1997

The Impact of Technological Change on the Economic Viability of Individual Production Centers: The Case of the 1840-1880 British Ocean-Going Iron and Steam Shipbuilding Industry.

Daniel Stephen Allen
Louisiana State University and Agricultural & Mechanical College

THE IMPACT OF TECHNOLOGICAL CHANGE ON THE ECONOMIC VIABILITY OF INDIVIDUAL PRODUCTION CENTERS: THE CASE OF THE 1840-1880 BRITISH OCEAN-GOING IRON AND STEAM SHIPBUILDING INDUSTRY

A Dissertation

Submitted to the Graduate Faculty
of Louisiana State University and
Agricultural and Mechanical College
in Partial Fulfillment
of the Requirements for the degree of
Doctor of Philosophy

in

The Department of Geography and Anthropology

by
Daniel Stephen Allen
B.A., University of Georgia, 1979
M.A., University of Georgia, 1990
December 1997

UMI Number: 9820709

UMI
300 North Zeeb Road
Ann Arbor, MI 48103

ACKNOWLEDGMENTS

Acknowledging all the people who have contributed to this dissertation is a very difficult task. So many people contribute to an undertaking of this size that you can never come close to listing them all. At the same, and more significantly, words alone can not adequately express my appreciation. With that said, however, I will make an attempt.

First of all, I want to thank Deirdre and her family. Without their love and support, especially at the beginning, I would not have had the opportunity to pursue this degree. I do wish things had turned out differently, but they did not.

Next I want to thank friends, faculty, and staff at LSU. So many people in so many areas assisted me, from Middleton Library to the Graduate School. The help and insights provided by the members of my committee was invaluable and I want to acknowledge each: Dr. Carville Earle, Dr. Paul F. Paskoff, Dr. Richard H. Kesel, and Dr. James P. Geaghan. I also want to express my appreciation to Sandra Henderson, Ann Whitmer, and others in the Department of Geography and Anthropology who have been my friends and protectors for more years than I care to think about. And a special thanks goes to Dmitry Mesyanshinov, who found articles for me and spent a rainy Saturday afternoon at the computer with me.

The people who directly contributed to my research in Scotland deserve special attention. To start, I want to than Dr. Robert C. West and the West Fellowship he established that provided funding for me and many other graduate students in the department to conduct our fieldwork. Douglas and Rhona Walker provided a place to stay while in Edinburgh. Last, but by no means least, I want to thank the McClernon family; Pauline for putting me up and putting up with me during my weeks in Glasgow; and John and Mary for taking me into their home and, along with the rest of the family, for treating me like one of their own.

The US Army Corps of Engineers Waterways Experiment Station and its research staff have provided me the opportunity to complete this dissertation. Not only have facilities, resources, and time been made available to me, but my interaction with the people who have become my friends and colleagues has allowed me to continue to grow intellectually. My thanks go to Roger Hamilton, who first offered me the job and has since become my friend; Corine Pugh, who has looked after me during my recent bout of "dissertationitis;" and Darrell Evans, who has allowed me to talk through too many methodological problems. Special thanks, however, go Eddie Melton and Bart Neal: both have given unlimited help in the preparation of the illustrations in this dissertation; have straightened out a multitude of hardware, software, and operator glitches; and still talk to me.

But most importantly, I have to thank the Drs. Veeck and family. Our friendship goes back many years, long before Dr. Veeck ever became my major professor. I want to thank Greg for his patience and perseverance, Annie for her encouragement and support, and Sarah and Robin for allowing me time with their father on weekends. If this dissertation is dedicated to anyone, it is dedicated to them.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

This dissertation examines the relationship between technological change and spatial industrial restructuring through a case study of the 1840-1880 British ocean-going iron and steam shipbuilding industry. The study tests the hypothesis that a shipbuilding center's share of the national British shipbuilding market was associated with its ability to generate or rapidly adopt technological change.

The study begins by establishing iron steamship technological changes introduced by British shipbuilders and the industry's attendant spatial restructuring. It then develops two site-specific variables: industrial viability and innovative ability. Data for both variables are obtained from the Lloyds Register of British and Foreign Shipping. The industrial viability variable ranks each shipbuilding center's annual share of the total national shipbuilding market in terms of its being a high, medium or low market share center. Innovative ability establishes each center's level of technological sophistication, in terms of either a technological leader or laggard, based on significant component technologies. These technologies are identified through a series of multiple regression models which, in addition to identifying significant technologies, allow for the testing of key assumptions in the historical literature regarding 1840-1880 British iron steamship technological change.

The relationship is assessed by testing for a statistical association between the industrial viability and innovative ability rankings using contingency tables in conjunction with the chi-square statistic. Additional analysis includes measurement of the strength and direct of the association and identification and assessment of individual table cells that make significant contributions to the overall chi-square statistic.

The results demonstrate that industrial viability and innovative ability were associated. Further, the association was positive, although weak to moderate, indicating that innovative ability, while important, was not a precondition for an 1840-1880 shipbuilding center's industrial viability. Also, small shipbuilding centers that produced small, technologically lagging ships for the British coastal trade made a significant contribution to the association. These findings suggest that other considerations, such as access to markets, initial advantages, and factor inputs were as important as innovative ability in explaining the industry's spatial restructuring.

CHAPTER I

INTRODUCTION

The spatial industrial structure of the United States and other industrialized countries is undergoing significant changes. This restructuring process is characterized by the shift of manufacturing activity from established industrial core regions to new, formerly peripheral regions. Regional economists argue that these shifts are caused by the peripheral regions' greater capacity for generating or adopting new products and production processes, or technological changes. Following their lead, local economic development agencies have implemented industrial recruitment policies that attempt to attract what are perceived to be innovative firms and industries. These firms and industries, in turn, will serve as growth poles in attracting related support industries and other innovative firms.

Such policies implicitly assume that the more innovative an industrial center is, then the greater will be its regional and, by extension, local economic viability. While economic geographers have examined this restructuring process, they have not directly investigated the relationship between innovation and local economic viability. Two reasons for this can be identified: first, economic geographers do not examine technological change directly; and, second, they conduct their research at regional or national scales that obscure the performance of individual places.

This dissertation assesses the impact of technological change on industrial locational viability by examining the relationship between innovation and place. This is accomplished through a case study of the 1840-1880 British deep-water iron and steam shipbuilding industry. During this period, British shipbuilders perfected iron ship construction and steam propulsion, developments which, according to British shipbuilding historians, also rearranged the industry's spatial structure. Obviously, industrial restructuring is a complex process and many different conditions and forces interact to result in the emergence of new places. This study recognizes this complexity from the outset but, still, will focus on the importance of technological innovation in this process.

This study hypothesizes that innovative shipbuilding centers enjoyed a competitive advantage over non-innovative shipbuilding centers. The hypothesis is tested by: a) assessing each shipbuilding center's annual market share of production to establish its industrial viability; b) using the independent variables derived from multiple regression analysis to rank the innovative ability of individual shipbuilding centers, in terms of technological leaders or laggards, for each year they were in production; and c) exploring the association between established levels of industrial viability and innovative ability through the generation of contingency tables used in conjunction with the chi-square statistic.

This study makes two contributions to the sub-discipline of economic geography. First, it presents a dynamic analytical framework that investigates spatial industrial restructuring induced by technological change using actual changes in technologies rather than changes in employment or other intermediate measures. Second, it reincorporates the individual industrial center, the level most effected by these changes, into studies of regional and national restructuring.

1. TECHNOLOGICAL CHANGE AND SPATIAL RESTRUCTURING

One consequence of the spatial restructuring process over the past thirty years has been the decline of manufacturing activity in traditional industrial regions coupled with manufacturing growth in formerly peripheral regions (hUallacháin, 1990; Wijers, 1985). Using the United States as an example, industrial restructuring has been characterized by the migration of manufacturing employment out of the old Manufacturing Core and into the southern tier of US states, the Sunbelt, if not out of the country altogether (Berry, Conkling, and Ray, 1997; Hanink, 1993; Johnson, 1989; Rees and Stafford, 1979; Souza and Stutz, 1994; Weinstein, Gross, and Rees, 1985).

Many regional development specialists argue that the spatial restructuring process has been caused by the failure of the traditional manufacturing core regions to generate, or rapidly adopt, technological change. According to this explanation, the traditional manufacturing regions once served as innovation seed-beds, areas from which product and process innovations, technological changes, originated and then diffused to peripheral regions (Rees, 1979; Norton and Rees, 1979). These regions, simply put, are no longer competitive with the periphery because they do not generate or adopt technological changes at the same rate as do industries in the emerging growth regions (Wijers, 1985; Bailey and Chakrabarti, 1988).

This interpretation follows from economists who argue that scientific advance and technical change are necessary prerequisites for economic growth (Rothwell and Zegveld, 1981). Based on the works of Schumpeter (1935) and Kuznets (1930), these economists define technological change as the process of invention, innovation, and diffusion (or imitation) which brings about productivity growth. Technology is considered to incorporate physical tools and social processes, as well as the changes in these tools and processes--technological change--which bring about productivity growth. Productivity growth improves production efficiencies which, in turn, leads back to greater increases in productivity growth (Berry, Conkling and Ray, 1997; Link, 1987).

Based on this interpretation, regional scientists and economic geographers, especially the regional development specialists Hamilton and Linge (1983), argue that technical innovation is the source of economic growth and regional economic change. Following this line of reasoning, regional planners have implemented industrial development policies that attract innovative industries. These development strategies, which are referred to as innovation-oriented as opposed to growth-oriented (Stöhr, 1986), attempt to attract industries with higher than average rates of technological change. Once these innovative industries are in place, they foster agglomeration through backward and forward linkages, thus promoting industrial competitiveness and stabilizing regional employment (Fusi, 1990; Sweeney, 1987; Tsongas, 1981).

The implicit assumption behind these policies is that there is a direct and positive relationship between technological change and a production center's continued industrial viability. Unfortunately, neither the nature nor extent of the relationship between innovation and place has been appropriately tested. This lack is especially glaring in the sub-discipline of economic geography, which is ill-equipped to address issues of technological change-induced spatial restructuring because of methodological limitations and problems associated with specifying models of technological change. These difficulties are further complicated by issues of scale and theoretical constraints.

In the first instance, geographers make no attempt to examine directly technological change. By invoking the economist's black box, geographers equate innovation with a product's perceived degree of technical sophistication (Delaney, 1993), the number of patents granted to individual firms (Ceh, 1997), or an industry's rate of employment growth (Barkley, 1988; Norton and Rees, 1979). Unfortunately, these approaches serve as surrogate measures and do not actually measure technological change. The second problem with current geographical analyses of technological change concerns issues of scale and theory. Neo-classical industrial location theory, because of its concern with locationally-specific factors, would seem to provide a suitable analytical framework (Smith, 1980; and Rees and Stafford, 1986). However, its analytical techniques hold technology constant, effectively eliminating consideration of technological change. Structuralist industrial location theory, despite its concern with the dynamics of change within larger economic spatial systems (Massey, 1979a and 1979b; Massey and Meegan, 1979), precludes consideration of specific industrial centers and technological change across actual places and time.

The technological change induced spatial restructuring process can not be understood until the relationship between technological change and the competitive ability of particular places is clarified. The question that needs to be examined, then, is whether or not the individual production center's ability to generate or rapidly assimilate new products or production processes enhances that center's ability to compete successfully with other production centers. Answering this question requires an analytical framework that, first, develops a method to measure technological change at individual production centers and, second, relates this measure to the changes in the market share of these centers within the context of larger spatial industrial systems.

2. TECHNOLOGICAL CHANGE AND THE NINETEENTH CENTURY BRITISH IRON AND STEAM SHIPBUILDING INDUSTRY

This dissertation investigates the relationship between innovation and place through a case study of the spatial restructuring of the 1840-1880 British iron and steam shipbuilding industry. This industry and time period have been selected for study for three reasons. First, shipbuilding analysts consider technological change to be both the initiator of, and a key determinant in, this industry's periodic relocations (Harrison, 1983; Todd, 1985). Second, between 1840 and 1880, British shipbuilders perfected iron ship construction and marine steam propulsion and, in so doing, revolutionized ocean transport (Gilfillan, 1935). Third, and more importantly from a geographical perspective, the new ship technology relaxed the industry's traditional locational constraints and altered the industry's spatial structure from the national to inter-regional geographic scales (Pollard and Robinson, 1979).

In the late 1830s, British shipbuilders introduced iron construction and steam propulsion into ocean-going ships. The new ship technologies were then perfected during a forty year innovation cycle that lasted until 1880, when steel construction and the quadruple expansion steam engine initiated a new cycle (Brock and Greenhill, 1973; Rowland, 1971; Waine, 1976; Abell, 1981). As early as 1872, Britain dominated the global iron-steamship market and, despite the fact that other national shipbuilding industries were clearly capable of building iron steamships, its dominance remained unchallenged until 1918 (Jones, 1957; Pollard, 1957; Pollard and Robinson, 1979).

2.1. Iron and Steam Shipbuilding Technological Change

Shipbuilding historians argue that Britain's early lead in the development of the iron steamship was a result of the nation's early start in the industrial revolution. The superiority of the British iron and mechanical-engineering industries conferred comparative advantages in these technologies and, with the growth of the nation's merchant marine, created demand and supply feedback loops between the shipbuilding, shipping, iron and steel, and mechanical-engineering industries. Innovations in each of these industries dramatically raised the technical efficiency and economic productivity of the ship and accelerated the innovation process (Gilfillan, 1935; Thornton, 1959; Hughes and Reiter, 1958; and Moyse-Bartlett, 1968).

Iron was introduced as a shipbuilding material in the late eighteenth century. Experiments with iron shipbuilding were stimulated by increasing difficulties in obtaining suitable timber for ships combined with declining iron prices created by technological changes within the iron industry. As shipbuilders gained experience with the new material, iron proved to be both stronger and more weight-efficient than wood. Coupled with new hull forms and new ship designs made possible by iron construction techniques, ships became ever larger and more cargo efficient throughout the study period. By 1880, when the industry began to replace iron with stronger and lighter steel, modern construction systems, hull forms, and ship designs were in place.

Although experiments with steam propulsion occurred simultaneously in both Britain and the United States, British shipbuilders were installing steam engines in iron hulls by the early 1820s, and iron steamships successfully crossed the Atlantic Ocean under continuous steam power in 1838. These ships demonstrated the practicality of the new ship technology as an ocean-going cargo carrier. A series of improved engine designs, steam boilers and condensers, and propulsion systems was introduced and improved upon over the next forty years. The marine steam propulsion systems in place by 1880 remained the industry standard until the introduction of the marine diesel engine at the beginning of the twentieth century.

2.1.1. Ship Changes

By 1850, the new ship technologies had been accepted by the shipping industry, and by 1872 the British iron steamship was the accepted world standard. Innovations between 1840 and 1880 were directed toward increasing ship size and power. By 1880, when steel construction and the multiple expansion engine introduced a new innovation cycle, modern ship construction techniques, propulsion systems, and ship designs were essentially established (Jones, 1957; Musson, 1978; Pollard and Robinson, 1979; Whitehurst, 1986).

These changes can be seen in the following illustrations which document the evolution of the iron and screw steamship during the study period. Figure I-1 shows the

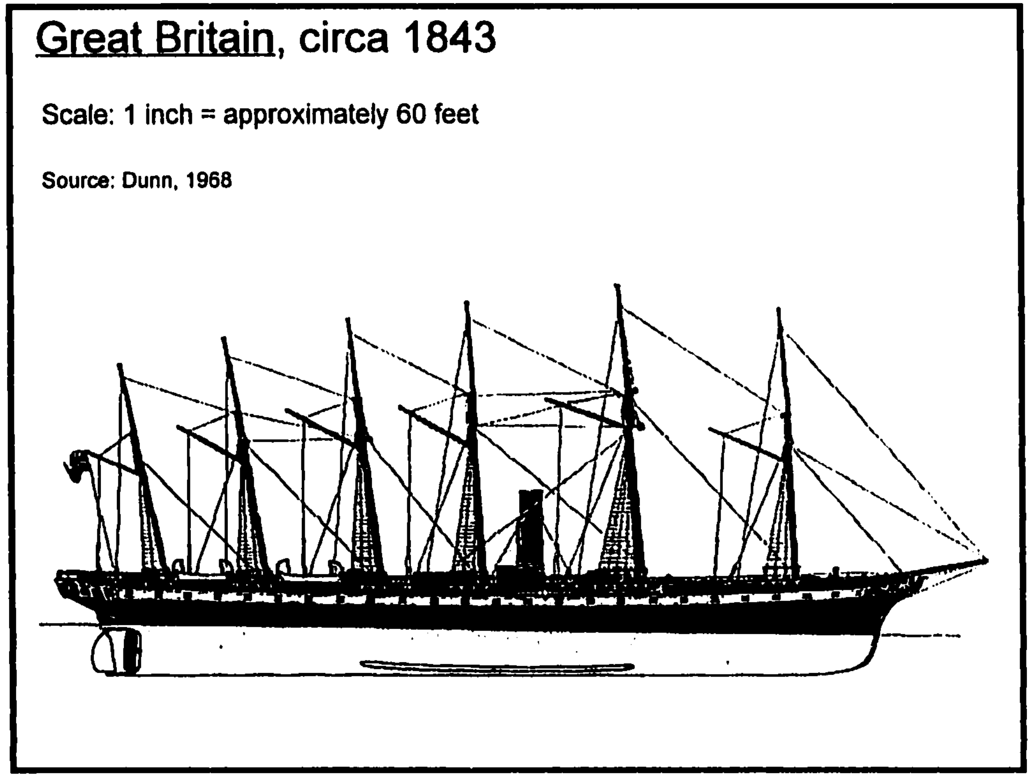


Figure I-1: Great Britain, circa 1843

Great Britain, built in Bristol, England and launched in 1843. This ship, 289 feet long and 50 feet wide, was the largest ship built up to that time. It was also one of the first iron and screw-propelled liners designed to carry passengers, mail, and high value freight between Europe and North America (Rowland, 1970; Gilfillan, 1935; Cunningham, 1903). As indicated by the lines of the bow and stern, the ship was designed like a wooden sailing ship, and its six rigged masts demonstrate its capability to raise sail in case of engine break-down or to conserve coal if favorable winds allowed.

