THE EXTINCTION OF THE EASTERN ARCTIC BOWHEAD

by

Robert C. Allen
Department of Economics
University of British Columbia

and

Ian Keay
Department of Economics
McGill University

June 1999
Discussion Paper No.: 99-18
The Extinction of the Eastern Arctic Bowhead

Robert C. Allen AND Ian Keay
Department of Economics Department of Economics
University of British Columbia McGill University
1873 East Mall 855 Sherbrooke St. W.
Vancouver, B.C. Montreal, P.Q.
V6T 1Z1 H3A 2T7
allen@econ.ubc.ca ikeay@leacock.lan.mcgill.ca

June, 1999

1The authors would like to thank workshop participants at U.B.C. and St. Francis Xavier, as well as those who offered comments and suggestions at the C.E.A. meetings in Toronto, May 28-30, 1999. We have also benefited from suggestions provided by Tony Ward, Tony Scott, Gordon Munro, Cherie Metcalf, Gor Ruseski and Brian Copeland. All remaining errors and omissions are the responsibility of the authors.
Abstract

In this paper we argue that the expansion of the British whaling industry at the end of the eighteenth century and beginning of the nineteenth century led to the collapse of the Dutch industry and the permanent depletion of the eastern arctic Bowhead stocks. A set of endogenous variables have been simulated, using a system of equations which explicitly model the links between economic and biological variables characterizing the Dutch pelagic whaling industry in both Davis Strait and off the east coast of Greenland, to facilitate counterfactual experimentation in support of our claim.

J.E.L. Classification: L79, N53, Q22.

Keywords: Renewable Resource Economics, Economic History-Europe-Pre 1913, Industry Studies-Renewable Resources.
1 Introduction

“...(P)robably all the great sea-fisheries are inexhaustible; that is to say that nothing we do seriously affects the number of fish. And any attempt to regulate these fisheries seems, consequently..., to be useless.” (Excerpt from Thomas Huxley’s inaugural address to the 1883 London Fisheries Exhibition.)¹

Economists predict that in an open access environment agents will enter an industry until rent, or economic profit, is driven to zero. At this point all inputs are just earning their opportunity cost and there is no incentive to apply greater effort in the industry.² Clark (1973) modeled this phenomenon in the context of a renewable resource industry and found that with reasonable assumptions regarding price : cost ratios open access resource exploitation suffers from not just rent dissipation, but possible stock extinction.

Today there is little doubt that technology exists which allows pelagic whalers to permanently damage whale stocks before it becomes unprofitable to continue their exploitation. However, as the quote which opens this paper indicates, it has not always been clear that a hunt could be continued profitably until a given whale stock was unrecoverably depleted prior to the introduction of steam powered vessels, harpoon guns and factory processing ships.

In their exhaustive study of American whaling during the nineteenth century Davis, Gallman and Gleiter claim that, “...most of the evidence indicates that the stocks of Sperm whales and Humpbacks were decidedly not running out (during U.S. exploitation)...Hunting was certainly a heavier burden to...(Rights, Grays and Bowheads)...but it was probably not so heavy as to make them generally scarce.”³ Writing about pelagic fishing in general Anthony Scott argues that, “...the stocks were so large and robust that, for centuries, the expanded fishing effort hardly affected (global stocks)...”⁴ Scott believes that until the end of the nineteenth century humans were capable of only insignificant changes in global fish stocks. Both Davis, Gallman and Gleiter and Scott base their conclusions on the apparent impact of fishing effort on global stock levels. This is potentially misleading. Just because the total number of whales, or fish, in the world’s oceans was so large that the global impact of fishing effort was relatively minor does not mean that individual stocks were not being permanently depleted. In other words, if individual stocks could be permanently damaged prior to their exploitation becoming unprofitable, then the technology did
exist which would allow for permanent depletion with non-negative levels of economic rent. The fact that there were so many potentially exploitable stocks that the overall impact was negligible does not mean that fishing effort was not depleting global fish stocks prior to the late nineteenth century.

The exploitation of the Bowhead (Balaena Mysticetus) whale stocks, which were resident off the east coast of Greenland and in Davis Strait, during the late seventeenth, eighteenth and nineteenth centuries, by Dutch and British pelagic whalers provides an excellent opportunity to study the interaction between economic and biological forces under open access conditions, early pelagic whaling technology and in the presence of internationally diverse government subsidies and input productivities. The Dutch hunted from the Greenland stock of Bowhead whales from the 1660s until the end of the eighteenth century. Intensive Dutch effort was not directed at the Davis Strait stock until 1719. Throughout most of the seventeenth and eighteenth centuries the Dutch operated the only substantial whaling industry in the world. However, after repeatedly suffering losses the Dutch industry was shut down in the first years of the nineteenth century. The British, on the other hand, began commercial whaling off the east coast of Greenland and in Davis Strait only after substantial government subsidies were offered in 1733. During the last years of the eighteenth century the British became the largest single nation hunting the Greenland and Davis Strait stocks, after having wrested this leading position from the Dutch. British whalers continued to commercially exploit these stocks until 1911. By the mid-1830s the eastern arctic Bowhead whale populations had been irreparably depleted. This is an example which illustrates that early pelagic whaling technology was capable of driving a distinct stock to extinction while maintaining a viable commercial industry.

In this paper we argue that British competition led to the collapse of the Dutch whaling industry and, contrary to the Davis, Gallman and Gleiter and Scott depiction of early whaling technology, the permanent depletion of the eastern arctic Bowhead stocks. We believe that the substantive difference between the Dutch and British industries during the first years of the nineteenth century was the relatively high British capital productivity levels. Differences in output prices, input prices and government subsidies do not appear to have been responsible for the British industry’s relative longevity and profitability. It has been suggested that the British fortified the hulls of their ships, which allowed them to participate in early spring hunting, they employed their inputs more
intensively, they did not have to spend resources or effort trying to avoid war privateers, and they
did not cooperate amongst themselves to conserve the whale stocks they were exploiting. These
unique characteristics could have resulted in the greater productivity and profit levels enjoyed by
the British industry.

Section 2 begins the body of the paper with a brief history of early European commercial
whaling, a review of the whaling technology employed by the first pelagic whalers, and a discussion
of the products of commercial whaling industries provide an economic and historical context for our
study of the Dutch and British whaling industries during the seventeenth, eighteenth and nineteenth
centuries. Section 3 briefly reviews the available data sources from which the evidence presented
here has been collected. The fourth section describes the derivation of population estimates for the
Greenland and Davis Strait Bowhead whale stocks. These population estimates indicate that there
were three distinct regimes during the era of intensive exploitation. The next section identifies
the role played by British competition in the demise of the Dutch industry and the change in
population regimes. To quantify the impact of increasing British competition at the end of the
eighteenth century a simulation model which captures the biological and economic features of the
Dutch whaling industry has been used. This model simulates twelve endogenous variables for the
Davis Strait and Greenland hunting grounds. Stock levels, whale oil and whale bone prices, effort
levels, catch, and quantity of whale oil and whale bone captured have been simulated, annually,
throughout the period of intensive Dutch exploitation. In an effort to determine the sources of the
British industry’s continued viability, and the Dutch industry’s collapse, Section 6 compares Dutch
and British output prices and input costs, and presents the results from several counterfactual
experiments which quantify the impact government subsidies and productivity levels had on the
Dutch pelagic whaling industry. The final section suggests some conclusions we can draw from the
evidence presented.

2 Commercial Whaling From 1600-1900

2.1 Historiography

Prior to 1600 commercial whaling by Europeans was rare. The only commercial industry was
maintained by Basque whalers on the southwest coast of France. This small scale industry was
exclusively shore based. Shore based whaling involved the search for whales from high masts erected on the beach, overlooking the sea. When whales were spotted close enough to shore to encourage pursuit long boats with between four and six oarsmen, one whom doubled as the harpooner, and a steersman set out. If the long boats managed to get close to a whale the harpooner would stand in the bow and throw the harpoon, which was affixed to a six foot long lance, into the whale. The harpoons had a rope of up to 300 fathoms attached, which was passed around a bollard in the bow of the long boat for resistance. When the whale next surfaced for air more long boats would converge and more harpoons would be launched to increase the resistance on the diving whale. When the whale became exhausted lances were used to finish the job. The whale’s tail was removed immediately after capture because it made towing the dead whale more difficult and it had no commercial value. The whale would then be towed back to a shore based whaling tent where it would be butchered and the oil and bone processed.

