became increasingly so. Between the 1860s and the 1880s the wages of common laborers increased by about one-third and stood in the 1880s at about $1.30 a day. Common labor in Norway could be hired for $0.30, and a seaman on a whaler earned only $0.48. Over the same two decades the wages of skilled American workers grew even faster, with the ratio of wages of skilled to those of unskilled workers increasing from about 1.6 to about 1.9.[3]

In a similar vein the owners of both capital and entrepreneurial talent found the rewards in activities closer to home continually more attractive. The burgeoning manufacturing and transport sectors were drawing capital; for those of a somewhat more risk-taking proclivity, opportunities in the West were expanding rapidly. Even the great whaling families were not slow to take advantage of these new opportunities. The Rotches invested in railroads, toll roads, banks, insurance companies, and real estate. Charles W. Morgan invested in an ironworks. The Howlands also saw potential profits in the railroads, and their investments helped make New Bedford the third leading center of cotton textile manufacture in Massachusetts. Nor were whaling agents loath to turn their entrepreneurial skills to these alternative pursuits. The Howlands provided a part of the entrepreneurial force behind New Bedford's first cotton mill; Weston Howland opened the city's first petroleum-refining plant.

Thus, while the free availability of the ocean's whales made it possible for the United States to achieve its midcentury leadership in whaling, in the long

3. Norwegian wages, expressed in øre, are from Tønnessen and Johnsen 1982, 12, 13. American unskilled wages are from Abbott 1905, 361. The skilled to unskilled (artisans to laborers) ratio is from Williamson and Lindert 1980, 306.

run that availability made it possible for the Norwegians to dislodge the Americans from that position. Lower wages, lower opportunity costs of capital, and a lack of entrepreneurial alternatives pushed the Norwegians into exploiting the whale stocks. Higher wages, higher opportunity costs of capital, and a plethora of entrepreneurial alternatives turned Americans—even those from New Bedford—toward the domestic economy.