By 1879, the packet liner had evolved into the Pacific and Oriental Line's Oriental (Figure I-2), the largest and most powerful ship of her day. Differences between this ship and the Great Britain are striking. Most apparent is the Oriental's greater size, made possible by advances in both iron construction and marine steam engine technology. Also, the fewer number of masts and minimal rigging indicate that sails could be raised in an emergency to maintain headway, but the arrangement of the masts and rigging reflect their primary use as cargo booms.

Although less romantic than the great packet liners, the contribution of small coastal steamers and colliers to the new ship's acceptance by the shipping industry was even more significant (Hughes and Reiter, 1958). The ship in Figure I-3 is a traditional wood and sail collier, built on the English North East Coast to haul coal from the region's coal fields to London and northern European ports (Abell, 1981; Waine, 1976). These ships had two drawbacks: first, they could not sail against contrary winds and tides; and second, they had to make their return voyage in ballast. The first iron and steam collier, similar to that in Figure I-4, was the John Bowes built by Palmers of

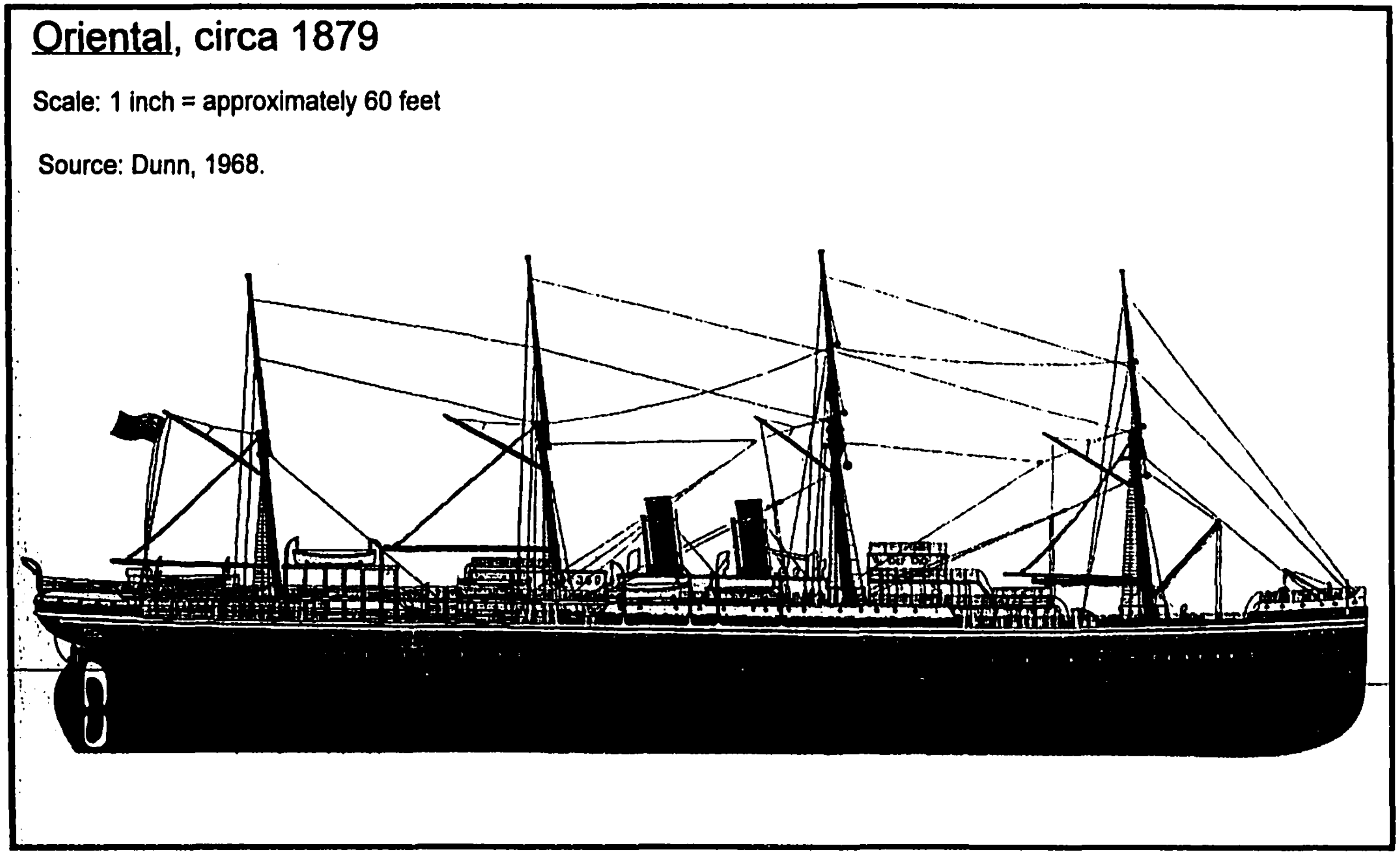


Figure I-2: Oriental, circa 1879

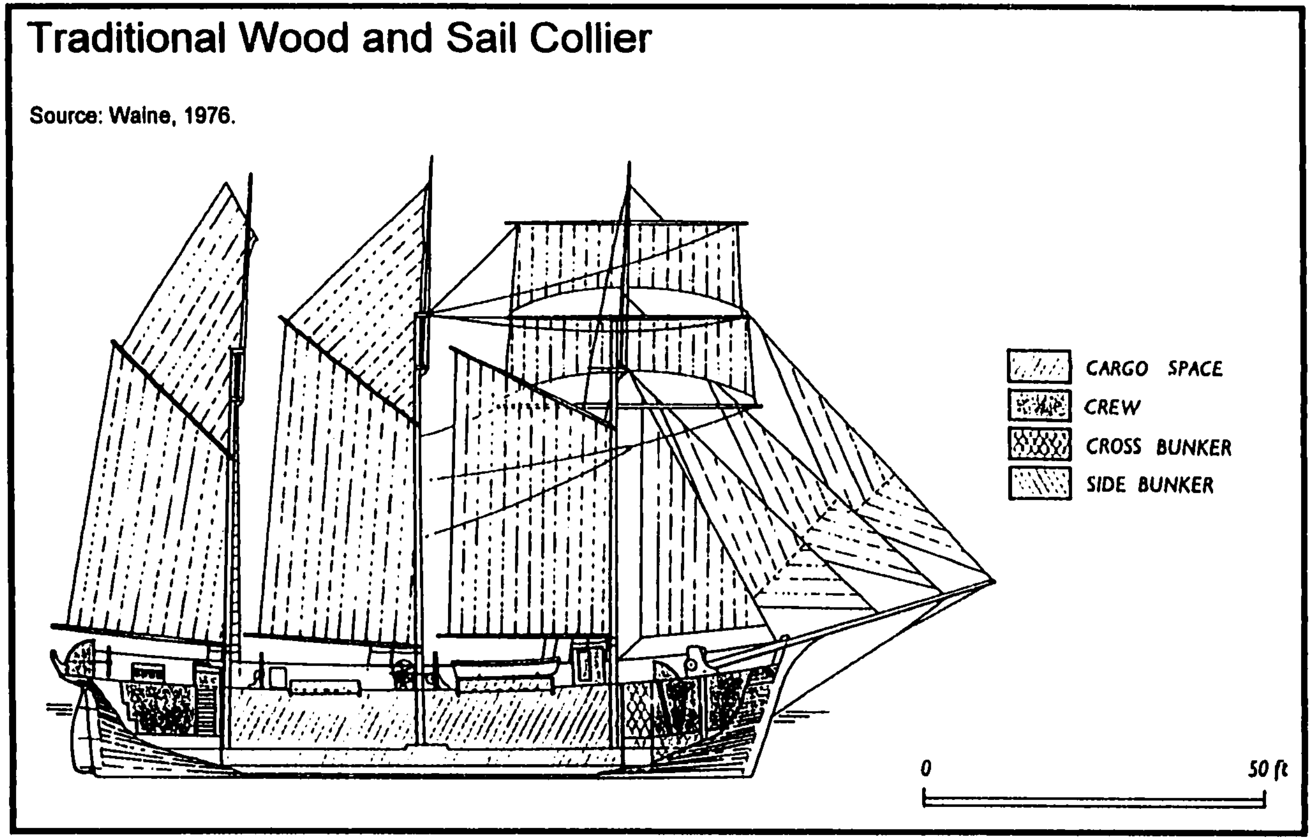


Figure I-3: Traditional Wood and Sail Collier

Early Iron and Steam Collier, circa 1852

Source: Waine, 1976.

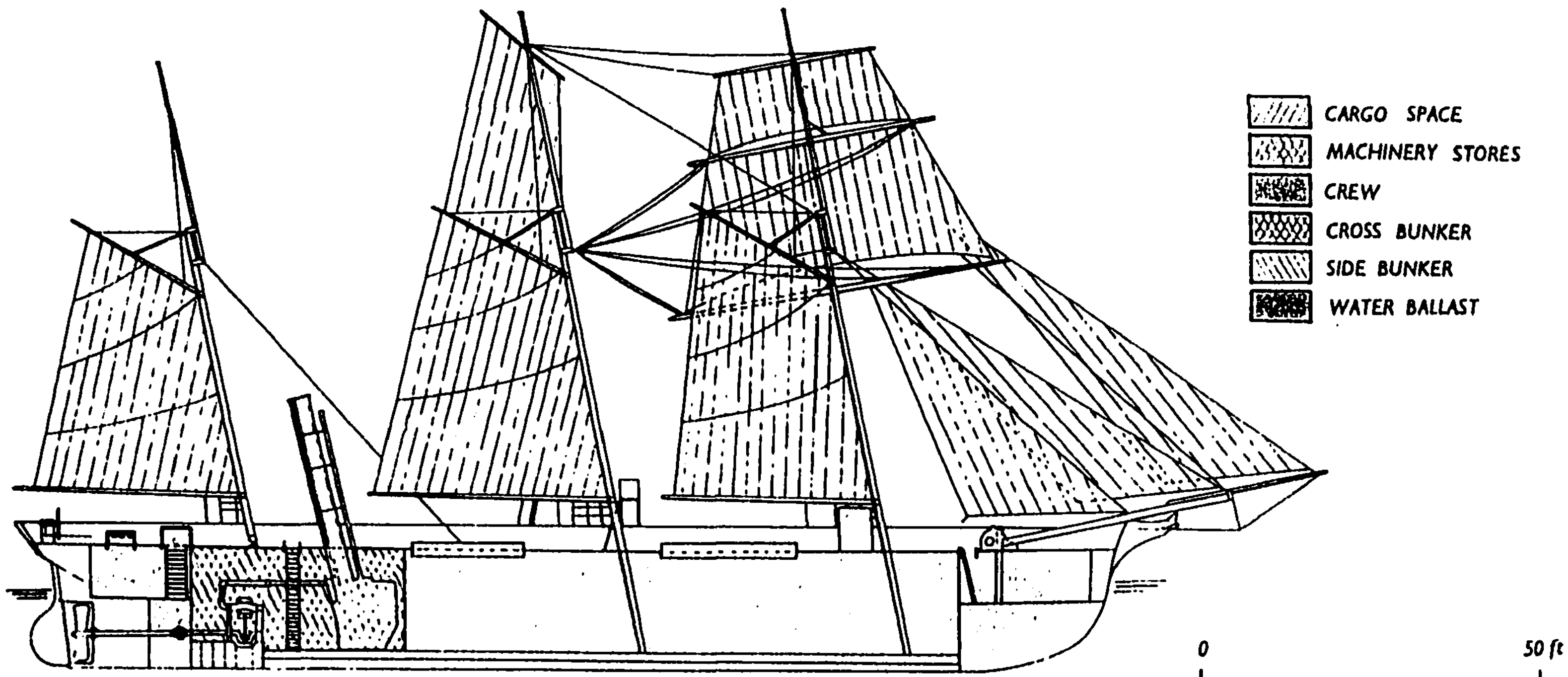


Figure I-4: Early Iron and Steam Collier

Newcastle in 1852. Use of the steam engine meant that cargo ships were no longer forced to stay in port because of contrary winds and tides. Iron construction, in addition to permitting larger ships, allowed for the fitting of water ballast tanks for stabilizing the ship's trim when sailing without a cargo. Both changes meant that the same ship could make many more voyages per year and that those voyages could be scheduled, which revolutionized both the collier and coasting trades (Abell, 1981; Dougan, 1968; Waine, 1976).

By 1880, the coastal steamer had evolved into the tramp steamer, shown in Figure I-5. This particular ship, though built in 1890, is representative of circa-1880 coaster/colliers and incorporates such modern features as cut down rigging and a raised quarterdeck. These features are characteristic of modern ocean-going cargo ships. Their appearance by this date illustrates both the greater reliability and power of the 1880 marine steam engine compared to that of 1840, and the fact that modern ocean-going cargo carriers evolved during the 1840-1880 period.

2.2. Spatial Change in British Shipbuilding

One practical effect of the adoption of the iron steamship was that it completely altered the spatial structure of the British shipbuilding industry. Before 1840, shipbuilding was constrained to locations with suitable river-frontage and proximity to raw materials and markets. These constraints favored rivers in the south of England, with the largest concentration of shipbuilding firms and shipyards found on the rivers Thames and Solent (Figure I-6). Tools and equipment were negligible, construction methods primitive, and little capital was required for entry. As a result, the industry was