In 1596 William Barrents discovered a small island north of Iceland and east of Greenland. Barrents named the island Spitzbergen. Spitzbergen had many small harbors and, in 1596, a large resident population of Bowhead whales. In 1602 the Dutch government granted a monopoly charter to whale in the North Atlantic, including Spitzbergen, to the Noordsche Compaigne. Rather than bear the risks associated with the journey to Spitzbergen, this company operated a tiny whaling industry off the north coast of the Netherlands for the next five years. In 1607 Henry Hudson returned to England with confirmation of the rich whaling grounds around Spitzbergen. Hudson was adamant that the small harbors of Spitzbergen were ideal for shore based whaling operations. Soon there were Dutch, British, German and Basque whaling operations competing for the island’s best harbors. These European whalers set out for Spitzbergen in early spring and returned to their home ports in late summer with whale oil and whale bone which had been processed in their whale tents on Spitzbergen.

By 1645 the Dutch government had seized on the idea of training sailors for naval service by encouraging whaling voyages. To achieve this, a number of measures were introduced between 1645 and 1650. These measures included revoking the monopoly charter of the Noordsche Compaigne, imposing a 4% import duty on all foreign whale products flowing into the Netherlands, outlawing the use of foreign sailors on Dutch whalers, outlawing the use of foreign supplies or equipment on Dutch whalers and forcing Dutch whalers to trans-ship all whale products through Dutch ports.
These changes in Dutch government policy coincided with two developments in the Spitzbergen whaling industry. By 1650 the whales around Spitzbergen were becoming scarce and more weary of the presence of humans. This meant that shore based whaling was becoming infeasible. The British, Germans and Basques abandoned their harbours, leaving the entire island to the Dutch, who continued to pursue the whales further and further from shore. By 1660 the Dutch had vacated their shore based whaling stations on Spitzbergen as well, but, rather than leaving the industry all together, they began the first large scale commercial pelagic whaling industry off the east coast of Greenland. Between 1660 and 1750 the Dutch operated the only substantial commercial whaling industry in Europe.

In 1719 the Dutch whalers diversified some of their effort away from the stock of Bowhead on the east coast of Greenland and ships began hunting another stock of Bowhead in Davis Strait, between the west coast of Greenland and Labrador. This effort diversification into the Davis Strait occurred when declining stock levels on the Greenland hunting ground had lowered rents per ship earned off the Greenland stock. Throughout the period of Dutch dominance rents earned per ship hunting from the Greenland stock and the Davis Strait stock were approximately equal. This suggests rational effort allocation between the two stocks. The Bowhead stocks on the east and west coast of Greenland were distinct from one another.10

Hamburg was the only significant non-Dutch whaling port between 1660 and 1750. The Germans rarely outfitted more than 10% of the whaling vessels hunting on the world’s oceans during this era. In 1733 the British government sought to encourage the training of British sailors on whaling voyages by offering a bounty of 20 shillings per ton for any British whalers over 200 tons.11 This inducement proved inadequate and it was not until 1749, and repeated increases in the offered bounty, that a substantial number of British whalers began to participate. Through the last half of the eighteenth century there was a fairly constant growth in the number of British whalers and the quantity and value of British whale products. This increase in the size of the British industry was in spite of the fact that the government lowered the bounty substantially and both the Dutch and German whalers were having more and more trouble capturing enough blubber to make their voyages profitable.12

After 1783 the number of Dutch whalers declined substantially, while the British and Americans were becoming far more active and began pursuing a wide variety of whales and many different
stocks in all of the world’s oceans. By 1803, after a number of years of low profits and continued competition from British vessels on the eastern arctic hunting grounds, the commercial Dutch pelagic whaling industry came to an end. Early in the nineteenth century, American whalers periodically hunted the Greenland and Davis Strait stocks, but only the British continued to exploit these stocks intensively. By the mid-1830s, the eastern arctic stocks had been driven to the brink of extinction. Only small numbers of British vessels continued to hunt these stocks commercially after 1840. By 1911 there was no commercial exploitation of the Greenland or the Davis Strait stocks. Today there is no identifiable stock of Greenland Bowhead whales and a small, but recovering, stock of Davis Strait Bowheads.\(^{13}\)

### 2.2 Whale Products

There were primarily two whale products extracted from Bowhead whales; whale oil and whale bone. The whales’ blubber was boiled and refined into whale oil, which was used primarily as a lubricant and a luminant. Unlike sperm whale oil, most qualities of Bowhead whale oil burned poorly and were foul smelling. This meant that Bowhead whale oil was an inferior substitute for comparable products refined from vegetable oils.\(^{14}\)

Baleen whales, such as the Bowhead, have strong but flexible cartilage which hangs from their upper jaw and is used like a sieve to strain food out of sea water they take into their mouths. This cartilage, or whale bone, was removed from captured baleen whales and used in a wide variety of products which today would use wire or springs. Typically whale bone accounted for less than 10% of the value of a captured whale.

### 2.3 Pre-Twentieth Century Whaling Technology

Pelagic whaling during the seventeenth, eighteenth and nineteenth centuries was similar to shore based whaling during the earlier era, except that the whales were spotted from on board whaling vessels and the long boats would set out from these ships. Blubber and bone was removed from the whales as they were partially suspended along side the vessel and, due to the fear of fire at sea, there was no processing of the blubber on board Dutch or British vessels. American whalers began processing blubber, using on board try-works, in the mid-nineteenth century. This innovation allowed U.S. whalers to participate in multi-season whaling voyages. However, the Dutch and
British whalers who hunted the eastern arctic Bowhead stocks simply harvested and stored the blubber in casks until the end of the season, at which time it was unloaded at the whaling vessels' home ports in Europe and processed into whale oil there. Therefore, from the late seventeenth until the mid-nineteenth century pelagic whaling techniques were fairly static and Dutch and British pelagic whaling methods were virtually identical.

Dutch and British whaling vessels from this era had very similar physical characteristics. They averaged 200 - 300 British tons, carried approximately forty crew and officers and between four and six long boats. Most of the crew were paid a fixed amount per month, while the officers and harpooners were paid a fixed amount plus a share of the oil captured. This revenue sharing arrangement spread the risks involved in financing a whaling expedition to include those on board with the most control over an expedition’s success or failure. The Dutch and British whaling vessels sailed from their home ports in early spring and reached the ice cap east of Greenland and in the Davis Strait as the spring break up was occurring. They then sailed with the ice flows south along Greenland’s coasts hunting Bowhead amongst the ice. At the southern tip of Greenland they would turn north again to repeat the circuit. Two or three circuits would be completed each season. The most active Dutch whaling ports included Amsterdam, Rotterdam, Sardam and Ryp. The largest British whaling ports were Hull and London.

This brief discussion of the historical and technological context in which Dutch and British pelagic whalers operated between 1660 and 1900 suggests that this industry is an excellent case study for investigating the interaction of economic and biological forces in the exploitation of a renewable resource. Between 1660 and 1750 Dutch whalers operated the dominant commercial whaling industry. This dominance was lost to the British by 1800. The inputs employed had fairly static characteristics over the entire period, there were no institutional limits on access and the British managed to profitably exploit a distinct stock of whales to the point of extinction during an era when other authors have claimed this was technologically impossible. The most attractive aspect of this industry is that good data exists which allow us to study the differences between the Dutch and British industries.
3 Data

During the eighteenth century there were a number of business manuals published which contain information which was pertinent to individuals interested in conducting business in various European nations. The information in these manuals includes conversion factors for weights, measures and currency, as well as principal statistics for the main industries of the major economies in Europe. One of these manuals, *Traité Générale du Commerce*, written by Samuel Ricard (1781), contains time series information on the main industries in the Netherlands, including whaling.