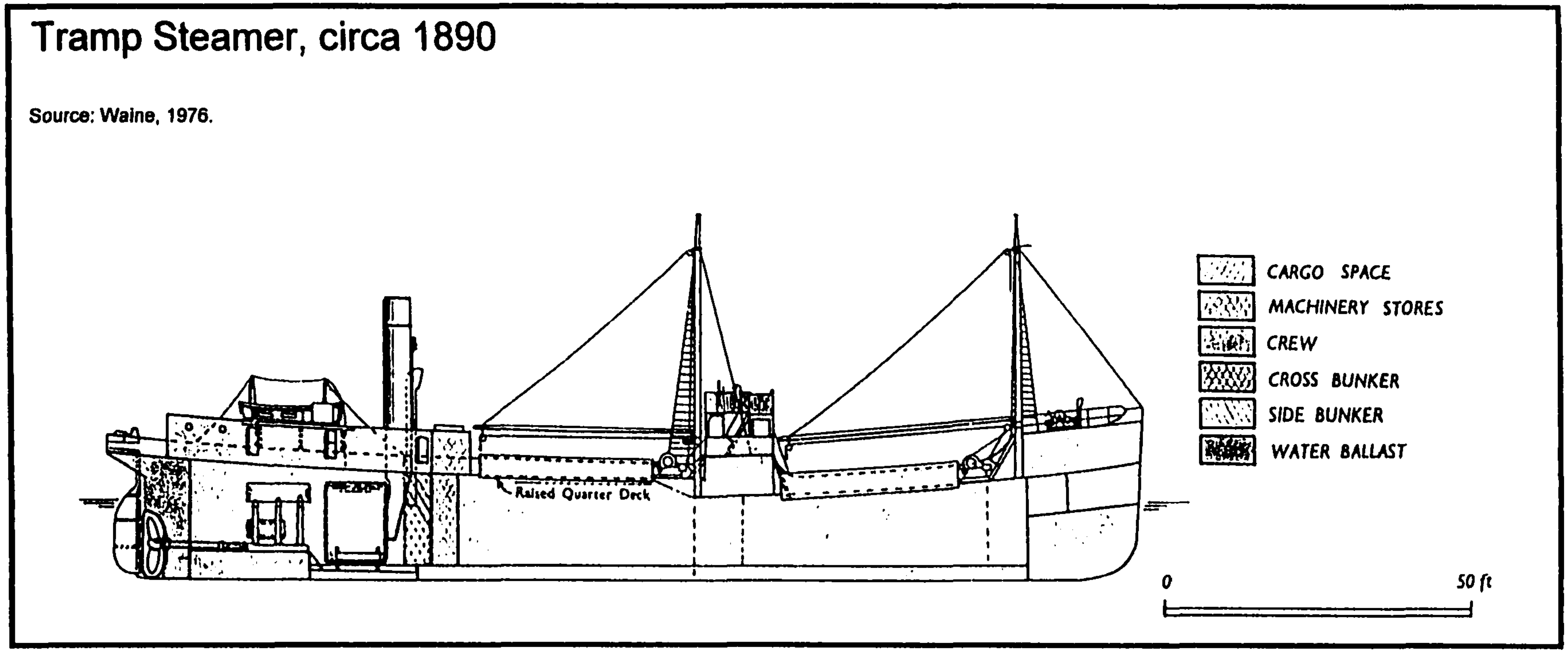


Figure I-5: Tramp Steamer, circa 1890

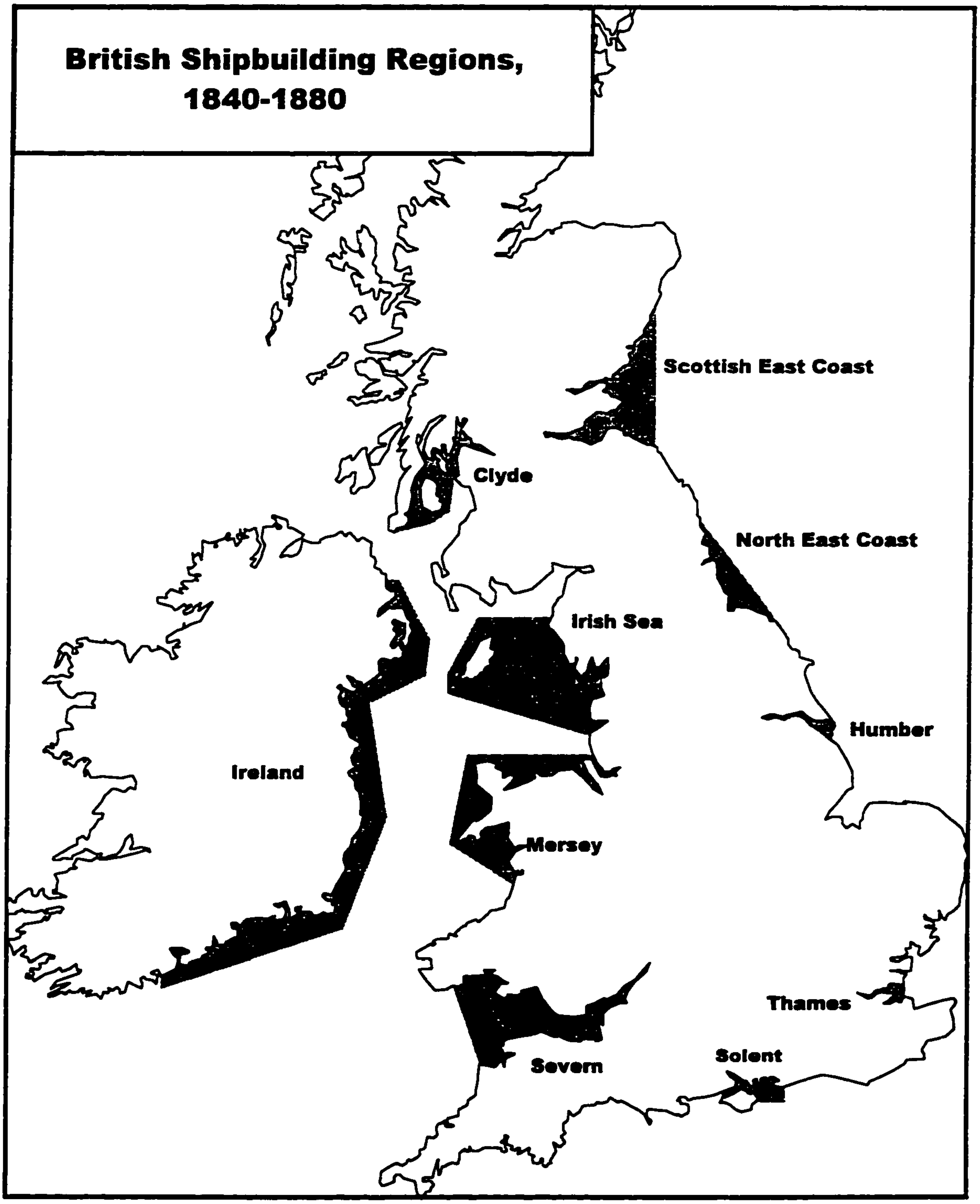


Figure I-6: British Shipbuilding Regions, 1840-1880 made up of a large number of highly competitive, small-scale producers characterized by relatively easy entry and exit (Jones, 1957; Pollard and Robinson, 1979).

After 1850, when iron replaced wood, the industry's scale and complexity changed. As ships got larger, the construction process became more complicated and required more space and capital. Shipbuilding shifted from an industry of small handicraft firms to large, highly capitalized firms with large labor forces of semi-skilled machine workers, laborers, and craftsmen using complex power tools. Not only did the scale and complexity change, but shipbuilding activity experienced a profound spatial re-orientation toward the iron and mechanical-engineering industries located on northern rivers: the most famous being the Clyde; and the Tyne, the Wear, and the Dees on the English North East Coast.

The growth of Scotland's Clyde-side industry (Figure I-6) has been attributed to the joint ventures of shipowners and boiler makers. On the Clyde, many shipbuilders began their careers as boilermakers and continued to rely on spatial proximity and industrial linkages with iron manufacturers and mechanical engineers. From the outset, the Clyde region's shipbuilders drew upon the external economies associated with the region's iron, mechanical-engineering, and shipping industries to develop reputations for highly efficient marine steam engines, boilers, and propulsion machinery (Bremner, 1969; Robb, 1958; Turnock, 1982; and Walker, 1984).

England's Northeast Coast was already an established wooden shipbuilding region, but a new market for colliers and other bulk cargo vessels gave the region's industry new life. The new iron and mechanical-engineering industry formed the nucleus around which the iron and steam shipbuilding industry developed (Waine, 1976). Although the first iron steamship was not built until 1850, the region's shipbuilding enterprises established solid reputations for their screw propulsion systems, cargo ship designs, and marine engines (Pollard and Robinson, 1979; Dougan, 1968; Smith and Holden, 1953).

The standard explanation for the growth of the British shipbuilding industry and shipbuilding centers implies a positive relationship between technological change and industrial locational viability. This interpretation, while intuitively appealing, is also misleading because it is based on interpretations of the post-1880 performance of the national shipbuilding industry and dominant post-1880 shipbuilding centers. All British shipbuilding centers did not, in fact, benefit from the new technologies. For example, London and Liverpool (Figure I-6) were routinely recognized as the dominant centers in the traditional wood and sail-based shipbuilding industry, but these centers did not survive the 1840-1880 period. Both cities, however, developed reputations as innovative iron and steam shipbuilding centers: London enjoyed a reputation for her innovative marine engineers and naval architects and pioneered twin-screw propulsion systems and machined boiler and engine parts. Liverpool's reputation was based on fast paddle steamers while Birkenhead, across the Mersey from Liverpool, was known for innovative warships. But, despite their renown, these cities declined in terms of gross production and market share during the 1840-1880 period because of factors unrelated to innovation, such as high labor costs, congestion, and a lack of cheap and readily accessible iron supplies (Banbury, 1971; Pollard, 1950; and Pollard and Robinson, 1979).

The fortunes of these British shipbuilding centers and regions reveal two contradictions in the assumptions that link technological change and place. First, as the London and Liverpool industries demonstrate, innovative ability need not necessarily guarantee industrial viability. Second, local industrial changes are caused by the net effects of growth and decline within a spatial system's individual production centers.

3. ANALYTICAL FRAMEWORK

One of the purposes of this study is to introduce an analytical framework that reconciles the consideration of structure and place in industrial locational analysis. As the above overview indicates, both economic structure and locationally specific attributes of particular centers operated to reconfigure the British shipbuilding industrial landscape: nineteenth-century technological changes were both introduced by shipbuilders and imposed on them by changes in world shipbuilding and related industries. What is needed, therefore, is an analytical framework which evaluates the effects of technological change on locational viability using both Structuralist and neo-classical techniques. Although these two theories are often presented as antithetical, spatial restructuring over time and space is the culmination of changes initiated at and imposed upon each and every location within an industrial system. Therefore, their apparent conflicts may be circumvented if analysis is conducted at multiple scales.

This study treats innovative ability as a locationally specific capacity for generating or rapidly assimilating innovations, while industrial viability specifically refers to a center's growth or stability, in terms of share of total gross tonnage output vis-a-vis the larger industrial system. The large scale-factors of time--the technological cycle--and space--the individual components of the industrial system--form the framework within which the locationally-specific variables of innovative ability and industrial viability are positioned. This framework allows for analysis of the technological performance of any center within the industrial system at any time during the technological cycle.

This study is not concerned directly with steamship productivity or efficiency gains associated with technological change. Rather it assumes that innovation and adoption are a response to efficiency and productivity gains and that their continued use in the modern merchant ship sufficiently establishes the case for their superiority. Nor is the study concerned with the original rationale for adopting these technological changes: it is assumed that each shipbuilder's decision to adopt a particular technology reflects a rational assessment of the prevailing economic situation, both within the shipyard and the industry as a whole.

4. METHODOLOGY

The relationship between technological change and locational viability is assessed by testing the hypothesis of a positive association between a British shipbuilding center's industrial viability and its innovative ability. Functionally, industrial viability is defined as a center's annual market share of total national shipbuilding output, while innovative ability is defined as a shipbuilding center's role as a technological leader or laggard.

The test of this hypothesis requires three steps. First, the industrial viability of each individual shipbuilding center for each year it was in production is determined by calculating its share of total national output for that year. The data on shipbuilding output are obtained from the Lloyds Register of British and Foreign Shipping. The Register is an annually published listing, beginning in 1834, of all ships inspected and certified by its ship surveyors. Once the individual ship data for each firm are aggregated by center, each production center's annual output is categorized as either a high, medium, or low production center. Based as it is on total annual tonnage output, this ranking reflects the center's competitiveness within its industrial system for each year that the center contributed a ship to the Register.

The second step establishes the innovative ability of each center through the derivation of a synthetic measure of component technologies which differentiates technologically leading and lagging iron steamships. This is accomplished in the following manner. First, a series of multiple regression models, one for each of four shipbuilding cycles, are specified to identify significant component iron steamship technologies (independent variables) that contributed to a ship's register tonnage (the dependent variable). Next, the significant set of component technologies for each ship are ranked and assigned a value ranging from one (lowest) to five (highest), based on the range of values for each variable. Each value is then summed to develop a score of each ship's level of technological sophistication. Finally, each center's annual status as technological leader or laggard is established by summing the score for each ship built at the center during a given year and assigning centers with scores above the mean to the rank of high (technological leader) and below the mean to the low rank (technological laggard). The data are obtained from the Register.

The last step in this analysis connects the industrial viability and innovative ability measures to investigate the relationship between innovation and place. The test is carried out using contingency tables in conjunction with a chi-square test statistic. Each center's industrial viability and innovative ability rankings are combined to produce four three-by-two contingency tables, one for each shipbuilding cycle. The chi-square statistic is then calculated to test for the presence of an association between innovation and place.

5. CONTRIBUTION OF RESEARCH

Changes in regional US manufacturing employment have raised concerns over an apparent lack of innovative ability in the world's industrial countries and the effects of this lack on the economic viability of established industrial centers and regions. These concerns are based on the implicit assumption that industrial viability is related to innovative ability, or the ability to generate or rapidly adopt technological change. At the same time, the literature on technological change, capitalist growth, and spatial industrial restructuring, all of which attempt to examine technological change, ultimately fail to examine this relationship because it does not deal realistically with the spatial aspects of the restructuring process. Instead, this literature often obscures our understanding of the impact of technological change on the individual production center because it obscures the interaction between structure and place. Hopefully, this analytical framework will provide us with greater insight into the problems facing production centers during periods of technologically-induced spatial industrial restructuring and help in the formulation of strategies that anticipate, rather than react, to change.

This study of the relationship between innovative ability and locational viability operates at two levels. First, it presents an analytical framework which reconciles the broad macro-scale concerns of the new economic development theories with the place-specific focus of the more traditional regional scientists. This framework is presented in a locational analysis of the technological change-induced spatial industrial restructuring that accompanied British development of the iron steamship which tests the assumption that locational viability is dependent upon a location's innovative ability. Understanding this relationship is fundamental to understanding not only the nineteenth-century restructuring of the British ocean-going iron and steam shipbuilding industry, but the spatial shifts in industrial activity occurring today.

At a broader level, this study seeks to incorporate place into considerations of spatial industrial restructuring. Although the current round of industrial restructuring has raised the issue of innovation and industrial viability, concern over theoretical issues has obscured the relevance of place in economic geographical analysis. While geographers have examined the relationship between technological change and industrial regions, few have examined the relationship between innovative ability and the individual production center--the place where innovations emerge and where spatial changes are most directly felt. In short, this study seeks to understand the interplay of structural and locational forces. This "squaring of the theoretical circle" is needed if more realistic models of the spatial restructuring process and more effective locational analytical techniques are to be developed.

CHAPTER II

LITERATURE REVIEW

The previous chapter introduced the argument that current studies of technological change-induced spatial industrial restructuring are inadequate because they fail to explicitly examine an important underlying assumption. This assumption is that the greater an industrial center or region's ability to initiate or rapidly assimilate innovations, then the greater its economic viability which translates directly as success in the market. Further, two reasons for this shortcoming were provided: First, economic geographers do not directly measure technological change; and, Second, they have not related technological change to the viability of individual production centers.

This chapter extends this argument through a review of the technological change literature which directly informs this research effort. This literature intersects the fields of economics, economic history, and economic geography. It begins by defining technological change and discusses the ground breaking work of two economists, Simon Kuznets and Joseph Schumpeter. These scholars have had a profound influence on the understanding and analysis of technological change and its relationship to economic growth. Indeed, their work has framed scholarly research into technological change and economic growth for much of the past sixty years. Next, the chapter examines the historical and historical-economic literatures on technological change in mid- to late-nineteenth century British shipbuilding and the industry's spatial restructuring. Finally, it surveys the literatures of regional science and economic geography that deal with theoretical, analytical, and methodological issues associated with technological change and the spatial analysis of the effects of technology on industrial location.

1. TECHNOLOGICAL CHANGE

This chapter will first define technological change and examine the contributions of the two individuals who have made the greatest contribution to research in technological change and economic growth. It begins by precisely establishing what is meant by technological change and the related concepts of invention and innovation. It then discusses the work of Simon Kuznets and Joseph Schumpeter, the two scholars who have provided the greatest insights into the relationship between technological change and economic growth. Their contributions are then contrasted in order to demonstrate how their views have influenced the analysis of technological and spatial economic change.

1.1. Definitions and Concepts

Technology is written or unwritten human knowledge applied in production (Rossegar, 1986) and is the physical representation of that knowledge manifested by either physical tools or social processes (Link, 1987). Usher (1954) viewed technology as being the result of an innovation, and an innovation as the result of an invention (the emergence of "new things" requiring "act of insight" going beyond the exercise of technical or professional skills). Accordingly, Mansfield (1968) regarded technological change as the advance of technology, often taking the form of new methods for producing existing products; new product designs with important new characteristics; and new techniques of organization, marketing and management. These technological advances bring about productivity growth, which improves production efficiency, which in turn leads back to higher productivity growth (Link, 1987).

1.2. Kuznets and Schumpeter on Technological Change

Although the classical economists, from Smith to Marx, recognized the importance of technological change, interest in the subject languished among economists until the 1930s. During this decade, two economists, Simon Kuznets and Joseph Schumpeter, began work that has profoundly influenced scholars interested in technological change and spatial economic growth and change. Both individuals considered technological change to be the primary cause of economic growth, and both identified technological change as the primary cause of regular, periodic cycles of economic growth and decline.

1. 2.1. Simon Kuznets and Joseph Schumpeter

Simon Kuznets (1930, 1940, 1962) and Joseph Schumpeter (1939, 1950) both argued that ceaseless change was the dominant characteristic of the modern economic system and that technological change was its primary cause. Both also argued that neo-classical analytical methods incorporating assumptions of stable systems, or equilibrium conditions, were unsuited to examine this change.

Kuznets believed that regional and national disparities in economic growth rates were caused by differential rates of growth among industries. These disparities were due to the positive effects of technological changes on a succession of leading industries coupled with the impediments to growth created by older industries for which the greatest benefits of technological advance had been realized. Technological change is realized within an industry following the introduction of an invention. The invention is endogenous to the industry but stimulated by population growth or demand. The industry experiences rapid growth as the original invention is perfected through a continuous process of innovation. However, vigorous expansion eventually slows because the rate of technical progress slackens; slower growing industries retard faster growing, but complementary, industries; the relative amount of funds available for expansion decrease as the industry expands; or the growth of an industry in one country is retarded by competition from the same, but rapidly expanding, industry in another country. This results in the decline of the industry and the regions dependent upon that industry. In this sense, Kuznets' work was explicitly spatial.

Joseph Schumpeter (1939, 1950) also maintained that technological change was the driving force behind capitalist growth because it produces regular and period economic revolutions that greatly increase economic growth. These economic revolutions are caused by radical technological changes that are exogenous to the industrial system and that are introduced by new firms during depressions in an attempt to improve their competitive position. For Schumpeter, technological change is a disequilibrating mechanism rather than the series of adjustments to the equilibrium production function as maintained by Kuznets and especially Salter (1960): the new innovations create entirely new production functions as factors of production are shifted out of the old and into the new techniques. As an innovation diffuses and techniques are standardized during periods of economic prosperity, however, production functions begin to converge on, or approach, equilibria. This convergence continues until all the benefits of the original innovation have been exploited and economic depression sets in, at which point a new wave of innovations are introduced and the capitalist system is reinvigorated in what Schumpeter termed the process of "Creative Destruction" (1950, pg. 83).

1.2.3. Contrasts between Kuznets and Schumpeter

While both Kuznets and Schumpeter identified technological change as the driving force behind economic growth and identified a regular temporal pattern in the relationship between technological change and economic growth, the similarities end there. First, Kuznets considered technological change to be a continuous process endogenous to a given industry. Since innovations are introduced continuously, the production function continuously adjusts to a series of equilibrium conditions which can then be analyzed using neo-classical econometric techniques. For Schumpeter, economic growth is a stochastic, disequilibrating mechanism because innovations radically alter the production function. Accordingly, the student of technological change is required to the analyze the economic and industrial system within which it originates, and neo-classical techniques are inappropriate for such analysis.

The second major distinction between the two is their view of the business cycle. Kuznet's business cycle focused on major industries or systems of related industries, so that their impact on regional or national economies reflects the industry's importance within that economy. Schumpeter's business cycles, conversely, were predicated on the introduction of revolutionary products and production processes. The new technologies changed all that came before and continued to do so until the introduction of the next round of new technologies that are initiated during the final stage of the cycle.

2. TECHNOLOGICAL CHANGE AND 1840-1880 BRITISH SHIPBUILDING

This section reviews the literature relating to contemporary and mid- to late-nineteenth century shipbuilding technological changes and related spatial industrial changes. This industry is especially pertinent to an analysis of the impacts of technology on spatial industrial development because shipbuilding analysts consider technological change to be the primary cause for the regular, periodic spatial restructuring of shipbuilding activity. This section begins with a review of studies that establish the importance of technological change to the economic viability of the industry. It then concludes with a survey of historical and historical economic studies of the 1840-1880 British industry that deal with iron steamship technological change and the British industry's spatial structure.

2.1. Technological Change and Shipbuilding

The recent and significant declines of shipbuilding employment in North America and Western Europe relative to Japan and other Pacific Rim countries have generated a sizeable literature on the impacts of technological change on the contemporary industry. This literature identifies technological change as one of the primary causes for the industry's "West to East" spatial shift and the resultant loss of shipbuilding employment in the West. Harrison (1983) argues that spatial shifts in the shipbuilding industry are the consequence of Schumpeterian-type technological change cycles which significantly alter either ships or ship-construction techniques. He identifies five periods of spatial restructuring, beginning with the dominance of the Dutch industry in the seventeenth century and ending with the current dominance of the Pacific Rim countries, and speculates that innovation is as important to continued growth as are management, industrial relations, and productivity.

The most comprehensive work on the impact of technological change on shipbuilding has been conducted by Daniel Todd (1985) in his examination of the British shipbuilding industry. Using case studies from the British experience, Todd maintains that technological change is one of five factors that determine the location of shipbuilding activity. He argues that process and product innovations change the competitive position of individual firms, as well as regional and national industries that are best able to take advantage of those changes. Both Todd and Rother (1985) argue that the industry's shift out of Western Europe and into Japan was due to both lower factor input costs and product and process innovations introduced by the Japanese industry in the early 1960s. In addition to lower wage rates and newer shipyard facilities, Frankel (1990) identifies the increasing integration of the ship into intermodal transport systems as the most important recent ship technological change. Hillings (1989) attributes ship intermodality to the restructuring of the British system of ports as cargo-handling capability shifts out of larger ports and into revitalized smaller ports.

2.2. Nineteenth Century British Shipbuilding

Shipbuilding historians attribute the industry's domination of the world shipbuilding industry by 1872 to its pioneering efforts in and perfection of the iron steamship. The shift of world shipbuilding to Britain in the mid- to late nineteenth century is the third of Harrison's (1983) five restructuring periods and, according to this author, was due to the British industry's innovative leadership in iron steamship construction. Todd (985), in his examination of the origins of British dominance, attributes the industry's growth to the shipbuilding industry's ability to introduce and perfect new shipbuilding techniques and ship technologies.

Shipbuilding was one of the major industries that contributed to Britain's nineteenth and early twentieth century dominance of the world economy. Despite its importance, however, the pre-1872 iron and steam shipbuilding industry and its spatial change has not received a great deal of attention. Most of the studies that have been produced consist of qualitative introductory analyses or regional shipbuilding histories. This section examines these studies, by historians and economic historians, that either directly or indirectly relate to technological change or the industry's spatial restructuring.

2.2.1. Technological Change and Spatial Industrial Change

Since it was one of the few British industrial success stories of the late nineteenth century, the shipbuilding industry has generated its own significant body of literature. Musson (1978) bases the shipbuilding industry's growth on the iron steamship revolution, which resulted in advances in the established iron and steel and engineering industries, and the increasing inter-relationship between these industries and shipbuilding. Pollard and Robinson (1979) consider the industry to be so important to the national economy that cycles in the demand for new ships affected the whole economy. These authors argue that because Britain was an island nation with sheltered ports which notably controlled a large share of world trade and also held abundant capital, it was poised to become the leading shipbuilding nation once an economical supply of raw materials were made available. Finally, Deane and Cole (1962) emphasize the importance of the industry by demonstrating that the total value of merchant vessels produced in British shipyards during 1914 accounted for approximately 1.25% of British gross domestic product; more than 2% of all wages; and 30% of British steel production.

Introductory chapters in several books outline the British development of iron steamship technology and its revolutionary impact on raw materials, construction techniques, and propulsion. Whitehurst's (1986) analysis of the decline of the United States shipbuilding and repairing industries discusses the competition between American and British shipbuilders following the repeal of the British Navigation Acts in 1849. He argues that British shipbuilders revolutionized both the world shipbuilding and shipping industries by developing the iron steamship while the American industry continued to build wooden sailing ships. By the mid-nineteenth century British shipbuilders had significantly lowered their production costs relative to the more traditional, and complacent, United States industry. Jones (1957) considers Britain's head start in metal shipbuilding; cheap materials, especially iron and steel; and abundant skilled labor as British advantages that were established during the first half of the nineteenth-century and fully realized during the second half. Further, and as a result of these advantages, Britain was identified with iron and steam shipbuilding by the 1870s and had displaced other countries as the world's leading shipbuilding nation.

Studies of the industry's role in keying Britain's impressive late-nineteenth-century economic growth emphasize the demand and supply feedback loops between interrelated industries and their impacts on the shipping and shipbuilding industries. Several authors emphasize the shipping industry's need for fuel efficient and cargo efficient vessels as causes of innovations in construction and propulsion (Cunningham, 1903; Moyse-Bartlett, 1968; MacGreggor, 1980 and 1984; and Thornton, 1959). Economic analyses have also been conducted (Pollard and Robinson, 1979; Pollard, 1957; and Harley, 1974). Other authors (Rowland, 1971; Waine, 1976; Abell, 1981; Jones, 1957; Parkinson, 1960; Graham, 1958; and Gilfillan, 1935) emphasize technological changes in the iron-working industries that lowered raw material prices, improved strength and malleability, and raised the quality of high tolerance machine work.

The spatial impact of these technological changes have also been studied. Bremner examined the role of technological change on the growth of the Clyde shipbuilding region in a series of articles originally published in 1868 (1969). More contemporary work on the importance technological change on the Clyde's growth includes Robb (1958), Turnock (1982), and Walker (1984). Relatively little has been written concerning the English North East Coast, but Smith and Holden (1953), Dougan (1968), and especially Waine (1976) relate the region's growth and mid-nineteenth-century importance to the development and implementation of product and process innovations in iron and steam shipbuilding.

Other authors have examined the decline of shipbuilding activity in traditional shipbuilding regions as well. Banbury (1971) and Pollard (1950) have examined the London industry, arguing that shipbuilding declined because its pioneering and highly innovative marine engineers and iron shipbuilders could not overcome such disadvantages as river congestion, high land and labor costs, and the distance from raw materials. Pollard and Robinson (1979) make a similar argument for the decline of the Mersey industry, and add that Liverpool's harbor management board, in addition to driving up waterfront land prices for shipbuilders, refused to provide them with adequate rail facilities.

2.2.2. The Technology and Productivity Debate

The economic impacts of the mid-nineteenth century British iron screw steamship have stoked a lively debate among economic historians that began in 1958. In this year, Hughes and Reiter (1958) examined technological changes in the 1860 British iron steamship merchant fleet. These researchers argued that iron construction and the marine steam engine increased cargo-carrying capacity and ship speed, and that these new ship technologies accounted for the dramatic shipping productivity gains of the British merchant fleet between the mid-nineteenth and early twentieth centuries.

This argument was challenged by Max Fletcher (1958) and Douglas North (1958, 1968). Fletcher argued that the opening of the Suez Canal had the greater impact on shipping productivity gains because it rendered the sailing ship obsolete and directed ship technological changes, for both iron screw steamships and traditional sailing ships, toward those that best exploited the "least distance" trade routes afforded by the Canal. North explicitly challenged the view that technological change is the most important factor in economic growth by contending that shipping productivity gains pre-dated the introduction of the iron steamship and that these productivity gains were the result of the development of new regions that produced agricultural staples and provided paying cargos for both legs of the ship's voyage. Other changes that reduced shipping costs were the decline in piracy and improved business organization within the shipping industry. These arguments have been examined in more detail by North's students Walton and Shepherd

(1979). Ville (1986) also argued that British shipping productivity gains, at least in the coastwise coal trade, predate the introduction of the iron and screw collier, a bulk cargo-carrier used to haul coal from the English North East Coast to London and other coal markets. According to Ville, the factors contributing to lowered shipping costs included, among others, improved cargo-handling techniques, lower manning requirements, stable insurance costs, and quicker turnaround time and, hence, more voyages.

The arguments of North and Ville have been challenged on a number of points, however. Harley (1988) noted that North only considered US and Caribbean shipping data (and made several computational errors at that). Based on his analysis of a much larger dataset incorporating a greater diversity of trade routes, Harley contended that worldwide improvements in shipping began with the application of the iron steamship to ocean transportation because the new ship saved on factor inputs and increased competition in the shipping industry. Hausman (1987), in a discussion of Ville's article, maintained that productivity gains in the coal trade had little impact on the British economy and were much smaller than for those in other industries. He also observed that the single most dramatic change in the technology of the shipping industry was the adoption of the iron screw steamer, and thus, the actual question to be answered is why shipping costs did not fall even more rapidly.

3. TECHNOLOGICAL CHANGE AND INDUSTRIAL LOCATION

The concerns of the shipbuilding-specific literature mirror the essential components of the broader debate regarding the overall importance of technological change and both economic and regional economic growth. Due to its interest in the spatial distribution of economic activity, the sub-field of economic geography has generated a sizeable literature on the impacts of technological change to the spatial distribution of economic activity in general. Since the late 1970s especially, this literature has focused on the role of technological change in the industrial location decision and regional economic development. This literature is often characterized by what might best be described as an at times acrimonious debate among two competing paradigms.

3.1. Industrial Location Theory

This section reviews the two most commonly used industrial location theories, the neo-classical and the structuralist. It also notes their analytical shortcomings, namely, their inability to realistically explicate the links between technological change and spatial industrial restructuring. Further, it argues that elements of both theories in synthesis, rather than one or the other, are required to understand this phenomenon.

3.1.1. Neo-classical Industrial Location Theory

The older of the two theories, the neo-classical economic location tradition, held sway until the industrial and employment dislocations within the US and Western European economies in the early 1970s. Up until the 1970s, it was generally accepted that net investment, rather than technological change, was the primary cause of economic growth (Link, 1987). However, these social disruptions raised questions about the utility of investments in explaining the spatial restructuring process and attendant job losses. At the same time, neo-classical theory, which holds technological change constant, was also found wanting.

Neo-classical industrial location theory regards locationally-specific factor endowments or factor costs to be the primary determinants in the industrial location decision. The analytical approach was first introduced by Weber (1929). Weber's analytical framework identified the "best" location for a manufacturing establishment using neo-classical micro economic theory. He argued that industrial locations are fundamentally determined by differences in costs, and that cost differences are due to natural conditions, such as climate, transport costs, or the spatial distribution of raw materials and labor. Further, cost differentials can only be changed by technical progress or by economic or social conditions which alter interest rates, labor skills, and living standards. However, only transport and labor costs vary with location, so that the identification of the optimal, least-cost location requires the identification of cost differentials from one production location to another. The result was a transport and labor deterministic model.

The approach has been broadened, however, by factors other than transport and labor costs, and as Smith (1981) argues, neo-classical location theory still provides a valid framework for examining the location decision. The framework is still used extensively by economic geographers who are concerned with locationally-specific attributes that influence the location of industrial activity. Oakey and Cooper's (1989) locational analysis of high technology firms, which emphasizes locational considerations such as psychic income, least cost location, and agglomeration, explicitly points out the utility of neo-classical location theory in understanding the locational behavior of these firms. Cornish (1997) analyzes the spatial interaction of innovation and new product introduction to argue that innovative activity is a function of the spatial proximity between producers and markets and is based on locationally specific attributes. The neo-classical framework is also used extensively by economists and regional scientists, with examples being Jin's (1991) analysis of technological change and Chinese industrial structure using Cobb-Douglas type production functions, and Frenkel and Shefer's (1996) modeling of regional innovativeness that employs a LOGIT behavioral model to evaluate the probabilities of a firm's adoption of innovations.

Neo-classical industrial location theory provides a framework for identifying the considerations involved in the individual firm's location decision. However, it is ill equipped to consider technological change for two important, if overlooked, reasons. The first is that while its practitioners are aware that technological change alters factor availability and price, neo-classical assumptions of economic equilibria assume away adjustments to factor inputs that are the result of the dynamic process of technological change. This is a fundamental problem for regional scientists: their methodological approaches adequately describe a steady-state system, but such approaches become awkward when change over time is introduced to the analysis. The second drawback is that traditional locational analysis, because of its emphasis on the individual firm or industry, takes a bottom-up approach that does not consider the economic and organizational environment within which the location decision is made.

3.1.2. Structuralist Industrial Location Theory

Currently, the most commonly used theoretical framework for assessing the industrial location decision is Structuralism. Structuralist industrial location theory, strongly influenced by the Marxist critique of the capitalist system, regards the location decision as directly related to the dynamic disequilibria of capitalism which is, in turn, caused by technological change. The structuralist critique of neo-classical industrial location was introduced by Massey and Megan in 1979 and has its origins in the social dislocations associated with the "stagflation" of the 1970s (Freeman, 1982).

Massey (1979a) objected to neo-classical marginalist economic theory and its idealized, but unrealistic, model of the firm. She argued that neo-classical industrial location theory cannot account for spatial behavior because its approach, which begins with the firm and then works up to the broader economy, eliminates historical and individual variations in behavior. As a result, it ignores the dynamics of the system in which the firm exists. Her observations, in many ways, reflect the Marxist view expressed by Storper and Walker (1989) and Sayer (1983) who see technological change as a negative consequence of the capitalist economic system, i.e., as the instrument of uneven spatial economic development. To correct these deficiencies, Massey and Meegan (1979b) introduced a structuralist, top-down analytical approach which isolates conditions within the larger economic structure and traces their impact down to the individual firm and its locational strategy.

Structuralist industrial location theory has been widely adopted by economic geographers interested in the relationship between technological change and industrial restructuring. Freeman (1982) stressed that accelerated economic growth is associated with major innovations but that hierarchical regional industrial structures concentrate research and development efforts in a few select locations. This view is echoed by

Sweeney (1987) who has argued that self-generating economic growth requires high rates of innovation and the formation of new firms, but that regions differ as to their innovative and entrepreneurial ability. Markusen (1985), whom we will discuss later in relation to her Profit Life Cycle, takes an explicitly structuralist view, while Faberberg et al. (1997) explain unequal European regional growth of gross domestic product in terms of the unequal distribution of research and development activities. The structuralist approach is also used in formulating the "new economic development theory" which promotes the endogenous creation of innovative firms based on the existing industrial structure and composition of a region or area (Teitz, 1994).

Models based on structuralist industrial location theory, based as they are on dynamic disequilibrium, offer a powerful analytical framework for understanding the relationship between technological change and spatial industrial change. They are predicated on the fact that spatial industrial behavior cannot be understood unless the dynamics of change, conditions in the overall economic system, and variations in firm behavior are taken into account. At the same time, however, the approach is limited by the level of generalization at which it operates. Studies using the structuralist framework take a top-down analytical approach, confining themselves to regional level studies rather than investigating the impact of technological change on individual production centers. As Smith (1981) observed, focusing exclusively on larger economic systems overlooks the site-specific factors upon which industrial viability is contingent. Warren (1991), in his industrial location analysis of the Consett Iron Works, concluded that any study which is based exclusively on theoretical considerations and disregards the experience of actual firms or locations inevitably ignores discrepancies in the performance of individual centers and their larger industrial region.

3.2. Life Cycles

Kuznets' and Schumpeter's concepts of the business cycle, although differing on major points, have had a profound impact on economists and economic geographers because they provide a framework for examining technological change through time. Schumpeter has had an especially strong influence because the employment dislocations over the course of the past twenty-five years have been directly linked to the stagnation and depression phases of his business cycle model. Schumpeter is often invoked by scholars who consider new industries, especially information technology industries, to be the leading sectors of a new industrial era (Berry, 1991, 1997; Mensch, 1978).

The first explicit use of the business cycle as an analytical framework for understanding the spatial dynamics of technological change was Raymond Vernon's Product Life Cycle (1966). Vernon's cycle provides Kuznets' model of industrial growth with a spatial dynamic and allows for the assessment of location decisions based on the industry's trajectory in particular phases of the cycle (Norton and Rees, 1979; Rees, 1979). Vernon postulated that an industry goes through three development phases: an innovation phase leading to the industry's spatial concentration in areas offering agglomeration economies; a growth phase during which production becomes standardized, allowing for new firms and production locations to become established, and during which the industry is characterized by increasing sales and competition; and a standardization or mature phase characterized by declining sales, intense competition, and a production process so standardized that the industry becomes "foot loose" and seeks out new low cost production locations. The Product Life Cycle has been used by geographers to link technological change to the North-South shifts in US manufacturing activity (North and Rees 1979; Rees, 1979) as well as to the growth and decline (circa 1979) of the Petro-Crescent along the US Gulf Coast (Weinstein, Gross, and Rees, 1985; Weinstein and Gross, 1987).

An important structuralist reformulation of the Product Life Cycle has been presented by Markusen (1985, Markusen et al., 1986). She argues that the changing regional distribution of plants and jobs in any industrial sector reflects the priorities of corporations at each stage of an evolutionary profit cycle. Locational strategies vary over the course of the five stages that range from an emphasis on innovative activities in early stages to the creation of market power and/or rationalization in its final stages. Each strategy has unique sets of demands on factor inputs and market access which, in turn, are unevenly distributed across regions. The model is therefore market-driven as opposed to technology-driven.

Although both the Product Life Cycle and Profit Life Cycle provide valuable analytical frameworks for conceptualizing technological change-induced spatial restructuring through time, these theories are controversial. Examples of the debate over the utility of the Product Life Cycle are Sherwood-Coll's (1992) use of the framework to confirm the geographic dispersion of the electrical components industry, while Johnson (1991) contends that a complete explanation of branch-plant locations in the non-metropolitan US South cannot be obtained within the Product Life Cycle framework.

Clark (1989) considers the Profit Cycle to be one of the most sophisticated theoretical tools for conceptualizing the regional growth process, but he reserves doubt on the impact of cyclical or structural patterns. Similarly, Sorenson's (1997) empirical tests of Markusen's key hypotheses of regional industrial composition and cycle trajectories produce mixed results

3.3. The Measurement of Technological Change

This section concludes with a review of the techniques used by economic geographers and regional scientists in relating technological change and place. As Acs and Andretsch (1991) acknowledge, measuring technological change presents researchers with serious difficulties. The problem is one of measuring new knowledge and its contribution to technological progress. As Kuznets (1962) observed thirty years before, the difficulty lies in finding meaningful measures of innovative inputs and outputs. Because of this difficulty, investigators have relied on three proxy measurements: input-output analysis; the market share of new products relative to old products; and the measurement of investment in research and development.