The data on Dutch whaling contained in this manual spans the years 1669-1779 and includes ships returned, whales captured and barrels of blubber landed, for both Greenland and Davis Strait. These figures have been supplemented by information on ships lost, pounds of whale bone landed and cost figures for both Greenland and Davis Strait in De Jong’s (1979) *A Short History of Old Dutch Whaling* and his 1983 article on historical whaling records. De Jong also reports similar information on German (Hamburg) and British (Hull) whaling during the eighteenth and nineteenth centuries. Catch and effort levels are reported for all of Britain during the 1700s and early 1800s by Jackson (1978). Prices of whale oil and whale bone can be found in De Jong, Ricard and Posthumus (1946) for Amsterdam and in Tooke (1838) for London. Additional cost information on Dutch and British whaling voyages and production costs can be found in Proulx (1986) and Scorsby (1820). Data on Dutch, British, German and American effort and catch levels in the Davis Strait have been published in Ross (1979).

The prices for barrels of whale oil and pounds of whale bone, in Amsterdam, have been converted into grams of silver per liter and per pound, respectively, so they can be compared to their closest substitutes, and to British output prices. The figures for oil and bone captured and prices have been combined to yield revenue figures. The revenue figures, with data on average fixed and variable costs, allow us to calculate an estimate of rent, or economic profit, generated in the Dutch whaling industry over the period of study. Appendix B contains a graphical presentation of the available data.
4 Stock Estimates

The first step in understanding the simultaneous extinction of the eastern Arctic Bowhead, the decline of the Dutch industry and the rise of the British industry is to determine the pattern of stock depletion, for which we need to model the evolution of the Greenland and Davis Strait Bowhead whale populations through the seventeenth, eighteenth and nineteenth centuries. An ideal biological model of the Greenland and Davis Strait Bowhead stocks would incorporate information on the age and sex distributions of the whales, food availability, ice pack and climatic conditions and other sources of volatility in natural mortality and pregnancy rates. Unfortunately we have none of this information. Therefore, we have been forced to implement a biological model which uses the most basic structure, yet still captures the key features of stock adjustment to human predation and to changes in stock density. A number of parameterizations of a delay-difference population model have been used to generate stock estimates using observed catch figures. Only the preferred specification of the model is presented here.

A delay-difference population model assumes that the stock level in any period \( t+1 \) is a function of various biological parameters, period \( t \) stock and catch levels and the stock and catch levels during period \( t-\tau \), where \( \tau \) is the number of years between birth and sexual maturity. We can write:

\[
b_{t+1} = (1 - M)z_t + f(z_{t-\tau})
\]

where:

- \( b_{t+1} \) = stock at time \( t+1 \)
- \( z_t = b_t - \gamma w_t \)
- \( w_t = \) catch at time \( t \)
- \( \gamma = \) kill : catch ratio (= 1.20)
- \( M = \) natural mortality rate (= 0.05)
- \( \tau = \) years from birth to sexual maturity (= 5)
- \( f(\cdot \cdot \cdot) = \) generalized logistic growth function

\[
f(z_{t-\tau}) = g z_{t-\tau} \left( 1 - \left( \frac{z_{t-\tau}}{b_{\text{max}}} \right) ^{\alpha} \right)
\]

where:

- \( g = \) maximum exponential growth rate (= 0.07)
- \( \alpha = \) density dependence parameter (= 2.39)
- \( b_{\text{max}} = \) environment’s maximum holding capacity (= 107 053 for the Greenland Stock and 38 343 for the Davis Strait stock)

The mathematical properties of a delay-difference model similar to that presented here, including the conditions for the stability of the biological equilibrium described as the pristine state, are
available in Clark (1976).

To implement this stock model we require not only annual catch figures, which we have collected from the sources outlined in Section 3, but at least one year for which we have a reliable estimate of the population size. From this seed value we can iterate this model to derive annual estimates of the number of whales in the Greenland and Davis Strait stocks. De Vries and Van Der Oude (1997; Pg. 263) suggest that the pristine population level for the Greenland stock was 22,000 individuals. This estimate is consistent with the International Whaling Commission’s estimates of the initial population size.\textsuperscript{26} It cannot be correct. Under any reasonable parameterization of the delay difference model described above an initial stock level of 22,000 for the east coast of Greenland would have led to extinction long before the Dutch, much less the British, industry ceased their commercial exploitation. To avoid the problem of premature extinction we have assumed that there were fewer than 1,000 whales remaining in the Greenland and Davis Strait stocks in 1911 and used this number as a seed value. Therefore, we have iterated our stock model backwards from 1911 to 1605. This method suggests that the pristine population level was 63,380 whales in the Greenland stock and 22,701 whales in the Davis Strait stock. These estimates are fairly insensitive to reasonable changes in the model’s parameterization and to potential measurement error in annual catch figures. Appendix A contains a graphical presentation of the model’s population estimates for the Greenland and Davis Strait stocks.

From our population estimates we can identify a number of distinct periods in the life cycle of the Greenland stock. During the pre-pelagic whaling era (1605-1660) annual catches were small and the subsequent declines in population modest. As the Dutch became the dominant whaling nation more vessels entered the industry, annual catches rose, and the stock began a long slow decline (1660-1780). This decline became precipitous as the British fleet expanded dramatically and, even after the Dutch industry shut down, annual catch figures increased substantially (1780-1835). After this period of rapid decline there was a long era in which there were very few whales, pursued by very few British and American vessels and annual catches averaged fewer than 21 whales (1835-1911). These patterns are even more pronounced when we look at the log of the population estimates. The yearly change in the log of population reflects rates of change in the Greenland Bowhead stock. It appears that the rate of change in the Greenland stock was consistently negative, but very low, except for the short period of intensive British exploitation. Between the years 1780
and 1835 the British commercial whaling industry not only drove the Dutch commercial whaling industry to extinction, but was almost as successful at driving the Bowhead whales to extinction.

The same trends can be observed for the Davis Strait population estimates. The Dutch industry’s predation practices seem to have resulted in a slowly declining Bowhead stock (1719-1790). When the British began to exert substantial effort on the Davis Strait ground the population estimates plummet (1790-1840). Another long period of slow decline followed this burst of British effort (1840-1911). Once more these stock patterns are even more pronounced when one observes the log of the Davis Strait population estimates.

This brief review of the population estimates for the Greenland and Davis Strait stocks suggests that the life cycles of these stocks reflect three distinct regimes. The first regime coincided with the period of Dutch dominance. It was characterized by slowly declining stock levels and a long period of profitable exploitation. The second regime, during the period of intensive British exploitation, was characterized by more rapidly decreasing stock estimates and the collapse of the Dutch industry. The final regime marked the long, slow decline in the stocks to virtual extinction. Understanding the unique characteristics of each of these regimes, and hence, the causes of the virtual extinction of the stocks, requires a detailed study of the economic and institutional differences between the Dutch and British commercial pelagic whaling industries.

5 The Collapse of the Dutch Industry, The Extinction of the Eastern Arctic Bowhead and British Competition

At the turn of the nineteenth century the Dutch pelagic whaling industry shut down. There were periodic voyages after 1800, but never more than three Dutch ships participated and the catch was never more than eleven whales captured. This represented a dramatic decline in an industry which just ten years earlier had been sending out well over sixty ships per year and capturing over two hundred whales. The rapid collapse of the Dutch industry is even more striking given that the British pelagic whaling industry was in the midst of an expansionary period which saw significant increases in the number of vessels participating and the number of whales being captured.

In the section above we illustrated that there were substantial numbers of Bowhead whales remaining in the Greenland and Davis Strait stocks when the Dutch abandoned the industry.27 In
the years leading up to the turn of the nineteenth century the Dutch pelagic whaling industry was consistently earning negative economic rents. The negative rents discouraged effort to the point where virtually no new Dutch ships were participating in the hunt and the established whaling vessels were slowly depreciating.\textsuperscript{28} The Dutch industry appears to conform to the Davis, Gallman and Gleiter and Scott depiction of early fishing and whaling industries and their effect on global stock levels. However, the fact that the British continued to intensively hunt the eastern arctic Bowhead stocks until the 1830s and less intensively, but consistently, sent ships to these hunting grounds until the early 1900s implies that there was something different about the British industry. The British pelagic whaling industry did not fit the Davis, Gallman and Gleiter and Scott characterization of pre-1900 commercial whaling industries. The British continued to profitably hunt the stocks until they were on the very brink of extinction.\textsuperscript{29}

It certainly seems unlikely that the very rapid decline in the Greenland and Davis Strait Bowhead stocks, the collapse of the Dutch commercial whaling industry, and the dramatic expansion of the British effort levels, all of which occurred at the very end of the 1700s and beginning of the 1800s, could be coincidental. In an effort to quantify the effects of increasing British competition on the Dutch whaling industry and the eastern arctic whale stocks we have constructed a simulation model with which we can perform counterfactual experiments to measure these effects.

5.1 Simulation Model

To simulate the Dutch whaling industry we have constructed a model with twelve equations which characterize the evolution of both economic and biological variables over time. Five of these equations describe the biological and economic characteristics of the Dutch fleet which hunted from the Greenland stock. There are five matching equations for the fleet which hunted from the Davis Strait stock. The final two equations characterize the evolution of whale oil and whale bone prices in Amsterdam. The estimated parameters which characterize these twelve equations, with seed values for stocks, prices, effort levels, catch figures, barrels of oil captured and pounds of bone captured, and annual time series of exogenous variables allow us to simulate each of these variables at each point in time for the Greenland and Davis Strait stocks and fleets. With a model which accurately simulates the observed endogenous variables we can perform counterfactual experiments by mapping out the consequences of changing the exogenous variables.
The delay-difference recruitment model we use to simulate stock levels is described in detail in Section 4. The estimated population figures for the Greenland and Davis Strait stocks for the years 1656-1661 have been used as seed values to initiate the simulation model. The population figures derived from our delay-difference model have also been used to econometrically estimate production functions for the Greenland and Davis Strait fleets.

A number of specifications of the production functions for catch, oil and bone have been estimated.\textsuperscript{30} The preferred specification for the catch function is an unconstrained Cobb-Douglas function, which uses data from 1661-1803. We have assumed that the number of whales captured is a function of effort exerted, available stock and a dummy variable which takes the value of one in years in which the Dutch industry was shut down due to war. The estimated catch functions for both the Greenland fleet and Davis Strait fleet have increasing returns to scale. This implies that a doubling of the Dutch effort levels and the Bowhead stock levels would have led to an increase in catch of more than 100%. Production functions which were constrained to be constant returns to scale have been estimated and the simulation model has been run with these estimates without any qualitative differences in the conclusions we reach.

We have assumed that the quantity of oil and bone landed was a function of the year of the voyage, as well as the number of whales landed, because the size of the whales landed was falling over time. A war dummy has also been included in the oil and bone production functions for both the Greenland and Davis Strait fleets. Our oil and bone production function estimates indicate that the whales captured from the Greenland stock were smaller than those captured from the Davis Strait stock and the size of the Greenland Bowheads was falling over time. These conclusions are consistent with the existing literature.\textsuperscript{31}

The effort functions we employ reflect our assumption that effort (measured as ships returned) directed towards the Greenland or Davis Strait stock in period $t + 1$ was a function of rent earned per ship in period $t$, effort in period $t$, effort squared in period $t$, a time trend, a time trend squared, and a war dummy. The lagged effort levels reflect the fact that the ships employed as whalers were unique to the industry. Whaling vessels could be, and were, used as merchant ships or in times of war as naval ships. However, they were specifically designed to be whalers and their owners intended them to be profit making units of capital. This suggests that the number of Dutch whaling vessels was inflexible in the short run. As we expected the estimated parameters
associated with the lagged effort terms tended to be positive,\textsuperscript{32} reflecting the fact that once a whaler was built and outfitted, there were few alternate uses for it. The time trend terms were included to capture the productivity gains associated with technological advances in the use of the vessels and the learning by doing one would expect to find as the industry matured. In all cases we observe the expected positive signs on the estimated time trend parameters and negative signs on the quadratic time trend parameters. The signs on the rent earned per ship parameters are positive for both the Greenland and Davis Strait fleets. This suggests that higher rents earned by ships hunting the eastern arctic stocks in the previous year led to greater effort exerted in the current year. The effort functions have been estimated using data from the years 1661-1760 to characterize the effort decisions of the Dutch whalers prior to intensive British competition. To characterize the effort decisions of the Dutch whalers during the era of substantial international competition on the eastern arctic whaling grounds another set of effort functions have been estimated using data from the years 1761-1800.\textsuperscript{33}

Prices are determined in each period in this model with log-linear inverse demand functions. Prices are treated as an endogenous variables because the seasonal nature of the industry implies that whale oil was supplied inelastically in each year. We have assumed that the price of whale oil was a function of whale oil consumption per capita in the Netherlands, the price of rape seed oil in Amsterdam, the general retail price level in Amsterdam, a nominal wage for building labourers in Amsterdam, a time trend, a time trend squared and the war dummy. The bone price equation is defined in a similar manner, except for the omission of the rape seed oil price independent variable. The whale oil demand equation’s parameter estimates suggest that demand for whale oil was very elastic and that whale oil and rape seed oil were very close substitutes. The negative parameters on the nominal wage variables for both whale oil and bone suggest that whale oil and bone were inferior goods.\textsuperscript{34} These conclusions are consistent with the discussion in Davis, Gallman and Gleiter concerning the economic and physical characteristics of whale oil and whale bone during the nineteenth century.\textsuperscript{35}
The Model

Greenland Stock:

\[ b_{t+1} = 0.95\hat{b}_t - 1.14\hat{w}_t + 0.07(b_{t-5} - 1.20w_{t-5}) \left(1 - \left(\frac{b_{t-5} - 1.20w_{t-5}}{107053}\right)^{2.39}\right) \]  
\[ \hat{b}_t = \text{simulated stock in time } t \]  
\[ \hat{w}_t = \text{simulated catch in time } t \]

Davis Strait Stock:

\[ b_{t+1} = 0.95\hat{b}_t - 1.14\hat{w}_t + 0.07(b_{t-5} - 1.20w_{t-5}) \left(1 - \left(\frac{b_{t-5} - 1.20w_{t-5}}{22701}\right)^{2.39}\right) \]

Greenland Catch:

\[ \ln\hat{w}_t = -0.0009^{**}\text{yrs} - 1.205^{**}\text{wardum} + 1.006^{*}\ln(\hat{e}_t) + 0.266^{*}\ln(\hat{b}_t) \]

* denotes statistical significance at the 95% level.
** denotes statistical significance at the 90% level.
\[ \hat{e}_t = \text{simulated effort in time } t \]
\[ \text{yrs} = \text{time trend} \]
\[ \text{wardum} = \text{dummy variable (}=1 \text{ during war years}) \]

Davis Strait Catch:

\[ \ln\hat{w}_t = -0.005^{*}\text{yrs} - 1.289^{*}\text{wardum} + 0.781^{*}\ln(\hat{e}_t) + 1.092\ln(\hat{b}_t) \]

Greenland Quantity of Oil:

\[ \hat{bbl}_t = -0.378^{*}\text{yrs} - 653.450\text{wardum} + 55.137^{*}\hat{w}_t \]

\[ \hat{bbl}_t = \text{simulated barrels of oil in time } t \]

Davis Strait Quantity of Oil:

\[ \hat{bbl}_t = 0.040^{*}\text{yrs} - 72.044^{*}\text{wardum} + 74.911^{*}\hat{w}_t \]

Greenland Quantity of Bone:

\[ \hat{bn}_t = -6.694^{*}\text{yrs} - 11568.000\text{wardum} + 1322.700^{*}\hat{w}_t \]

\[ \hat{bn}_t = \text{simulated pounds of bone in time } t \]

Davis Strait Quantity of Bone:

\[ \hat{bn}_t = 3.773^{*}\text{yrs} - 6725.900^{*}\text{wardum} + 1773.000^{*}\hat{w}_t \]
Greenland Effort (1661-1760):

\[ e_{t+1} = 0.211^{**} yrs - 0.0001 yrs^2 + 0.001 \frac{\hat{rent}_t}{e_t} - 0.340^{**} \hat{e}_t + 0.004 \hat{e}_t^2 - 130.270^{*} wardum \]  
\[ \hat{rent}_t = \text{simulated rent generated in time } t \]

Greenland Effort (1761-1800):

\[ e_{t+1} = 0.874^{*} yrs - 0.0005^{*} yrs^2 + 0.002 \frac{\hat{rent}_t}{e_t} + 0.084 \hat{e}_t + 0.004 \hat{e}_t^2 - 36.819^{*} wardum \]