The two most commonly used methods in the regional science and economic geography literature for measuring technological change are based on the surrogates of research and development expenditures and production functions which measure technological change. The first method is based on Gilriches study of the social returns of hybrid corn, while the second is a variant of the Hicks-neutral technological change production function developed by Solow. An example of the first approach is the general equilibrium model of North-South trade developed by Segertrom, et al. (1990) in which research and development expenditures are used to determine the rate of new product development. An example of the second approach is an estimation of a firm's ability to incorporate innovations by Green et al. (1991) in which the error term from the production function is split to isolate random variations which are outside of the firm's control and those which can be attributed to the firm's technological inefficiency.

The largest component of the economic geographic literature examines the spatial behavior of high technology industries such as electronic components and bio-engineering. These studies make no attempt to determine the innovative ability of the industry being studied. One example of this approach is Delaney's (1993) study of the urban agglomeration of bio-engineering firms in which innovative ability is treated as a given.

More rigorous approaches rely on either proxy measurements such as employment change, research and development expenditures, or patent counts to establish spatial innovative ability. Examples of these approaches are Sherwood-Coll (1992) and Markusen (1985, Markusen et al. 1986). Many of these studies are methodologically sound and provide valuable insights into the relationship between technological change and place. An example is Feldman and Florida's (1994) study that models the geographical distribution of innovation in the US in 1982 in which the number of innovations originating in a state is a function of university research, industrial research and development, networks of related firms, and specialized business services.

The approaches discussed above provide methods for measuring the impacts of technological change and relating those changes back to the spatial system. However, none of these methods actually measure technological change. It is one thing to measure costs associated with research and development or the number of patents that originate in a particular area (and to disregard the question of whether or not the patents are ever brought to the market). It is quite another to use actual data to measure the technical changes that actually arise from research, development, and patents.

4. SUMMARY AND CONCLUSIONS

This chapter has reviewed the literature that guides this research effort. It began by defining technological change and introducing the work of Simon Kuznets and Joseph Schumpeter, the two scholars who have had the greatest impact on contemporary studies of technological change and spatial industrial change. It then discussed the historical and economic historical literature concerning the 1840-1880 British iron and steam shipbuilding industry. This literature has directed the discussion and analysis of the assessment of the relationship between industrial viability and innovative ability that follows. It concludes with a review of the theoretical and analytical frameworks used by geographers to investigate current issues of technological change-induced spatial restructuring. These frameworks are extensively utilized in this study because of the insights and analytical frameworks they provide for any study of the relationship between innovation and place.

CHAPTER III

METHODS

This chapter describes the methods that will be used to investigate the relationship between innovative ability and industrial locational viability. As discussed earlier, the measurement of technological change and its linkage with the performance of individual centers within an industrial system present researchers with serious problems. As a result, this study employs a rather complex methodology to establish and locate technological changes in iron shipbuilding and to relate those change's to a center's industrial viability.

The data used for the study were obtained from the Lloyd's Register of British and Foreign Shipping. The Register, which began annual publication in 1834 and continues to the present, is an efficient source of information for the British iron and steam shipbuilding industry and provides an excellent opportunity to explore the importance of technology to the industrial viability of individual production centers. However, the data are not without their problems. These problems will be discussed in more detail in later sections of this chapter.

The chapter begins by establishing the conceptual model of technological change and its impact on individual production centers that guide this research. Next, it provides definitions for key terms and concepts. It then presents the methods used to develop required variables and specifies the test that will be used to assess the association between industrial viability and innovative ability.

1. CONCEPTUAL FRAMEWORK

This chapter begins by identifying guiding concepts and defining key terms. The analytical framework, including key concepts, is introduced first. Next, it provides a working definition of the industrial center and its role and importance within larger industrial structures. This is followed by a discussion of the rationale for technological change and its implications on innovative ability and locational viability.

1.1. Analytical Framework

This research combines the disequilibria concept of change with the traditional neo-classical concern with place. Although these two theories are often presented as antithetical, spatial restructuring over time and space is the culmination of changes initiated at and imposed upon each and every location within an industrial system. The large scale-factors of time--the technological cycle--and space--the individual components of the industrial system--form the framework within which the locationally-specific variables of industrial viability and innovative ability can be examined. This framework allows for analysis of the technological performance of any center within the industrial system at any time during the technological cycle.

An *industrial center* is defined as a single firm or collection of firms producing a similar product or related products and operating in the same location. Firms locate at specific locations for access to markets, factor inputs, or both, and compete with other firms. These centers collectively form progressively larger portions of the industrial system at regional, national, and international scales.

Innovation is initiated or adopted by individual firms in an attempt to improve profitability. Early adopters enjoy excess profits by improving their profitability relative to firms using old technology, while late adopters imitate early adopters so as to maintain their competitiveness. As the rate of technological change increases, locational instability and disruption occur as the new technologies alter the relative importance of factor inputs. Since factor prices vary in space, new firms can locate at new least cost locations which can then become viable production centers. Established firms can either move to new least cost locations, or maintain their locational viability by generating innovations or adopting the most current, but rapidly changing, "best practice" techniques (Salter, 1960).

Innovative shipbuilding centers enjoy locational advantages over less innovative centers. This is because during periods of rapid technological change locational viability depends upon the ability to generate, adopt, and incorporate "best practice" techniques. Competitive advantages due to innovative ability can then mitigate against locational disadvantages in factor inputs.

1.2. Definitions

Innovative ability and *locational viability* are considered to be locationally specific attributes that allow for the assessment of the relationship between innovative ability and industrial locational viability. Innovative ability is a production center's ability to generate or to assimilate technological changes. Industrial viability is a center's growth, stability, or decline, in terms of gross output, within the industry's spatial system and is indicated by its market share.

Ships incorporated in this research are limited to ocean-going ships that were made of iron, propelled by marine steam engines and screw propulsion systems, and carried cargo. These ships were the direct predecessors of the modern trans-oceanic cargo carrier. Although the production of fishing vessels, dredgers, tugs, and similar vessels was an important component of many production centers' output, these vessels are excluded from this study because their functions, and hence their technological requirements, were different from cargo carriers. Paddle-steamers are also excluded because, although they were highly innovative ships for a time and their production was important at many centers, these vessels were obsolete as cargo carriers and for use on ocean-going trade routes by 1865.

The analysis of technological change is restricted to the most significant component technologies which characterized the iron steamship. The study does not establish steamship productivity or efficiency increases to justify technological change. Rather, it assumes that these increases were the original reasons for innovation and adoption, and their superiority over other techniques is sufficiently established by their continued use, after further modification, in the modern merchant ship. Nor does the study inquire into why the individual firm adopted iron and steam construction. The shipbuilder's decision to adopt these technologies is considered to a be rational and correct assessment of his particular economic situation.

The iron steamship represents the combination of two complex technologies--marine steam propulsion and iron construction. A succession of innovations in propulsion and construction technologies were introduced during the study period. It is assumed that these innovations were adopted to improve efficiency or productivity, either for shipowners or shipbuilders, and that innovative centers enjoyed competitive advantages over their rivals.

2. METHODOLOGICAL FRAMEWORK

This section presents the methods used to develop the variables that measure innovative ability and industrial viability. It begins with a discussion of the data source, the Lloyd's Register, and its limitations. Next, it introduces the periodization scheme that is used to sub-divide the 1840-1880 period. Finally, it presents the methods that will be used to develop the required variables and the procedure for testing the relationship between industrial viability and innovative ability.

2.1. Data

Data for this study are obtained from the Lloyds Register of British and Foreign Shipping. The Register collected and reported technical descriptors of individual ships. This information was then used by marine insurance underwriters to determine a ship's insurance risk. Although it was not intended as such, the Register also provides information needed to test for the relationship between a British iron and steam shipbuilding center's industrial viability and innovative ability.

The Lloyds Register, not to be confused with the insurance market Lloyds of London, was the largest and most prestigious of several ship classification societies. These societies, under the authority of both the British government and the insurance and shipping industries, were responsible for certifying a ship's seaworthiness by inspecting the ship during construction and at regular intervals thereafter. All ships surveyed by Lloyds, either new ships or older ships whose owners desired a Lloyds classification, were listed in the annually published Register. The amount of information increased over the course of the 1840-1880 study period. By 1872, information in the listing consisted of the ship's name, the name and location of the builder, the year of construction, registered tonnage, and various technical measurements including dimensions and engine specifications such as engine type, cylinder size, rated boiler pressure, and horsepower. As such, the Register offers an efficient source of locational and technological data.

These data were collected during the summer of 1993 from published Registers held by the Social Science Department of the Mitchell Library in Glasgow, Scotland. Using each Register published in 1840, 1845, 1850, 1855, 1860, 1865, 1870, 1875, and 1880, all iron steamships built between 1840 and 1880 were identified. All new ships and ships inspected after launching but not modified in some manner were entered into a standard spreadsheet. Data for each ship includes the following information: construction material - iron or steel; tonnage - net, gross, and underdeck; dimensions - length, width, and depth; number of bulkheads; number of decks; double bottom or partial double bottom ballast tanks; name and location of shipbuilder; type of ship--paddle, screw, or twin screw; engine type--lever, diagonal, oscillating, compound, and inverted; engine configuration (angle at which cylinders are mounted on a stationary engine bed); engine cylinder volume (number of cylinders x diameter x stroke); boiler pressure; horsepower; name and location of engine builder; and the year in which the ship was built. The database for this research consists of over 2,200 ships from 100 shipbuilding locations in Britain, Europe, Asia, North America, and New Zealand.

The dataset was later "culled" to remove all vessels that did not carry cargo, such as tugs, dredgers, fishing boats, paddle-steamers, and other iron steam vessels, or that were obviously too small for ocean-going trade. The final dataset consists of 1544 ships. The data for individual ships are not always complete, especially for ships built early in the study period and for ships built at remote ports. The first reason for incomplete data is that the data quality and quantity improves over time as Lloyds reporting improved, the second reason is that Lloyds seems to have neglected small, isolated British outports and foreign ports. Neither of these has much effect on the research findings.

Despite the very large number of observations and variables, these data have several problems that restrict the methods that can be used for this study. Four problems can be identified. The first is that few variables are available for the entire study period; more variables were reported in the Register as the study period progressed. Second, many variables in the dataset could not be included in this analysis. This is especially true for structural features such as decks, bulkheads, and water ballast tanks because it is not always clear if the Register's compilers simply failed to record this information or if the ship was not equipped with these features. Third, the Register does not include all ships produced during the study period so that a full time series is lacking. Finally, and perhaps most importantly, there is a high degree of multicollinearity between many variables, especially for register tonnage, dimensions, and horsepower.

2.2. Innovation Cycles

The final issue which must be discussed before presenting the methodology concerns the sub-division of the 1840-1880 period into shorter sub-periods. As the extended discussion in Chapter IV will more clearly demonstrate, the study period consists of four distinct shipbuilding cycles, each characterized by growth and then decline of British total shipbuilding output. These cycles also correspond to fluctuations in the rate of technological change.

As a result, the study period is divided into four separate and distinct shipbuilding cycles and are:

Cycle 1: 1840 - 1855
Cycle 2: 1856 - 1865
Cycle 3: 1866 - 1872
Cycle 4: 1873 - 1880

This periodization scheme is necessary for two reasons. The first reason is that the use of these shipbuilding cycles allows for the inclusion of more technical measurements from the Register as they become available. The second reason is that both the rate of technological change and the contribution of the component technologies varied from cycle to cycle.

2.3. Methods

This section presents the methods that will be used to calculate the key site-specific variables. As stated at the beginning of this chapter, the study's spatial and temporal considerations as well as the constraints imposed by the data source, require a somewhat complex analytical methodology. The section begins by presenting the industrial viability variable used to establish the individual shipbuilding center's viability within the larger shipbuilding industrial system. This is followed by a discussion of the development of the innovative ability variable that will assess the center's ability to introduce or assimilate technical innovations. Finally, the section outlines the test used to assess the relationship between these two variables.

2.3.1. Industrial Viability

The index of industrial viability establishes the individual British shipbuilding center's relative competitiveness within its larger spatial industrial system. The first step in the computation of this variable is to calculate each center's annual percent share of total annual British shipbuilding output recorded in the Register. Since the majority of ships were built on consignment, this variable represents the shipbuilding center's market share relative to all other centers. Each center's annual percent share is then ranked into one of three categories to produce an index of annual market share. This index is then used in the final stage of this analysis.

2.3.1.1. Market Share

The index of annual market share is calculated using the gross tonnage measurements provided in the Register. Although net tonnage is provided by official annual shipbuilding statements, gross tonnage is the measurement of shipbuilding output used by shipbuilding analysts and historians because it represents the total volume of the ship as opposed to net tonnage which only measures cargo carrying capacity (Todd, 1985). The annual output share variable is calculated in the following manner. First, and for any given year during the study period, the gross tonnage of all British-built ships is summed to give total annual national output. Next, the gross tonnage of all ships built at each shipbuilding center during a given year is summed to give the center's total annual output. Finally, each center's total output is divided by national annual output to provide each center's share of the total national shipbuilding market. The procedure is expressed in the following formula:

$$\text{Output Share} = T_{cy} / T_y$$

Where:
T_{cy} = total gross tonnage built at shipbuilding center *c* during year *y*
T_y = total national gross tonnage built during year *y*

2.3.2. Market Share Rank

With each center's annual market share calculated, it is necessary to transform this variable to make it more amenable to further analysis. Transformation is required because a large number of centers produced an extremely small annual output while a small number of centers produced an extremely large amount, resulting in a distribution skewed to the left. To counter this problem, each center is assigned to one of three annual output categories: high, medium, or low. This ranking system was chosen based on the visual inspection of scatter plots of market share and innovative values. This inspection revealed that three market share categories, as well as two innovative ability categories, adequately capture the joint occurrences of the two variables.

2.4. Innovative Ability

Innovative ability measures a center's capacity for generating or adopting technological change. This is the most problematic variable in this analysis because measuring technological change, not to mention innovative ability, presents scholars with serious methodological problems (i.e., how do you measure new knowledge and its contribution to technological progress). As a consequence, most studies of technological change use one of three approaches that rely on proxy measurements: input-output analysis; the market share of new products relative to old products; and investment in research and development (Acs and Andretsch, 1991; Rosegger, 1980).

This study utilizes a more direct measure of technological change based on Hughes and Reiter's (1958) "transport capacity measure." These authors estimated the annual amount of cargo-carrying capacity of the British merchant steam fleet to argue that technological changes associated with increased ship size and speed directly contributed to the British shipping industry's productivity growth before 1860. Their estimates were developed from net tonnage and horsepower measurements for individual ships obtained from a published list of pre-1860 British steamships as well as estimates of ship speed.

Hughes and Reiter's approach provides the basic framework for identifying each shipbuilding center's annual innovative ability using the technical and locational data available in the Register. First, a series of multiple regression models, one for each shipbuilding cycle, are specified to identify innovations that made a significant contribution to explaining the increasing ship size (economies of scale)--the most important technological change that occurred during the study period. Variables for the models and their construction are discussed later in this section. Next, the independent variables are used to develop innovative indices that score the level of technological sophistication of individual ships. Finally, each center is assigned an annual ranking, in terms of either a high or low innovative center, based on the position of each center relative to the mean score of the calculated innovation index for all ships built at each center during a given year relative to the mean score for all ships built during the cycle. The use of a dichotomous ranking scheme allows for the identification of technological leaders and laggards which allows for a more straightforward assessment of the results of the test for association. The following sections discuss these three steps in more detail.

2.4.1. Modeling Technological Change

The first task in identifying technologically leading and lagging shipbuilding centers is to establish a criteria of technological change in iron steamships against which ships from individual centers can be compared. This is accomplished by specifying a series of OLS multiple regression models, one model for each of the four shipbuilding cycles, that incorporate the technical measurements that best characterize steamship technological change. These characteristics are based on component ship technologies and their change through time. The models serve two purposes: first, they describe the relative contribution of key innovations to iron steamship change; second, they identify significant innovations used later to rate the technological performance of individual shipbuilding centers.

Multiple regression tests measure a hypothesized relationship between several independent variables and a single dependent variable. They are used in this study to identify significant innovations which contributed to the world dominance of the British shipbuilding industry. This is accomplished by testing the hypothesis that increasing ship size, the most important change in iron steamships throughout the study period, was a function of innovations that improved the efficiency of several key component technological systems. The models are specified as:

$$\text{Ship Size (Registered Tonnage)} = \text{technology}_1 + \text{technology}_2 + \text{technology}_n$$

Four models are specified using two-stage multiple regression analysis for each individual shipbuilding cycle. The reason for developing models for each cycle rather than the entire study period is that one model does not provide an adequate explanation of overall 1840-1880 iron steamship technological change because of the emergence of new technologies (and new variables). The two-stage approach is used because it allows for the testing of hypotheses regarding the contribution of important technical changes identified in previous research by leading shipbuilding historians.

The two-stage approach begins with a theoretical model for each cycle that describes important innovations. The model is assessed based on the explanatory power of the model as indicated by the F statistic and its significance; the significance and expected sign of the individual regression coefficients; and the sequential contribution of individual variables to Adjusted R^2. If these conditions are not satisfied, then the model is respecified by adjusting the dependent and independent variables as appropriate.

2.4.2. Variables

The data used to specify the technological change models consist of the year in which the ship was built, two register tonnage measurements, and five variables that represent important technical changes in iron construction and steam propulsion. These variables are obtained from the Register and entered, either as raw or derived variables, into the model. The use of derived variables minimizes collinearity and so maximizes the explanatory power of each independent variable. The following section discusses these variables, with a summary provided in Table III-1.