Davis Strait Effort (1719-1760):

\[ e_{t+1} = 0.996^{*} yrs - 0.0006^{*} yrs^2 + 0.001 \frac{\hat{rent}_t}{e_t} + 0.227 \hat{e}_t + 0.003 \hat{e}_t^2 \]

Davis Strait Effort (1761-1797):

\[ e_{t+1} = 0.209^{**} yrs - 0.0001^{**} yrs^2 + 0.0003 \frac{\hat{rent}_t}{e_t} + 0.193 \hat{e}_t + 0.013 \hat{e}_t^2 - 13.446^{*} wardum \]

Oil Price:

\[ \ln \hat{pbbl}_t = -0.0002 yrs + 0.000002^{*} yrs^2 - 0.081 wardum - 0.123^{*} \ln \left( \frac{\hat{bbl}^{agg}_t}{\text{pop}_t} \right) \]
\[ + 0.543 \ln(p^{RS}_t) - 0.278 \ln(cpi_t) - 1.564 \ln(wg_t) \]  
\[ \hat{pbbl}_t = \text{simulated price of whale oil in time } t \]
\[ \hat{bbl}^{agg}_t = \text{aggregate simulated barrels of whale oil in time } t \]
\[ \text{pop}_t = \text{population of the Netherlands in time } t \]
\[ p^{RS}_t = \text{price of rape seed oil in Amsterdam in time } t \]
\[ cpi_t = \text{retail price index in Amsterdam in time } t \]
\[ wg_t = \text{nominal building labourers' wage in Amsterdam in time } t \]

Bone Price:

\[ \ln \hat{pbn}_t = -0.011^{*} yrs + 0.000007^{*} yrs^2 - 0.028 wardum - 0.005 \ln \left( \frac{\hat{bn}^{agg}_t}{\text{pop}_t} \right) \]
\[ -1.436 \ln(cpi_t) - 2.546 \ln(wg_t) \]  
\[ \hat{pbn}_t = \text{simulated price of whale bone in time } t \]
\[ \hat{bn}^{agg}_t = \text{aggregate simulated pounds of whale bone in time } t \]

Therefore, we have twelve equations characterizing the evolution of the endogenous variables over time. The system is calibrated using the econometric estimation results and initiated using the observed endogenous variables from the first year, 1661. This system can be run forward for
Table 1: Simulated / Observed, Annual Averages (1661-1803)

<table>
<thead>
<tr>
<th></th>
<th>Greenland</th>
<th>Davis Strait</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effort</td>
<td>0.912</td>
<td>0.832</td>
</tr>
<tr>
<td>Catch</td>
<td>1.003</td>
<td>0.908</td>
</tr>
<tr>
<td>Oil</td>
<td>1.002</td>
<td>0.910</td>
</tr>
<tr>
<td>Bone</td>
<td>1.002</td>
<td>0.912</td>
</tr>
<tr>
<td>Stock</td>
<td>1.052</td>
<td>1.010</td>
</tr>
<tr>
<td>Oil Price</td>
<td></td>
<td>1.137</td>
</tr>
<tr>
<td>Bone Price</td>
<td></td>
<td>0.725</td>
</tr>
</tbody>
</table>

143 years and the end point simulated endogenous variables can be compared to the end point observed endogenous variables to determine its ability to accurately characterize the economic and biological interactions within the Dutch industry. Simulated rent figures have been calculated by multiplying simulated prices by simulated oil and bone quantities to derive revenue figures. Cost per ship and production costs are assumed to be exogenous to the system.

The annual averages and end points of the simulated endogenous variables fit the observed endogenous variables very closely. This is not surprising given the relatively high $R^2$ from the regression equations. See Appendix B for a graphical presentation of the simulation results.

5.2 No British Competition Counterfactual

The model described above not only simulates the endogenous variables which characterize the evolution of the Dutch pelagic whaling industry and the eastern arctic Bowhead stocks throughout their life cycles, but it allows us to conduct counterfactual experiments. A counterfactual experiment attempts to quantify the impact of changes in the exogenous variables in the model on the simulated endogenous variables. In other words, we can map out the evolution of the endogenous variables under conditions which were not experienced by the industry. The first experiment we conduct seeks to quantify the effects of increased British competition on the Dutch industry and the eastern arctic whale stocks.

British competition appears in our simulation model in two places. British catch figures are subtracted from the simulated populations of the Greenland and Davis Strait stocks, and the parameters associated with the Dutch whalers’ effort functions are assumed to change with the introduction of intensive British competition in 1760. By setting British catch figures to zero for
the entire 1661-1803 period and employing the pre-1760 effort functions throughout we are assuming that British whalers did not hunt from the eastern arctic stocks in our counterfactual.\textsuperscript{36}

The removal of British competition from our simulation model has two dramatic effects. First, if there had been no British competition the Dutch industry could have continued to profitably exploit the Greenland stock into the twentieth century. This implies that the counterfactual stock levels, effort levels and rent levels were positive until at least 1911. Second, the Greenland stock would have had over 8,500 whales remaining in 1840 and still would have had positive stock levels into the early twentieth century. The no British competition counterfactual indicates positive, but slowly declining Greenland stock levels throughout the nineteenth century. Therefore, the removal of British competition would have resulted in higher stock, effort and rent levels. The Dutch industry could have continued profitable exploitation of a substantial Greenland stock for an additional 110 years in the absence of British whalers. The implication is that British competition appears to have been responsible for the collapse of the Dutch industry and the extinction of the Greenland Bowhead stock.\textsuperscript{37}

Therefore, our no British competition counterfactual suggests that the Dutch industry would not have collapsed and the Greenland stock of Bowhead would have had positive, but slowly declining, population levels throughout the 1800s if British whalers had not hunted from this stock. However, British whalers did hunt from the Greenland and Davis Strait stocks, the Dutch industry did collapse in 1803 and the eastern arctic Bowhead were virtually extinct by 1840. Given that these events occurred, and given that British competition was responsible, we now want to ask; Why did British competition have such dramatic effects on the Dutch industry and the whale stocks?; and; Why did the British not fit the Davis, Gallman and Gleiter and Scott depiction of early whaling technology? It is to these questions which we now turn.

6 The Dutch and the British Industries Compared

There are a limited number of characteristics which could explain why the Dutch abandoned the Greenland and Davis Strait stocks when they did, and why the British continued their exploitation to the point of virtual extinction. The British must have had lower costs per unit of effort or earned higher revenues per unit of effort if they were able to continue profitable exploitation after
the Dutch were forced to shut down. On the cost side it is unlikely that the British had lower input costs. On the revenue side the British do appear to have earned more per ship. However, this higher average revenue was not a result of output price differences or subsidy differences. We believe that the British industry’s substantially higher capital productivity allowed them to continue profitable hunting long after the Dutch vessels were not able to cover their costs. Possible explanations for the higher British capital productivity include: more intensive input use; technological innovations in the fortification of their hulls; lower security costs; or; a lack of cooperation amongst the participating whalers. Before comparing their ability to generate revenues, we first compare the input costs faced by the Dutch and British whalers during our period of study.

6.1 Input Costs

William Scorsby wrote a detailed description of typical British whaling voyages during the era of British dominance, *An Account of the Arctic Regions With a History and Description of the Northern Whale Fishery, Vol. 2* (1820). In this volume Scorsby claims that the average cost per voyage for British whaling vessels hunting from the Greenland ground was £833 between the years 1669-1778. Scorsby also mentions that processing costs for whale oil in British rendering plants in Hull averaged seventeen shillings per barrel of oil during the same period. A detailed break down of the costs is provided for a 291 ton vessel which sailed from Hull to the east coast of Greenland in 1803, the *Resolution*. The cost break down includes the cost of fortifying the hull, insurance, supplies, provisions and labour costs.