Table III-1: Variables Available for Technological Change Models

Variable	Calculation	Comment	Year	Cycle
Year	None	Year ship was built.	1843	All
Gross Tonnage	None	Total permanently enclosed volume of ship less certain deductions.	1843	All
Net Tonnage	None	Gross tonnage less non-earning spaces: i.e., accommodations, engine and machinery space.	1852	2, 3, 4
Net:Gross Ratio	Net Tons / Gross Tons	Monitor ship design changes maximizing net tonnage relative to gross tonnage.	1852	2,3,4
Length-to-Beam Ratio	Length / Width	Monitor changes in ship length relative to width.	1861	3,4
Ship Power	Gross tonnage / horsepower	Motive power of ship. Unitizes horsepower to gross tonnage.	1843	All
Boiler Pressure	None	Rated boiler pressure.	1869	4
Cylinder Volume per gross tonnage	Cylinder volume / gross tons	Engine size per unit ship volume.	1870	4
Cylinder volume per net tonnage	Cylinder volume / net tons	Engine size per unit cargo-carrying capacity.	1870	4

Source: See Text

Register tonnage, both gross and net, measures the enclosed volume of the ship. One ton equals 100 cubic feet. Gross tonnage is the total permanently enclosed volume of the ship less deductions for water ballast tanks, wheel house, galley and lavatories. Net tonnage is the ship's cargo-carrying capacity, or total earning space. It is legally defined as gross tonnage less all non-earning spaces, such as accommodations, and allowance for engine, fuel bunker, and machinery space. Gross tonnage is reported for the entire study period, while net tonnage was not reported on a consistent basis until 1852. Average gross and net tonnage increased throughout the study period.

The Net:Gross Ratio is a derived variable that establishes the percent difference between a ship's cargo-carrying capacity and its total volume. The ratio is calculated by dividing net tonnage by gross tonnage (Riegel, 1921). The variable is used to monitor changes in ship design that maximized ship cargo-carrying capacity but which were not reflected in net tonnage calculations.

The Length-to-Beam ratio also monitors changes in ship design. This variable is derived by dividing a ship's length by its width. Longer, but not necessarily wider, ships reduced water friction against the hull, which increased cargo-carrying capacity (and speed) without a corresponding increase in engine power. Pollard and Robertson (1979) identify increasing length-to-beam ratios as a key change in ship design.

Two derived variables are used to estimate ship motive power using the two register tonnage values and horsepower. These variables unitize horsepower to tonnage (i.e., one (1) unit of horsepower equals *n* tons) to provide a measure of either the number of gross or net tons propelled by one unit of horsepower. The variables are constructed by dividing the respective tonnage measure by horsepower. Both measures of ship power increased throughout the study period. (Two horsepower measurements were commonly used during the study period: "nominal horsepower," an arbitrary measure developed by Watt; or "indicated horsepower" which is calculated using engine specifications. The results of an independent calculation of indicated horsepower using a formula obtained from The Century Dictionary and Cyclopedia (1913) suggest that the Register recorded indicated horsepower.)

The rated pressure of the ship's boilers is also used. This variable also comes directly from the Register and is used to monitor increasing boiler pressure due to improved boiler designs.

The final variable is engine cylinder volume (in^3) per unit of net or gross tonnage. The variable provides a measure of engine size relative to the ship's cargo-carrying capacity or its total enclosed volume. Since cylinder volume is unitized to the tonnage variable, it allows for the monitoring of engine size efficiencies. The variable is constructed using the following formula:

$$\frac{\sum_{n=1}^{n} (1/2\, D_n^2 \pi)\, H_n}{T}$$

where:
V = cylinder volume
D = cylinder diameter
H = length of stroke
n = cylinder 1 through n
T = net or gross tonnage

All variables used in this calculation are obtained from the Register.

2.4.3. Innovative Ability Scale

The innovative ability scale is a synthetic measure of each center's innovative ability for each year it was in production. It is developed using the variables identified in the regression models. Since the independent variables have minimal multicollinearity, each independent variable's contribution is independent of the other variables in the model. Innovative ability is expressed as each center's annual rank as either a technologically leading or lagging shipbuilding center. A separate ranking is constructed for each of the four ship building cycles. The variable is constructed in the following manner.

For any given shipbuilding cycle model, the values for each independent variable are sub-divided into quintiles. The lowest score (1) represents the lowest possible level of technological sophistication for that variable, while the highest score (5) indicates the highest level. Every ship is then assigned to a class from one to five that corresponds to its position within the total range of the variable. This process is repeated for all variables in the model and the scores are summed to create a single value which reflects the innovations incorporated in each ship vis-a-vis all other ships for the time period. The number of variables used in creating the scale increase from one cycle to the next because new technologies were introduced over the course of the study period and because the Register increased the number of technical measures reported. Each ship's final score, therefore, depends on the number of independent variables in the model. For example, the model for the first shipbuilding cycle has only one independent variable. Therefore, the lowest possible ship score is one (1), while the highest possible score is five (5). For the last cycle, which uses five independent variables to calculate the innovation index, scores may range from five (5) to twenty five (25). Again, the final score indicates the ship's level of technological sophistication relative to all other ships built during that particular cycle.

After each ship is scored in terms of its technological performance, the technological rank for each shipbuilding center for each year can be calculated. Each center's rank is computed as the mean score for all ships built at the center during a given year. For example, if Glasgow produced 15 ships in 1876, then the average innovative ability index is computed using those 15 ships. Once the mean innovation index is calculated by center and year, each center is assigned to one of two classes: if the innovative index value is above the mean score for all centers, the center is designated as a technological leader; while a center with an index value below the mean is designated as a technological laggard. This process aggregates the individual ship innovation scores into measures of the innovative ability of individual centers for each year, thus repeating the shift in scale which is required for the locational analysis. These data, combined with the industrial viability ranking, allow for a final test for the association between a specific center's industrial viability and its innovative ability.

2..5. The Relationship Between Innovation and Market Share

The final stage of the statistical analysis tests for association, in a statistical sense, between the center's market share (the measure of industrial viability) and its innovative ability. The question is whether or not shipbuilding centers were rewarded economically, as indicated by their market share, for their innovative ability. The test assumes that a shipbuilding center's ability to compete successfully with other centers in its industrial system was directly related to its ability to generate or assimilate shipbuilding innovations.

The test is carried out using a chi-square contingency table test. Chi-square, a non-parametric statistical procedure, tests for an association between a set of observed categorical frequencies and a set of hypothesized frequencies. In order to carry out the test, the market share rankings are combined with the innovative ability rankings for each center and each year it was in production. As previously mentioned, the index scores for each center and for each year are assigned to three classes: high, medium, and low. Similarly, the innovative ability variable is divided into two classes: above the mean and below the mean for each cycle. The result is a two-by-three contingency table. A chi-square test statistic is calculated to test for the association between innovation and place for each of the four cycles. Additional analyses measure the strength and direction of the association using Kendall's Tau-c statistic, and assess the contribution of individual categories (cells) within the two-by-three contingency table to the total chi-square statistic. Given the sub-division of the study period into four cycles, there are four contingency tables and four sets of tests for association. The number of shipbuilding center and year observations available for each of the four tests of association vary because different locations enter and leave the Register during each year and each cycle.

3. SUMMARY AND CONCLUSIONS

Despite the implicit assumption of interdependence between technological change and the industrial viability of the individual production center, economic geographers have not examined the relationship between innovation and place. This chapter has presented an analytical framework for assessing this relationship. However, the complexities of the research problem combined with the nature of the data require a somewhat involved research design.

This research design provides a methodology for directly examining the relationship between industrial viability and innovative ability. It incorporates time--the technological change cycle--and space--the individual components of the spatial industrial system. This analytical approach allows for the examination technological change at a variety of spatial scales, from the national to the level of individual production centers, and provides economic geography with a methodological framework with which to assess the interaction between innovation and place.

CHAPTER IV

TECHNOLOGICAL CHANGE AND THE 1840-1880 BRITISH IRON SCREW SHIPBUILDING INDUSTRY

The 1840-1880 British iron and steam shipbuilding industry presents an excellent opportunity to examine the relationship between technological change and industrial restructuring. Innovations during this period dramatically increased ship size, power, and cargo-carrying capacity. The period also witnessed the establishment of modern ship construction techniques, propulsion systems, and designs (Abell, 1981; Brock and Greenhill, 1973; Jones, 1957; Pollard and Robertson, 1979; Parkinson, 1960; Rowland, 1971; Waine, 1976). More importantly from a geographic perspective, the new ship transformed the scale of the individual shipbuilding firm and reconfigured the industry's spatial structure as new centers emerged and older centers declined in importance.

This chapter provides a broad overview of the important changes in the iron steamship between 1840 and 1880. It begins with an introduction to, and brief outline of, British experiments in iron construction and steam propulsion before 1840. It then discusses key innovations in iron ship construction techniques and marine steam propulsion systems. Next, it examines the transition of the British shipbuilding and shipping industries from the traditional wooden sailing ship to the iron steamship. Based on this analysis, four distinct shipbuilding and innovation cycles within the study period are identified. The final section demonstrates that these changes resulted in continuous increases in ship size, power, and efficiency.

1. IRON STEAMSHIP TECHNOLOGICAL CHANGE

Although shipbuilding is one of that country's oldest and most important industries, Britain's perfection of new ship technologies allowed her to dominate world shipbuilding output from 1872 to 1918. The British shipbuilding industry's dominance was due to its development of and specialization in iron and steam shipbuilding. At the beginning of the nineteenth century, when shipbuilding was synonymous with wood and sail, British shipbuilders began experiments with iron construction and steam propulsion. By 1840, the new ship had established its economic viability for select trade routes, and a second innovation cycle began that perfected the new technologies. Changes during this period led to dramatic increases in ship size, power, and cargo-carrying efficiency (Musson, 1978; Pollard and Robertson, 1979) and by 1880 modern ship construction techniques, propulsion systems, and designs had been established (Abell, 1980; Waine, 1976).

1.1. Introduction of and Early Experiments in Iron and Steam Shipbuilding

Britain was able to experiment with and then perfect the new ship because of its head start in the Industrial Revolution. James Watt's improvements to the Newcomen engine (1763) provided a relatively efficient engine, while Cort's puddling process (1782) provided a cost-effective method for producing malleable iron bar and plate (Walker, 1984; Jones, 1957). Britain's pioneering efforts in the iron-working and engineering industries conferred initial and comparative advantages on that country which were most instrumental in the development of the new ship. This is evidenced by the fact that original experiments and financial support came from the mechanical engineering, civil engineering, and iron-working industries rather than shipbuilders and shipowners (Jones, 1957; Pollard and Robertson, 1979).

The first British experiments in iron construction and steam propulsion occurred at the end of the eighteenth and beginning of the nineteenth centuries. The first iron vessel was the Trial, built by John Wilkerson at Sunderland on the North East Coast. Iron shipbuilding was then confined to river and canal boats for the next twenty years (Cunningham, 1903; Dougan, 1968; Jones, 1957; Pollard and Robertson, 1979). Although steamboats were built earlier in the United States, the first practical British steamboat was the canal towboat Charlotte Dundas, built by Robert Symmington in 1801 near Glasgow. Further work on the Clyde culminated in the first commercially successful British passenger steamer, Henry Bell's Comet, built in 1812 (Jones, 1957; Rowland, 1970; Walker, 1984).

The first iron hulled steamship was the Aaron Manby, built in 1821 for the short ocean Liverpool to Ireland packet service. The advantages of installing steam engines in iron hulls were that iron is fireproof and, since stronger and lighter than wood, iron was better able to the support the heavy engine without sacrificing the ship's earning potential. Following the success of the Aaron Manby , iron steamships were built in increasing numbers for service on rivers, protected open water, and the English Channel and Irish Sea (Cunningham, 1903; Gilfillan, 1935; Jones, 1957; Rowland, 1970).

The iron steamship still required an efficient propulsion system before it could become a suitable ocean-going cargo carrier, however. The original steamers were propelled by the paddle-wheel, a propulsion system that made for very fast vessels and which was well-suited for the low piston speeds obtained by the early steam engines. Unfortunately, the paddle-wheel was very inefficient, since only the immersed paddles do useful work. Further, it was unsuitable for ocean-going trade routes because the paddles were easily damaged and came out of the water in heavy seas. The preferred system was the screw propeller because it eliminated the problems noted above: all blades are immersed and perform useful work; is less subject to damage because it is sturdier and below the waterline; and remains operable in all sea conditions. The introduction of an efficient screw did not occur until fairly late, however, because of the high costs associated with casting alternative screw designs. As a result, the first screw propeller was not introduced until 1826 and the first prototype of the modern screw propeller, installed on the Archimedes by Francis Smith, did not appear until 1839 (Graham, 1958; Gilfillan, 1935; Rowland, 1970; Walker, 1984).

By 1840 improvements in iron construction techniques and steam propulsion systems made the iron screw steamship superior to the paddle steamer and competitive with the traditional wooden sailer on select ocean-going passenger and cargo routes. The ship's acceptance by the shipping community was signaled by the entry of the Sirius in the Lloyds Register of British and Foreign Shipping in 1837. The feasibility of the new ships as long distance ocean carriers was demonstrated by the first trans-Atlantic crossing under continuous steam power made by this same ship in 1838. These two accomplishments signaled the end of the iron steamship's technological gestation period and initiated the 1840-1880 technological change cycle. By the end of this cycle the iron steamship was the dominate ocean-going cargo carrier on all but the longest trade routes.

1.2. 1840-1880 Iron Steamship Technological Change

Iron ship construction and steam propulsion systems perfected between 1840 and 1880 revolutionized ocean transport. In 1840 the new ship occupied a small niche within a British merchant fleet dominated by the traditional wooden sailing ship. By 1880, after progressive and unprecedented increases in ship size and power, the steamship was the dominate ship technology. Sailing ships were relegated to trade routes either too long for the steamer's coal requirements or with profit margins too low to justify the iron steamship's greater initial and operating costs. In addition, the period saw the establishment of shipbuilding techniques, ship designs, and propulsion systems that are the basis of the modern shipbuilding industry.

Iron steamship technological change was the response to both supply and demand factors. During the pre-1840 period and until the introduction of the John Bowes, which established the iron and screw steamship's advantages as a bulk cargo carrier, interest in iron ship construction was led by shipbuilders attempting to substitute increasingly scarce, and so more expensive, ships timber. In this respect, technological change can be considered to have been "supply pushed." At the same time, however, packet services became increasingly interested in the application of the steam engine to navigation, originally as towboats for canals and later for packet services on rivers and short ocean routes. In this sense, then, technological change can be considered to have been "demand pulled." After the acceptance of the iron steamship, however, innovations in iron construction and steam propulsion were driven by shipowner demand for more cargo- and fuel-efficient ships.

1.2.1. Iron

The main advantages of iron as a shipbuilding material are its reduced weight combined with greater strength. Wooden ship structural components embody a large amount of lost and dead weight. Twenty to fifty percent of framing-timber weight is lost immediately in planing and shaping, while dead weight cargo-carrying capacity is reduced because a full half of wooden hull weight is needed to simply hold the ship together. Iron, because of its greater weight and strength efficiencies, reduced hull thickness and so increased dead weight cargo capacity by 30 percent and hold capacity from 20 to 50 percent in proportion to exterior dimensions. Iron's greater longitudinal strength also allowed it to take greater structural stresses so that the length of iron hulls could exceed the 300 feet limit imposed by wood (Jones, 1957; Pollard and Robertson, 1979; Walker, 1984).

In addition to its weight and strength efficiencies, iron had several other advantages. Iron could take the localized stresses caused by the screw propeller, allowing for the full utilization of this propulsion system. The ends of iron plate could be overlapped and riveted to make for a stronger, water-tight vessel over its entire length, while water-tight bulkheads made for greater transverse strength. Finally, and not least, iron construction was much faster than wooden construction (Jones, 1957; Pollard and Robertson, 1979; Walker, 1984).

Despite its advantages, iron also had a number of drawbacks that had to be overcome before it could displace wood as the material of choice for trans-oceanic carriers. First, iron required anti-corrosion processes and the development of compasses that were not affected by the hull's magnetic field, both accomplished by 1839 (Gilfillan, 1935; Walker, 1984). Second, the cost of iron plates and frames had to be reduced and their quality improved. Both problems were addressed by the iron industry between 1840 and 1850 through technical improvements in iron rolling techniques as demand increased from the shipbuilding industry (Jones, 1957; MacGregor, 1980; Pollard and Robertson, 1979). Third, shipbuilders had to develop new construction techniques, machinery, labor practices, and shipyard layouts to fashion, assemble, and fasten individual structural pieces and systems (Jones, 1957; Pollard and Robertson, 1979; Walker, 1984). Finally, shipbuilders, shipowners, merchants, and ship surveyors had to be convinced that iron ships would withstand the stresses associated with trans-oceanic service (Jones, 1957; MacGregor, 1984; Waine, 1976).

1.2.1.1. Iron Construction

Basic ship construction techniques were essentially the same as those for wooden ships. The difference was that, rather than being a handicraft industry as was the case with wooden shipbuilding, iron shipbuilding became an industrial enterprise that altered 1) shipyard practices used to fashion, assemble, and fasten individual structural pieces and systems; and 2) shipyard layouts that maximized throughput. As such, it adopted many of the same techniques, machinery, and labor practices already developed in foundries and engine and boiler works. Although they were continually modified throughout the study period, the construction techniques and yard layouts were essentially in place by 1834 with the establishment of the first exclusively iron shipyard, located on the River Clyde (Abell, 1981; Jones, 1957; Pollard and Robertson, 1979; Walker; 1984).

Except for a few isolated experiments with the longitudinal framing system, used for steel ships after 1880, iron ships were built using the transverse framing system. This was the same system used to build the Vulcan, the first iron steamer built on the Clyde in 1818, and was a direct adaptation of the framing system used for wooden ships. The primary structural components and their order of assembly were as follows. The keel, an iron plate running the length of the ship, was assembled. Floor plates were then attached at right angles to the keel to form the bottom of the hull. The ribs, bent to the contour of the hull before erection, were attached to the ends of the floor plates. Bars that ran the length of the ship were used to tie in the ribs and floor plates for longitudinal support, while iron bulkheads and deck beams running the width of the ship provided transverse support. The last step in the assembly process was to attach the metal plates, shaped to the form of the outer hull or skin, which were overlapped and riveted to the floor plates and ribs and made watertight (Abell, 1981; Bremner, 1868; Walker, 1984).