If the *Resolution* was a typical British whaler, then it appears that British and Dutch per vessel costs were virtually identical. Jenkins (1921, Pg. 58) claims that the average Dutch whaling vessel was approximately 200-300 tons and manned by 35 sailors and six officers. The quantity and cost of the inputs used by the average Dutch whaler, provided by Jenkins, are very similar to the quantity and cost of the inputs used by the *Resolution* in 1803. Additional evidence which indicates that the Dutch and British pelagic whaling industries were facing very similar costs is presented in De Vries and Van Der Oude (1997, Table 7.3) and De Jong (1979, Statistical Appendix). Both of these sources claim that the average cost per voyage for Dutch whalers from 1660-1800 was 10 000 guilders and average processing costs for Dutch whale blubber was 10 guilders per barrel. These costs are identical to those quoted for the British industry at this time.
The largest component of variable costs for both Dutch and British whaling voyages were labour costs. Although we do not have data on Dutch and British sailors’ wages, we can say that at the end of the eighteenth and beginning of the nineteenth centuries building labourers in London were receiving higher nominal wages than building labourers in Amsterdam. This suggests that British labour costs may have been higher than Dutch labour costs during the late 1700s and early 1800s. Therefore, it is unlikely that the source of the British whaling industry’s continued profitability, in the face of dramatically declining stock levels, was due to relatively low labour costs.

The total costs per voyage faced by the British and Dutch whalers appear to have been very similar at the turn of the nineteenth century. This is not surprising since the British and Dutch industries employed very similar hunting techniques and sailing technology throughout this period. The physical characteristics of the whaling vessels and the employment of labour, supplies and provisions were common in both British and Dutch industries. The use of Basque whalers who had considerable experience as harpooners, butchers and sailors was common on both Dutch and British vessels, particularly in the early decades of their industries’ operation. Both the British and Dutch governments restricted the subsidies paid to vessels which chose to employ foreign crews. The repeated appearance of these restrictions suggest that the practice was common in spite of the government restrictions.

It is not likely that input price differences explain why the Dutch abandoned pelagic whaling just as the British were expanding their efforts substantially. All of the anecdotal and quantitative evidence indicates that Dutch and British whalers faced very similar fixed and variable costs and employed very similar techniques and technology.

6.2 Output Prices

If the technology employed by the Dutch and British was similar and the per voyage costs were virtually identical, then we must look elsewhere for reasons for the divergent reactions to declining whale stocks. It is possible that the British industry continued to profitably exploit the eastern arctic Bowhead stocks because the British whalers enjoyed higher output prices. Ricard (1781), De Jong (1983) and Posthumus (1946) report whale oil and whale bone prices for Amsterdam, which, taken together, cover the period 1661-1803. Tooke (1838) reports British prices for whale products for the years 1782-1838. Therefore, we can compare Dutch and British output prices for the key
period, 1782-1803.

If output prices explain the continued profitable operation of the British industry after 1800, we would expect the British prices to be greater than the Dutch. We do not find this to be the case. Dutch whale oil prices were, on average, 54% higher than British whale oil prices between 1782-1803. Whale bone prices in Amsterdam were over 61% higher than whale bone prices in London, on average, during this same period. Much of the difference in whale products’ prices at the end of the eighteenth century between the Netherlands and Britain may have been due to disruptions caused by war. The British pelagic whaling industry was, for the most part, undisturbed by European wars. However, the Dutch industry was completely shut down due to the demands for sailors and ships made by the navy on the whaling industry. The lack of domestic production of whale products in 1781, 1782, 1795, 1799, 1800 and 1801 meant that Dutch demand for these products had to be met by foreign, primarily British, sources of supply, or out of existing inventories. Therefore, it is not surprising that Dutch prices during this period, and particularly the war years, were higher than the British prices.

What is more surprising is that Dutch and British costs were very similar and Dutch output prices were higher than British output prices, yet the British industry was able to continue profitable exploitation of the eastern Arctic Bowhead stocks long after the Dutch were forced to shut their commercial industry down. If British longevity was not due to costs or prices, then it must have been due to variations in subsidy levels or productivity levels. We use our simulation model, described in Section 5.1, to study the effect of these two influences on the Dutch industry.

6.3 Subsidies Counterfactual

We know that the Dutch and British governments offered substantial subsidies to their domestic whaling fleets in an attempt to induce greater effort levels, and hence, the training of greater numbers of native born sailors who would be available for naval service in times of war. We also know that British competition drove the Dutch from the Greenland and Davis Strait hunting grounds in first years of the nineteenth century and reduced the Bowhead stocks resident on these grounds to virtual extinction by the mid-1830s. Contemporaries felt that British effort levels were very elastic with respect to the bounties paid. This appears to have been the case during the mid-eighteenth century as the British industry was getting established. However, the lowering and
eventual elimination of the bounties during the period in which the British industry was expanding
most rapidly and the Dutch industry was in decline suggests that, at this key juncture in the
bioeconomic life-cycle of the eastern arctic Bowhead stocks, subsidies did not play a significant
role.

All of the Dutch government’s support for the whaling industry was designed to promote in-
creased participation, and hence, increases in the number of native born sailors. The one Dutch
policy with this goal in mind which remained in effect throughout the period of intensive exploita-
tion was a 4% import duty on all whale products brought into the country. In addition to the import
duty the Dutch government agreed to pay 30 guilders per crew member, or approximately 1200
guilders per voyage, to domestic whalers starting in 1771 to ensure continued compliance with a
regulation requiring that all Dutch whaling vessels employ only native born sailors. This support
was gratefully accepted by the whalers but it was not enough to return the industry to profitability
in the face of increasing international competition, continued competition from rape seed oil for
the domestic luminant market and declining whale stocks. In 1788 the Dutch government again
stepped in and guaranteed each Dutch whaling vessel 50 guilders for every barrel of blubber below
a minimum level (100 barrels). Therefore, after 1788 Dutch vessels which captured no whales,
but employed a full crew of native born sailors, were guaranteed 5000 guilders by the government.

Like the Dutch, the British government sought to encourage whaling voyages so that there
would be a pool of trained sailors available in times of war. Rather than impose import duties and
pay crew subsidies, the British preferred a more direct approach. In 1733 the British government
offered a revenue bounty of 20 shillings per ton for any whaling vessels over 200 tons. This bounty
encouraged the beginnings of a commercial pelagic whaling industry, but success was limited.
Between 1733-1740 no more than six British ships set out for the Greenland hunting ground in
each year. In 1740 the bounty was raised to 30 shillings per ton, but British effort continued to
be insubstantial. There was a further increase in the bounty to 40 shillings per ton was offered in
1750. This level of revenue subsidy seems to have been sufficient to promote a significant exertion
of effort. After 1750 it was not uncommon for over 50 British vessels to be hunting the Bowhead off
Greenland’s east coast and in Davis Strait. By 1776 the British industry seemed well established
and the government felt that the bounties were becoming an unnecessary drain on the country’s
treasury. The bounty was lowered to 30 shillings per ton in 1776, and again to 20 shillings per ton
in 1781. Apparently the British industry was not as strong as the government had hoped. After the bounty was lowered the number of British whalers fell dramatically. Fearing that the industry would completely disappear the government again raised the bounty to 30 shillings per ton in 1786. Six years later the government again tried lowering the bounty to 25 shillings per ton. This time effort levels remained fairly constant. The British industry began to expand quite rapidly in the last years of the eighteenth century and the first decade of the nineteenth century, in spite of the fact that the British government lowered the bounty to 20 shillings per ton in 1798 and left the revenue subsidy at this level until it was totally removed in 1820.45

To study the impact government subsidies had on the Dutch industry and the eastern arctic whale stocks we have used our simulation model to conduct a counterfactual experiment which seeks to determine whether the Dutch industry could have profitably continued their exploitation of the Greenland Bowhead stock had they received subsidies equal to those paid to the British whalers. Our subsidies counterfactual experiment has two stages. We start by removing the subsidies paid by the Dutch government to their domestic pelagic whaling industry. We then replace these actual subsidies with hypothetical subsidies which are equal to those paid by the British government to the British whaling industry. We would expect the hypothetical British subsidies to lead to profitable continuation of the Dutch industry to the point of stock extinction if they were responsible for the British industry’s continued exploitation after 1800.