Changes in ship construction were directed towards maximizing dead weight cargo-carrying capacity and increasing ship length without an attendant loss in strength (Abell, 1981; Pollard and Robertson, 1979). Most of these changes were accomplished through learning-by-doing and learning-by-using. First, methods emerged for strengthening longitudinal framing pieces. Second, fastening systems for joining structural pieces were modified to strengthen joints and eliminate redundant framing pieces for weight and construction cost savings. Since these changes were embedded in the production process and are not discussed by shipbuilding historians, they are difficult, if not impossible, to date. Two significant changes which increased longitudinal strength (and so ship length) and which can be dated were the introduction of hollow floor framing systems for water ballast, introduced in 1842, followed by the double-bottom water ballast system introduced in 1860 (Abell, 1981; Dougan, 1968; Waine, 1976; Walker, 1984).

1.2.1.2. Hull Forms and Ship Design

Modern hull forms and ship design were also introduced during the 1840 to 1880 period. Based on available information, efficient hull forms were not introduced until the 1870s while changes in ship design began in the mid-1840s and culminated in the ship superstructures and additional decks and spaces typical of modern ships. The following discussion is composed of two parts. The first examines changes in hull form represented by changes in the length-to-beam ratio. The second examines changes in ship design that increased the ship's cargo-carrying efficiency.

1.2.1.3. Hull Form

The steam engine's greatest handicap, especially before 1852, was the amount of potential money earning space occupied by the engine and fuel supply. One of the most effective methods for maximizing engine efficiency relative to cargo-carrying capacity was to utilize iron's greater longitudinal strength to make the hull longer relative to its width. This relationship is referred to as the length-to-beam ratio and is expressed by the ratio Length : Width (Muckle and Taylor, 1975). Higher ratios allowed for increases in hull volume without a corresponding increase in engine power because the water resistance against the ship was not materially increased (Rowland, 1970).

The first significant change to the length-to-beam ratio was introduced by I.K. Brunel. Brunel built the Great Britain, the most celebrated of the early iron steamships, in

1843. Brunel utilized a length-to-beam ratio of 5.8:1 for this ship, radical for the period, and justified it by formulating the principle that the carrying capacity of a ship's hull increased as a cube of the ship's dimensions, while the power required to overcome water resistance increased only as a square (Rowland, 1970). By 1854, length-to-beam ratios for ocean steamers were between 5.5:1 and 6:1, as compared to the 3.5:1 common at the end of the eighteenth century. By 1860 the ratio had increased to between 8:1 and 9:1 (Pollard and Robertson, 1979; Rowland, 1970). According to testimony before the 1873 Royal Commission on Loss of Life at Sea, by the late 1860s ships already in service were being sent back to the yard for lengthening to increase both cargo-carrying capacity (allowed for by improved ship framing techniques) and length-to-beam ratios. Lengthening consisted of separating the ship at its midsection and inserting a new hull section. The fact it was a common practice by the early-1870s indicates that the greater advantages of the new construction and propulsion systems were clearly recognized within both the shipbuilding and shipping industries. While ships with ratios of 10:1 to 11:1 were built in the 1870s, such extreme ratios over-extended framing systems and were suspected of causing ship failure (Parliamentary Papers, Vol XXV, 1969). By the end of the study period the ratio stabilized at around 8:1 (Pollard and Robertson, 1979; Waine, 1976).

Changes in iron construction and steam propulsion dictated changes to hull forms, which were constantly modified throughout the study period. The earliest steamship hull forms, copied directly from those used for wooden sailers, were modified as the handling qualities of steamships and the capabilities of iron and steam became better known. These changes were based on the preferences of shipbuilders and shipowners as they gained more experience with the new ship technologies, but scientific methods for designing hull forms were introduced in the 1860s and 1870s.

The earliest hull form modifications extended hull length and made the bows finer, or sharper. Hull lengthening came about because iron hulls, due their greater longitudinal strength, were less subject to the stresses of hogging and sagging (longitudinal bending) caused by being driven through heavy swells (Rowland, 1970). Driving also resulted in bows being further sharpened to allow the ship to cut through heavy seas rather than sail over them. This was a common feature in iron steamships in the 1860s. Bows then became blunter in the 1870s as problems with hogging and sagging in the longer ships forced a return to the practice of riding over seas (Waine, 1976). The final change to hull forms, based on the experiments of William Froude and other naval architects, also came about in the 1870s with the squaring of hulls at the keel to reduce turbulence and resulting drag at the propeller (Pollard and Robertson, 1979; Waine, 1976).

1.2.1.4. Ship Design

Between 1840 and 1880 the iron steamship was transformed from being little more than a modified copy of traditional wooden sailers to prototypes of modern passenger and cargo ships with multiple decks, raised decks at the bow and stern, and superstructures. Although either neglected or given cursory attention by most shipbuilding historians, Waine (1976) provides important insights into these changes. The following discussion is based on Waine's discussion and ship drawings.

In 1840, deck layout and rigging systems were copied from wooden ships employed on the same trade routes. Changes began sometime around 1848, as indicated by plans for a ship built in that year, with the erection of a rudimentary bridge to allow for a better view forward. Sometime between 1848 and 1865, the exact date not given, the forecastle deck made a tentative appearance (Waine, 1976). The first specialized bulk cargo-carrier, the collier John Bowes, was built in 1852. Although it was designed like the wooden sailing ships employed in the trade, the ship featured water ballast tanks to adjust the depth and angle at which the ship rode in the water. Bulkheads were also added to separate hold compartments, which improved ship stability and cargo handling capability while reducing the threat of flooding in the event the ship's skin was punctured. Water ballast tanks and bulkheads are common to modern cargo ships (Dougan, 1968; Waine, 1976).

Although (somewhat surprisingly) no sources corroborate this, the Merchant Shipping, or Moorsom, Act of 1854 would appear to have had a profound impact on the development of modern ship designs. This act established new definitions for calculating register tonnage (one ton being equal to 100 cubic feet) used to assess harbor duties and other charges. The Act defined gross tonnage as the ship's total permanently enclosed volume less certain exempted spaces such as water ballast tanks, wheel house, galley, and lavatories. Net tonnage was defined as gross tonnage less non-earning spaces such as crew accommodations, as well as allowances for engine and machinery space.

Since harbor duties and fees were based on the ship's net tonnage, shipowners expected net tonnage to be kept as low as possible without jeopardizing cargo-carrying capacity. Shipbuilders responded by adding non-permanently enclosed decks and spaces above the tonnage deck (first permanently enclosed deck) that could still be used to carry cargo. These decks and spaces were used to calculate gross tonnage but met the exemption requirements for calculating net tonnage (Waine, 1976). The practice was common by 1872 and was suspected of making ships unstable, leading to the implementation of the Plimsoll Line (1894), a legally required mark on the hull used to indicate when a ship was overloaded and to set its trim (Parliamentary Papers, 1969).

The profile of the modern ship began to take form in the 1860s with the appearance of the hurricane deck, a deck fitted at the bow to keep water from sweeping over the decks. Since the space under the deck was not necessarily permanently enclosed, it created more gross tonnage but not net tonnage (Waine, 1976). The blunt bow and square hull was common by the 1870s, the first so that ships could ride over seas, rather than through them, while the second reduced water turbulence and resulting drag at the propeller. For smaller vessels, the raised quarterdeck (at the stern) was extended and the hatches were placed in the well deck (between quarter and hurricane decks) on small ships. For larger vessels, the raised quarterdeck was extended all the way to the bridge which was placed approximately in the middle of ship. Finally, the superstructure became permanent when the bridge was completely enclosed (Waine, 1976).

1.3. Steam Propulsion

The main advantages of the early steamships were their greater speed and dependability. Unlike sailing ships that are subject to winds and tides, steamers could keep pre-arranged schedules and were faster than sailing ships, important qualities for the

Irish and Continental packet services which depended upon regular service and rapid turn-around time. These qualities allowed shipowners to charge premium fares for both passengers and low bulk, high value express freight, essential if owners were to recapture the steamship's higher initial and operating costs (Cunningham, 1903; Rowland, 1970).

Still, the early steamers were not suitable as trans-oceanic cargo-carriers because of their gross inefficiency in terms of converting heat into propulsive energy. Early engines required one half ton of machinery and 4.7 pounds of coal to generate one unit of indicated horsepower. Improvements in the engine plant before 1850 were directed toward reducing engine weight and size and improving fuel efficiency. Improvements in weight and size were gained through the development of and refinements to a succession of engines that attempted to either improve engine power or reduce size and weight, while fuel efficiencies were gained through improved boilers and steam condensers. Other improvements in engine and boiler performance were gained by improved metal working techniques, such as boring and screw making machines and close tolerance metal working techniques introduced in the 1840s; the development of petroleum based lubricants beginning in the late 1840s and lasting throughout the study period; and the perfection of the screw propeller (Elkins, 1884; Gilfillan, 1935; Jones, 1957; Riegel, 1924; Rowland, 1970; Walker, 1984).

1.3.1. Engines

The two engines in common use at the beginning of the study period were the side-lever and oscillating engines. These engines were simple to operate and suitable for the low boiler pressures used in the early British steamships. However, because of their low boiler pressures, they consumed excessive amounts of coal. By the early 1850s screw propellers were becoming more common, but the side-lever and oscillating engines were unsatisfactory for the screw because crankshaft revolutions were too low and had to be stepped up three to six times. Transmission systems were introduced as early as 1843, but they remained unsatisfactory throughout the study period (Elkins, 1884; Riegel, 1924; Rowland, 1970; Walker, 1984).

Rather than develop new transmission systems, a new engine was introduced. This was the compound engine, originally introduced in 1804 but not patented for marine use until 1852. The benefits of this engine were that it took better advantage of steam pressure, was coupled directly to the drive shaft, and developed high enough crankshaft revolutions to drive the screw propeller.

With the compounding system, steam entered a large diameter (low pressure) cylinder where it expanded to drive the large cylinder. The steam was then exhausted into a second, small diameter (high pressure) cylinder where it expanded again to drive the second cylinder before being condensed and returned to the boiler. Since more work was done by the same steam, the compound engine saved thirty to forty percent in fuel costs over a single expansion engine of the same horsepower, while increasing the ship's sailing radius as fuel stores went farther (Elkins, 1884; Riegel, 1924). The first engine was installed on the Brandon in 1853, the same year that the Crimean War started, and the new engine was used extensively for the resulting build-up of the merchant fleet (Gilfillan, 1835; Jones, 1957; McNeil, 1990; Moyse-Bartlett, 1968; Rowland, 1970).

In addition to savings in operating costs, the engine increased the regularity of the turning moment, yielding higher propeller efficiency, while also decreasing stresses and strains on the ship and engine frames, shaftings, and bearings. The engine was also much simpler in construction than previous engines, which reduced materials and further reduced costs (Riegel, 1924; Rowland, 1970; Pollard and Robinson, 1979). Toward the end of the study period the engine had been enlarged to the triple expansion engine (three pairs of cylinders) and then to the quadruple expansion (four pairs of cylinders), the latter engine remaining the standard for cargo ships until the introduction of the diesel engine (Jones, 1957; Walker, 1984).

1.3.2. Boilers and Condensers

Better engine performance and fuel consumption were also achieved through improvements to boilers and steam condensers. The first significant change to the boiler occurred in 1844 with the introduction of the marine fire tube boiler. Rather than circulating water through tubes placed immediately above the fire, as was done in the early steamers, flat horizontal tubes connected the combustion chamber to the funnel uptake. The tubes were surrounded by water and steam was generated as the hot gasses passed through the tubes and on to the funnel (Gilfillan, 1935; Jones, 1957; Reigel; 1924; Rowland, 1970). The Scotch boiler, introduced in 1862, operated on the same principle as the fire tube but was cylindrical in shape rather than box-like. This boiler became popular after 1870 because it was sturdy, reliable, and suitable for pressures up to 600 pounds per square inch (lb/in^2), and so ideal for long haul cargo ships (Rowland, 1970).

A year after the Scotch boiler was introduced, the surface condenser made a second appearance. The condenser allows the engine cylinder to perform useful work on the piston's downstroke by exhausting all unexpanded steam in the cylinder to create a vacuum. This is Watt's major improvement to the original Newcomen engine (Usher, 1954). The most commonly used condenser before the introduction of the surface condenser was the jet condenser. This condenser, which sprayed water into the cylinder, did not differ greatly from that invented by Watt. It was replaced beginning in 1863 with an improved surface condenser, first introduced in 1834 but never gaining wide popularity because of its complexity and maintenance requirements. The new surface condenser used a pump to draw unexhausted steam out of the cylinder and then pass it through tubes of cool, fresh water. Its most important improvements were that it improved the cylinder vacuum by using a pump to draw the unexhausted steam out of the cylinder, and reduced maintenance by using distilled water and employing filters to draw off lubricant residues (Rowland, 1970).

1.4. Screw Propeller

Although screw propellers were in use by 1840, this system required further improvements before it became a dependable propulsion system. First, wooden hulls could not tolerate the vibrations inherent with screws, so that its full implementation had to wait until iron hulls became the industry standard between 1840 and 1850. Second, the crankshaft had to be made to turn fast enough to make the screw work efficiently. Several transmission systems were patented beginning in 1844, but the problem was not solved until the compound engine was introduced. Finally, the rapid wear and tear of the stern shaft and propeller bearings had to be overcome and non-leaking, dependable stern bearings developed to allow the propeller shaft to pass through the hull. These tasks were accomplished between 1839, with the patenting of Babbitmetal, a soft alloy used for bearings, bushings, and seals; and lignum vitae stern bearings introduced in 1855 (Graham, 1958; Rowland, 1970, Taggart, 1969).

2. THE TRANSITION FROM WOOD AND SAIL TO IRON AND STEAM

Previous sections have established the origins of technical changes in 1840-1880 iron screw steamships. Before proceeding with a examination of the impacts of these changes on the iron steamship, the transition of the British shipbuilding and shipping industries over to the new ship will be discussed. In addition, four individual shipbuilding cycles are identified. These cycles coincide with the introduction of important innovations which changed the technological composition of the iron steamship. The following discussion is based largely on Figure IV-1, which graphs British sail and steam shipbuilding tonnage output for the 1840-1880 period. The graph extends to 1883 in order to include the entire fourth shipbuilding cycle. Data are obtained from B. R. Mitchell's British Historical Statistics (1988).

Three observations are in order. The first is that 1840-1880 shipbuilding, like the modern industry, was a very volatile industry subject to periods of boom and bust (Todd, 1985; Ville, 1990). The cyclical nature of shipbuilding output reflected in the graphs correspond to British trade cycles (Saul, 1985; Thomas, 1954) which, like business cycles in the United States, are characterized by rising output followed by market saturation and glut. These cycles are directly linked to the larger economy as demonstrated by their

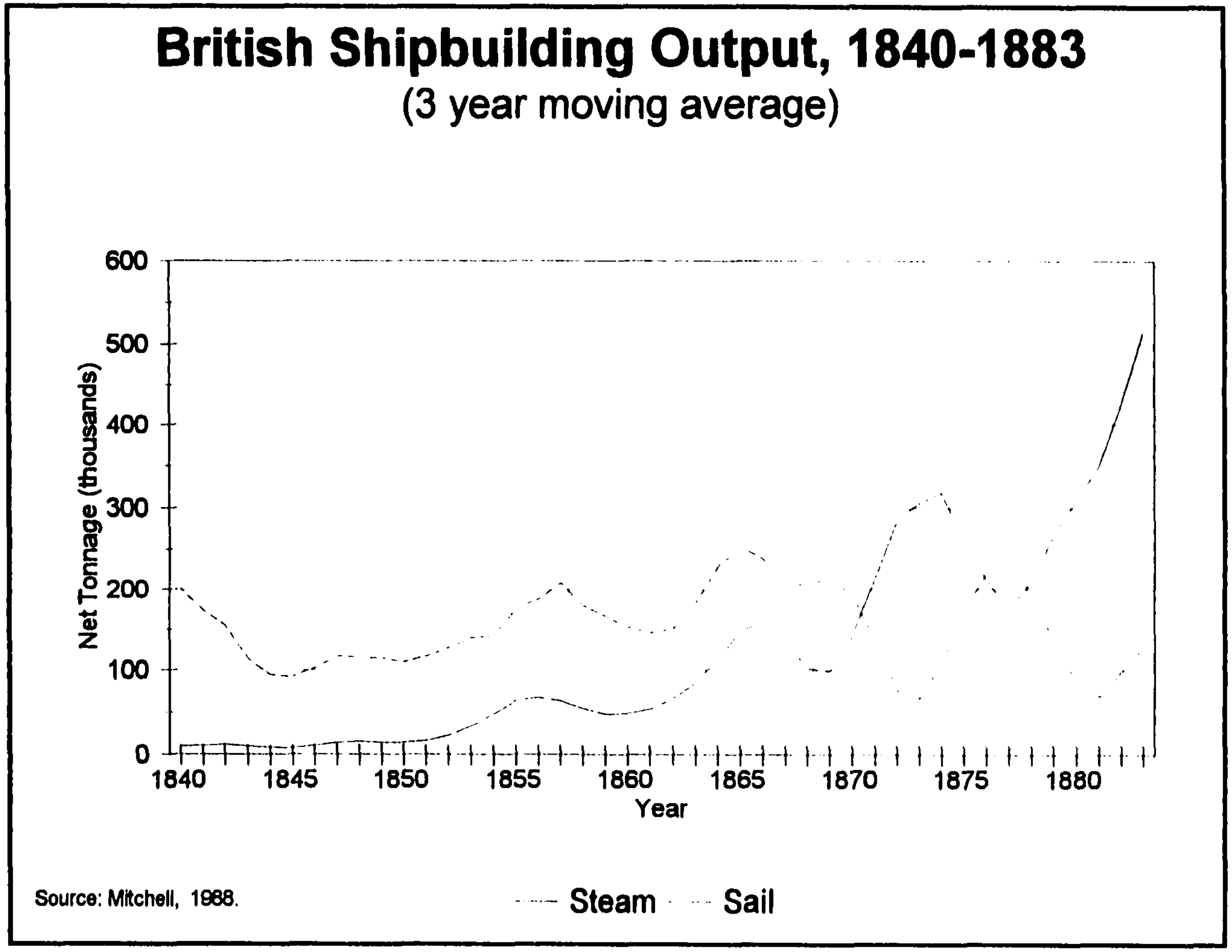


Figure IV-1: British Shipbuilding Output: 1840-1883 correspondence to fluctuations in British interest rates (Mitchell, 1991). The second observation is that the prolonged growth of iron steamship output between 1860 and 1866 clearly demonstrates the new ship's acceptance by the shipowning community, while the collapse in sail output coupled with growth in steam output demonstrates the change-over of the merchant fleet to steam. Finally, the opposite trend lines for the two ship technologies represents the existence of two distinct ship markets by 1869 and possibly as early as 1860.