In the first stage of this counterfactual we remove the Dutch subsidy supports. This involves three changes to the exogenous variables in our simulation model. We have assumed that Dutch whalers were able to price up to the tariff. This implies that they enjoyed output prices which were 4% higher than they would have been in the absence of the import duty. Hence, when we ask what would have happened had there been no government support we assume that the observed output prices were 4% higher than the counterfactual output prices. This implies that the simulated output prices must be multiplied by 0.962 under this counterfactual. We have also increased the cost per ship hunting in Greenland by 1200 guilders to compensate for the per crewman subsidy from 1771-1803. Finally, to adjust for the revenue subsidy the average quantity of whale oil per ship from 1788-1803 has been calculated and, for those years for which this average was below 100 barrels, the average subsidy per ship has been subtracted from the revenue per ship figures before deriving the counterfactual rents. This technique assumes that all vessels captured the average oil per ship
Table 2: No Subsidies / Simulated, Annual Averages (1661-1803)

<table>
<thead>
<tr>
<th></th>
<th>Greenland</th>
<th>Davis Strait</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effort</td>
<td>0.986</td>
<td>0.974</td>
</tr>
<tr>
<td>Catch</td>
<td>0.992</td>
<td>0.981</td>
</tr>
<tr>
<td>Oil</td>
<td>0.992</td>
<td>0.981</td>
</tr>
<tr>
<td>Bone</td>
<td>0.992</td>
<td>0.982</td>
</tr>
<tr>
<td>Stock</td>
<td>1.020</td>
<td>1.002</td>
</tr>
<tr>
<td>Oil Price</td>
<td></td>
<td>0.963</td>
</tr>
<tr>
<td>Bone Price</td>
<td></td>
<td>0.962</td>
</tr>
</tbody>
</table>

in each year after 1788. Without disaggregate data this method is the only available alternative. Therefore, had there been no government support for the Dutch whaling industry, output prices would have been 4% lower from 1661-1803, costs per ship would have been 1200 guilders higher from 1771-1803, and the average revenue subsidy per ship would have been zero from 1788-1803.

Our simulation model indicates that in the absence of government subsidy supports there would have been slightly less effort exerted on the whale stocks. Hence, if the government’s goal was to encourage effort and therefore increase the number of trained sailors, then this appears to have been only marginally successful. The counterfactual stock estimates would have been slightly higher due to the reduced effort and catches would have been virtually unchanged. Our model also suggests that the industry must have been quite pleased with the subsidies because the decrease in output price with the removal of the import duty and the lack of direct subsidies in the last years of the industry would have substantially decreased the total rent earned off the Greenland and Davis Strait stocks during the last years of the eighteenth century.

Having removed the subsidies from our simulation model we find that the effects on the endogenous variables are negligible. In the absence of government support the Dutch industry still shuts down at the same time and the stocks are still driven to the point of extinction by 1840. The Dutch government’s efforts to stimulate their domestic industry were ineffectual. However, this does not imply that a more substantial effort to support the Dutch industry would have been equally futile.

To perform the second stage of this counterfactual the simulated Dutch industry has been given the British subsidy levels. To do this we have assumed that all Dutch vessels were 250 tons. This was approximately the average size of a Dutch whaler.\textsuperscript{46} In the absence of micro data on Dutch vessel size, assumptions with respect to size are unavoidable. The British per ton bounty in each year has then been multiplied by 250 tons and added to the counterfactual revenue per ship figures
Table 3: British Subsidies / Simulated, Annual Averages (1661-1803)

<table>
<thead>
<tr>
<th></th>
<th>Greenland</th>
<th>Davis Strait</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effort</td>
<td>1.000</td>
<td>1.036</td>
</tr>
<tr>
<td>Catch</td>
<td>1.002</td>
<td>1.018</td>
</tr>
<tr>
<td>Oil</td>
<td>1.002</td>
<td>1.017</td>
</tr>
<tr>
<td>Bone</td>
<td>1.002</td>
<td>1.017</td>
</tr>
<tr>
<td>Stock</td>
<td>1.019</td>
<td>1.002</td>
</tr>
<tr>
<td>Oil Price</td>
<td></td>
<td>0.956</td>
</tr>
<tr>
<td>Bone Price</td>
<td></td>
<td>0.962</td>
</tr>
</tbody>
</table>

used to generate rents per ship in each year.

Not surprisingly the rents generated by the Dutch industry are higher when they receive the British revenue subsidies. However, they are not substantially higher because the simulated Dutch price levels are lower in the absence to the Dutch government’s 4% import duty. These lower prices kept the rents from increasing more dramatically when the British revenue subsidies were added on to the counterfactual Dutch revenue figures. Therefore, these slightly higher rents do not translate into dramatically higher effort levels. The stock levels are only slightly lower due to this increased effort. The lower stock levels and higher effort levels combine to leave the simulated catch levels virtually unchanged.

It appears that, on average, the British bounties would have had only a minor impact on the physical characteristics of the Dutch pelagic whaling industry. The Dutch industry would have shut down in the same year whether it was receiving Dutch or British subsidies or no subsidies at all. Government support of the Dutch pelagic whaling industry during the eighteenth and nineteenth centuries appears to have had significant effects on rents generated, but not on prices, effort levels, stock levels or catch levels. If the goal was to increase the number of native born sailors participating in the pelagic whaling industry, or lengthen the life span of the industry, then government subsidies appear to have been unsuccessful. These counterfactual results imply that there must be some other distinctive feature of the British industry which allowed them to continue to profitably exploit the eastern arctic Bowhead stocks after the Dutch abandoned the industry.
6.4 Productivity Counterfactual

One of the most striking features of the British industry’s expansion during the 1780s, 1790s and early 1800s is the dramatic increase in whales captured per ship. This increase in capital productivity has been noted by previous authors, but no consensus has developed as to its root causes. De Jong (1983, Pg. 89) suggests that by using extra fortification in the construction of their whaling ships the British were able to leave port earlier in the season and start their hunt as the pack ice was just beginning to break up. The extra fortification was needed to protect against the severe spring weather and the heavy ice flows. By bearing the dangers associated with an early start to the season the British could stay on the hunting grounds longer and early in the season the whales were confined to narrow stretches of open water, which made them far easier to capture. In addition to the lack of open water, spring hunting was more productive for the British because they could capture whales which were weak from the lack of food supplies available over the winter, young and naive whales and nursing mothers and their calves.

Scorsby (1820, Pg. 115) noted the change in British productivity levels, but he claimed that it was not due to any technological innovation, but simply more intensive use of the available inputs and the greater skills of the British captains and sailors.

It is also possible that the British enjoyed higher productivity levels because they avoided many of the time consuming and costly precautions the Dutch were forced to adopt to protect themselves from foreign privateers who operated against them during times of war. Another potential explanation is that the Dutch were actively cooperating amongst themselves to conserve the eastern arctic stocks by refusing to take young whales or nursing females, while the British harvested every whale they had access to regardless of the age or sex.

Whatever the reason, the British captured an average of 3.138 whales per ship between 1733-1779. This is approximately equal to the Dutch catch per ship over the same period (3.522 whales per ship). However, after 1780 the British catch per ship increased dramatically. From 1780-1834 the average catch per ship for the British whalers was 5.432 whales per ship, or a 73.1% increase in capital productivity. Because costs were fairly constant during this period the increase in capital productivity represented an increase in revenue and rent per ship for the British whalers. This increase in economic profit was in spite of the declining stock of whales.

To determine whether high British capital productivity was responsible for their continued op-
eration of a commercial whaling industry while the Dutch industry shut down, we have performed a counterfactual experiment using our simulation model which increases the productivity parameters in the Dutch production functions so that the average Dutch catch per ship is equal to the average British catch per ship from the years 1780-1834. This requires increasing the parameter on the $yrs$ variable in the Greenland catch function from -0.0010 to -0.00065 and the parameter on the $yrs$ variable in the Davis Strait production function from -0.0054 to -0.00485. By altering the parameters in this way we have given the Dutch industry the average catch per ship that was enjoyed by the British during their period of rapid expansion and peak productivity.

With greater productivity levels the Dutch industry would not have shut down in 1803. Our counterfactual indicates that the Dutch would have continued to profitably exploit the Greenland and Davis Strait Bowhead stocks until they drove them to extinction in 1821 and 1861, respectively. If the Dutch had been able to match the British productivity gains at the end of the eighteenth century, they would have experienced slightly higher effort levels and substantially higher catch levels. The key to this counterfactual is that, even though catch levels would have increased substantially, the price level is depressed only slightly because it is closely tied to the price of its closest substitute, rape seed oil. This implies that rents are much higher for the Dutch industry in the high productivity counterfactual. The slightly higher effort levels and significantly higher catch levels would have led to the Dutch rapidly driving the Bowhead stocks to extinction, while maintaining positive levels of rent and effort. With higher productivity levels the Dutch, like the British, would not have abandoned the eastern arctic stocks prior to extinction. It appears that the key to the collapse of the Dutch industry and the extinction of the Greenland and Davis Strait stocks was the intensive British competition, which was successful due to high British capital productivity during the 1780-1834 era.

7 Conclusions

The stock of Bowhead whales off the east coast of Greenland and in Davis Strait were distinct from each other and from other Bowhead stocks in the Bering Sea. Dutch and British pelagic whalers hunted from these stocks, using inputs with fairly common and static characteristics, in the seventeenth, eighteenth and nineteenth centuries. During the early nineteenth century the
Dutch abandoned the industry, even though there remained a substantial stock of whales on the two main hunting grounds. The British, on the other hand, continued to hunt the Bowhead intensively until the stock was driven to the brink of extinction during the mid-1830s. Davis, Gallman and Gleiter and Scott have argued that prior to the introduction of steam powered locomotion, harpoon guns and factory processing ships humans were not able to permanently deplete a stock of marine resources, including whales. The Dutch pelagic whaling industry seems to support this view, but the British industry offers an example in which a single, geographically distinct stock was hunted to extinction using early whaling technology. In this paper we have argued that the key difference between the Dutch and British industries was not per unit input costs, output prices or subsidies. Only the difference between the Dutch and British productivity levels can explain the British whalers’ ability to profitably exploit the Greenland Bowhead after the Dutch whalers abandoned the industry.

Input employment, input prices and output prices were very similar in both the Dutch and British pelagic whaling industries. The similarities imply that these variables could not have been responsible for the different responses to declining stock levels observed from the Dutch and British industries. To study the effect of subsidy levels and productivity levels on the Dutch industry a simulation model has been constructed. This model employs a delay-difference recruitment model with a generalized logistic growth function to simulate population estimates for the Bowhead during the period of intensive exploitation. In addition to the population model, our model employs a system of equations which explicitly model the links between economic and biological variables characterizing the Dutch pelagic whaling industry. Twelve endogenous variables, on an annual basis, over the 143 year period of intensive Dutch exploitation were simulated. Counterfactual experiments investigating the impact of government subsidy levels and productivity levels on the longevity and profitability of the Dutch commercial industry were then performed. These experiments indicate that increased government subsidies would not have resulted in continued profitable exploitation of the Bowhead stocks by Dutch whalers. However, greater productivity levels would have allowed the Dutch to hunt the Bowhead to extinction, while maintaining a profitable commercial industry. Therefore, it appears that the greater productivity levels enjoyed by the British industry were responsible for its continued profitability in the face of rapidly declining whale populations, while low productivity levels were responsible for the Dutch industry’s decline. The British industry’s
relatively high productivity levels may have been due to more intensive input usage, technological innovations associated with extra hull fortifications, the avoidance of costly precautions taken by the Dutch to prevent losses to privateers, or the presence of cooperation amongst the Dutch whalers in an effort to conserve the resource they were harvesting.
Notes

1 Quoted in Smith, 1994, Pg. 53.

2 Gordon, 1954.

3 Davis, Gallman and Gleiter, 1997, Pg. 148. A more detailed discussion of the derivation of Davis, Gallman and Gleiter’s stock estimates can be found in Davis, Gallman and Hutchins, 1988, Pg. 594.

4 Scott, 1996, Pg. 31.

5 De Jong, 1983, Pg. 90 and De Vries and Van Der Oude, 1997, Pg. 265.

6 Proulx, 1986, Pg. 27.

7 Jenkins, 1921, Pg. 126.

8 Davis, Gallman and Gleiter, 1997, Pg. 31.

9 Jenkins, 1921, Pg. 139-140.


11 Scorsby, 1820, Pg. 72.

12 Ibid, Pg. 86 and De Vries and Van Der Oude, 1997, Pg. 264.

13 Vibe, 1967, Pg. 81-82 and De Jong, 1983, Pg. 90.

14 Exceptions to this rule included oil rendered from freshly butchered whales and spermaceti, obtained from the head of sperm whales. The higher quality whale oil earned a premium price. See Davis, Gallman and Gleiter, 1997, Pg. 30.

15 Davis, Gallman and Gleiter, 1997, Pg. 36-37.

16 Jenkins, 1921, Pg. 158-159.

17 Proulx, 1986, Pg. 35 and 55.

18 Stock models of this type are common in the fisheries literature. For examples see Bjorndal and Conrad, 1987 and 1997.

19 In this model stock refers to the number of adult whales over the age $\tau$.

20 Ross, 1979, Pg. 91 and Davis, Gallman Gleiter, 1997, Pg. 140.

21 Conrad, 1989, Table 1.
22Ibid, Table 1.


24Conrad, 1989, Table 1 and Amundsen, Bjorndal, Conrad, 1995, Pg. 173.

25Derived under the assumption that there were fewer than 1 000 whales remaining in these stocks when the British finally abandoned the grounds in 1911.

26Both Mitchell, 1977, and Braham, 1984, estimate that the Spitzbergen stock was made up of approximately 25 000 individuals in 1679.

27Our preferred parameterization indicates that in 1800 there were over 11 000 whales remaining in the Greenland stock and over 18 700 in the Davis Strait stock.

28The slow depreciation of the existing Dutch vessels was due to the unique characteristics of the Dutch whaling ships, which made it unprofitable to redeploy these vessels into other activities. See Clark, Clarke and Munro, 1979, for a discussion of the problems of irreversible investment in fisheries industries.

29Our preferred parameterization of the delay-difference stock model assumes that the British abandoned the Greenland hunting grounds only after there were fewer than 1000 whales remaining in the stock. De Jong (1983, Pg. 89) has suggested that the British hunted the Greenland Bowhead stock to complete extinction.

30All estimation results are available on request from the authors. All econometrically estimated equations used in our simulation model have been estimated independently using ordinary least squares.

31De Jong, 1983, Pg. 87-88.

32These parameters were positive in three of our four preferred effort function specifications.

33A Chow test confirms that a statistically significant structural break occurred in the estimated effort functions in 1760. P values for the Chow test are 0.00 for the Greenland effort function and 0.13 for the Davis Strait effort function.

34The parameter on the wage variable for the bone equation is not statistically significant.


36We have performed counterfactual experiments in which our inverse demand equations are adjusted to capture an increase in foreign demand in response to the elimination of the British whaling industry. Because the price for whale oil is closely tied to the price of rape seed oil, increasing foreign demand has only insignificant effects on the evolution of the endogenous variables we have simulated. We have not adjusted our inverse demand functions in the counterfactual experiments reported in this subsection.
Even in the absence of British competition the Dutch would have abandoned the Davis Strait stock in 1797. However, because there were no other substantial participants in the hunt on the Davis Strait ground, the removal of the British and the continued lack of Dutch effort implies that the Davis Strait stock could have recovered to near pristine stock levels by the turn of the twentieth century.

Scorsby, 1820, Pg. 156. Scorsby claims that there were additional costs associated with the longer, more dangerous voyage to the Davis Strait, totaling £250.

Ibid, Pg. 393.

Again, the additional cost of voyages to Davis Strait are quoted as being approximately 3 000 guilders.

For information on Dutch and British wages and prices see Allen, 1998.

For more details on the common techniques and technology, physical characteristics of the ships, supplies and provisions and the labour employment practices see Jenkins, 1921, Pg. 158, Ricard, 1781, Pg. 63-64, Scorsby, 1820, Pg. 392-93 or Davis, Gallman and Gleiter, 1997, Chapter 1.

De Vries and Van Der Oude, 1997, Pg. 264.

Ibid, Pg. 264-65.

For a detailed discussion of the British subsidy levels see Scorsby, 1820, Pg. 72-87.

We have performed the counterfactual experiment assuming that all Dutch vessels were 200 tons and 300 tons. The results from these counterfactuals are qualitatively similar to those reported here.

Jenkins, 1921, Pg. 131 and 137, mentions that the Dutch were forced to convoy to and from the Greenland hunting grounds each season to protect against hostile privateers.

The average Dutch catch per ship was 3.922 between 1780 and 1800.
References