2.1. Output

The traditional sailing ship dominated British shipbuilding output from 1840 to approximately 1870. With the exception of the 1840 to 1845 period, when iron steamship production remained stable during a decline in sailing ship output, steamship output tracked that for the larger industry. This trend continued until approximately 1865 and 1866, when output for the two ship types began to diverge. In 1865, sailing ship output began a decline, with a similar decline for the steamship beginning the following year. By 1867, sailing ship output experienced a brief revival until 1869, after which output declined to its lowest level for the entire study period. Steamship production, conversely, declined until approximately 1869 and then began a revival and growth period lasting until 1873. This divergence in output for the two ship types, with peaks for one type corresponding to troughs for the other, demonstrates that the iron steamship became the industry standard either in 1869 (from the graph), or in 1870 (Pollard and Robertson, 1979).

The reasons for this divergence are that the steamship became economically viable on most routes while the sailing ship remained an attractive alternative for shipowners during depressions in overseas trade. Steamships became viable because of the introduction of the multiple expansion engine in 1852 and the opening of the Suez Canal in 1868. The introduction of the multiple expansion engine made the marine steam engine an efficient, cost effective propulsion system. The engine was specifically developed for screw propulsion and, when combined with the more efficient boilers that were coming into general use at this time, allowed for fuel savings of between 30 to 40 (Rowland, 1970) or 40 to 50 percent (Jones, 1957). The opening of the Suez Canal in 1868 considerably shortened voyages and reduced the distance between coaling stations, so that the steamship was now an economically viable ocean-going cargo carrier on most major routes (Fletcher, 1958; MacGregor, 1984; Moyse-Bartlett, 1968).

Shipowners continued to order sailing ships because they remained viable for the wool trade from Australia and the nitrate trade from the South American west coast until the opening of the Panama Canal (Cunnison and Gilfillan, 1958; Moyse-Bartlett, 1968). In addition, sailing ships remained attractive during depressions because they were cheap and therefore price competitive during periods of reduced shipping and trade. When trade increased, however, demand for the more expensive, but much more efficient steamships also increased, causing depression in the wooden shipbuilding industry (Cunnison and Gilfillan, 1958).

2.2. Cycles

Figure IV-1 also shows four distinct iron and steam shipbuilding cycles. Although two distinct cycles occurred at the beginning of the period, 1840-1847 and 1848-1855, iron and steam shipbuilding output remained fairly stable until the 1850-1855 upswing. As a result, the two early cycles are combined for this and all subsequent analysis. The four cycles are dated using Mitchell's tabular shipbuilding output, rather than the moving averages in Figure IV-1 which have been "smoothed." Each cycle runs from the year with the highest output and to the year immediately preceding the next peak in output. The exception are the first cycle, which began before the start of the study period, and the last cycle which ended in 1883. The cycles are:

Cycle 1: 1840-1855
Cycle 2: 1856-1865
Cycle 3: 1866-1872
Cycle 4: 1873-1880

Cycles for iron and steam shipbuilding correspond to those for the larger industry up until 1867. During the first cycle, 1840-1855, shipbuilding output is dominated by sail. Steamship output is relatively stable from 1840 to 1843, unlike the larger industry, suggesting that the market for steamships was somewhat distinct from that of the overall ship market. Steamship output comes into synch with the larger industry in 1842, after which its cycles are indistinguishable (except that peaks and troughs for steam occur from one to two years before those for sail) for those of the larger industry until 1865. The bust cycle ending in 1843 can be associated with the world wide trade depression beginning in 1839 (Temin, 1969), while the crashes in 1855 and 1865 are due to the gluts of shipping capacity following the Crimean and American Civil Wars, respectively (Pollard and Robertson, 1979; Todd, 1985; Walker, 1984). By the beginning of the third shipbuilding cycle, steam and sail output begin to diverge. In 1868 the two cycles take opposite tracks, with steam output entering a growth period in 1869 while that for sail is delayed until 1873 and never again reaches its 1865 peak. (The crash in 1873 can be associated with the world-wide financial crisis that began as early as 1866 (Kendleberger, 1990; Pollard, 1989; Saul, 1985).) This divergence demonstrates that the iron steamship became the dominate shipbuilding technology and that two distinct industries, sail and steam, had emerged by 1868.

3. IRON STEAMSHIP CHANGE

The technological changes discussed earlier resulted in increases in average ship size, power, and efficiency over the course of the study period. The following discussion is based on Table IV-1, which shows increasing engine plant efficiencies in terms of horsepower and coal consumption. These data are collected from various sources. Figures IV-2 through IV-4 graph annual changes in average ship size (gross tons per ship), engine horsepower, and ship power (gross tons divided by horsepower) based on technical measurements in the Lloyd's Register available for the entire study. At the same time, these changes are placed within the context of the shipbuilding cycles discussed above to show that technological changes introduced either in preceding cycles or immediately at the beginning of a cycle resulted in distinct phases in the development of the common practice steamship.

3.1. Engine Efficiency Gains

Efficiency gains to the entire propulsion system created by improvements in engines, boilers, condensers, and screw propulsion are shown in Table IV-1. The data are obtained from discussions of improved steam engine performance located in Elkins (1884) and Reigel (1921). Although incomplete, the data indicate steady steam engine efficiency gains throughout the study period. Boiler pressure, using the original box-boiler, was only 5 pounds per square inch (lb/in^2) in 1834. The use of the fire-tube boiler, introduced during the first shipbuilding cycle, and following improvements raised boiler pressures to between 25 and 40 lb/in^2 in 1862. Finally, at the end of the third cycle in 1872 and with the common use of the Scotch boiler, pressures had risen to between 45 and 60 lb/in^2.

TABLE IV-1: 1840-1880 Changes in Boiler Pressure and Coal Consumption

Year	Expansion	Boiler Pressure [1]	Coal Consumption [2]
1834	single	5 lb/in^2	***
1840 (Cycle 1)	single	***	4.7 lbs/hp
1852 (Cycle 1)	single	***	3.75 lbs/hp
1862 (Cycle 2)	compound	25-40 lb/in^2	***
1872 (Cycle 3)	compound	45-60 lb/in^2	***
1873 (Cycle 4)	compound	***	2.5 lbs/hp
1892	triple	***	1.5 lbs/hp

*** no data
Source: [1] Elkins, 1886; [2] Riegel, 1921

Reductions in coal consumption were even more dramatic. The amount of coal consumed to generate one unit of indicated horsepower (lb/hp) declined during the first cycle, from 4.7 lb/hp in 1840 to 3.75 lbs/hp in 1852. By the beginning of the last cycle, in 1873, and after the full implementation of the changes discussed above, coal consumption had fallen to 2.5 lbs/hp Coal consumption continued to fall with the introduction of the triple and quadruple expansion engines to a low of 1.5 lbs/hp in 1892.

3.2. Increases in Ship Size and Power

The following graphs conclusively demonstrate that the technological changes of the 1840-1880 period dramatically increased the size and power of the ship. However, these increases were not continuous but rather were accomplished through net gains from one cycle to the next. Note that dramatic increases in ship size and power occur either immediately before, during, or after the transitions between shipbuilding cycles. This suggests that the benefits of technological innovations introduced during one economic cycle are not fully realized until following cycles. This finding supports arguments made by authors ranging from Kuznets (1930) to Hyde (1977) to Mensch (1978). The declines in the later phase of the cycle are most likely due to the retrenchment within the shipping industry in response to declining trade.

The first graph in the series (Figure IV-2) reports average annual iron steamship size in terms of gross tons, a measure of permanently enclosed ship volume. The years 1843 and 1844 contain single observations which distort the trend and the following graphs at the beginning of the study period. The graph demonstrates that average ship size increased for the entire study period. Average gross tonnage rose from approximately 183 gross tons in 1845 to 1400 tons by 1880. The only exceptions to this record of steady growth in average ship size are three periods of decline: from 1857 to 1860; 1865 to 1868; and 1874 to 1877. Despite these periods of decline, however, average size never fell below the peak of the previous cycle. The periods of declining ship size correspond to

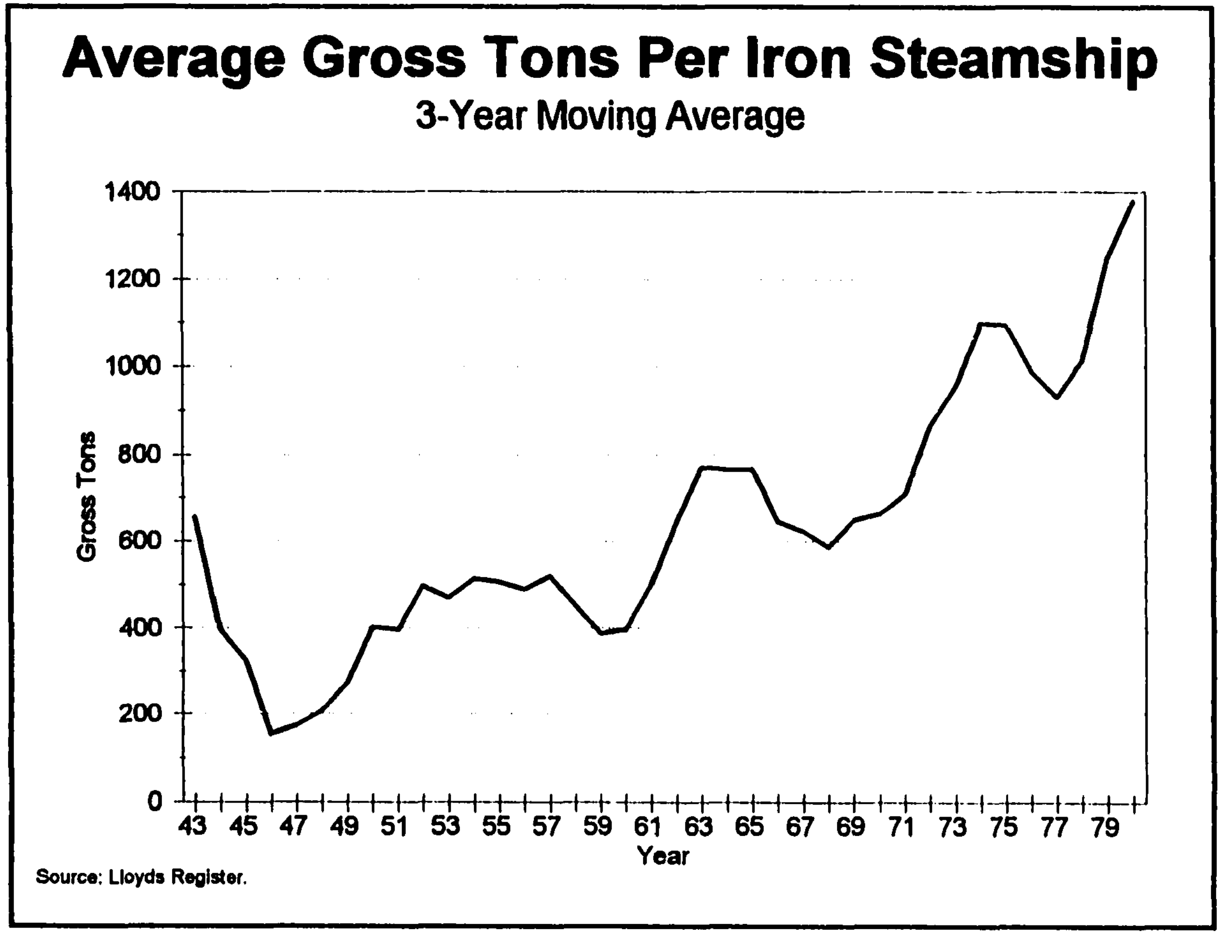


Figure IV-2: Average Gross Tons Per Iron Steamship periods of declining iron steamship output and most likely reflect demand within the shipping industry for smaller ships during periods of economic contraction. This observation is suggested by the fact that the first two periods correspond to ship market gluts following the Crimean War and American Civil War, respectively (Hughes and Reiter, 1958; Lester, 1975; and Spencer, 1983).

The trend for engine horsepower (Figure IV-3) is less clear than that for average ship size. The graph shows that, except for brief periods of fluctuation from 1852 to 1854 and 1856 to 1858, average engine horsepower increased steadily until 1863. This year is significant because it coincides with the introduction of the Scotch boiler (1862) and surface condenser (1863). After 1863, the trend for average horsepower is characterized by both large fluctuations and overall decline. Interestingly, periods of increasing average horsepower, either before or after 1863, correspond to periods of declining average ship size. The reason for this correspondence is unclear, but could possibly be due to the need for more powerful engines for smaller ships with larger length-to-beam ratios.

The reasons behind the decline in average horsepower clarify when we consider annual changes in average ship power (Figure IV-4). This variable is calculated by dividing the ship's gross tonnage by engine horsepower to measure the amount of gross tonnage propelled by one unit of engine horsepower. The performance of ship power is unlike that of average horsepower in that the period before 1869 was highly cyclical but characterized by a slight overall increase in power. The exception is the period of rapid growth beginning in 1861 and then the just as rapid decline until 1869. Periods of increasing and declining ship power correspond with those for average ship size and

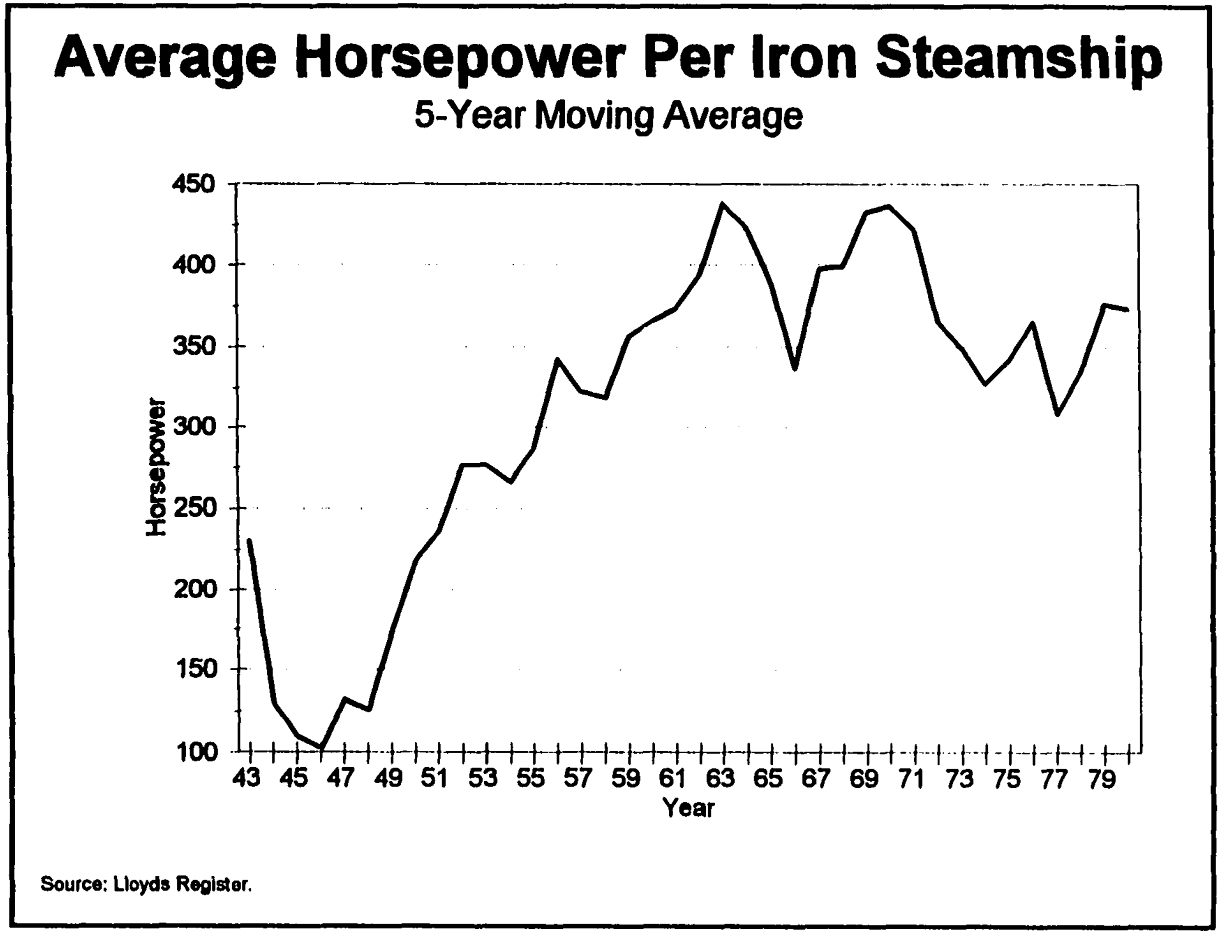


Figure IV-3: Average Horsepower Per Iron Steamship

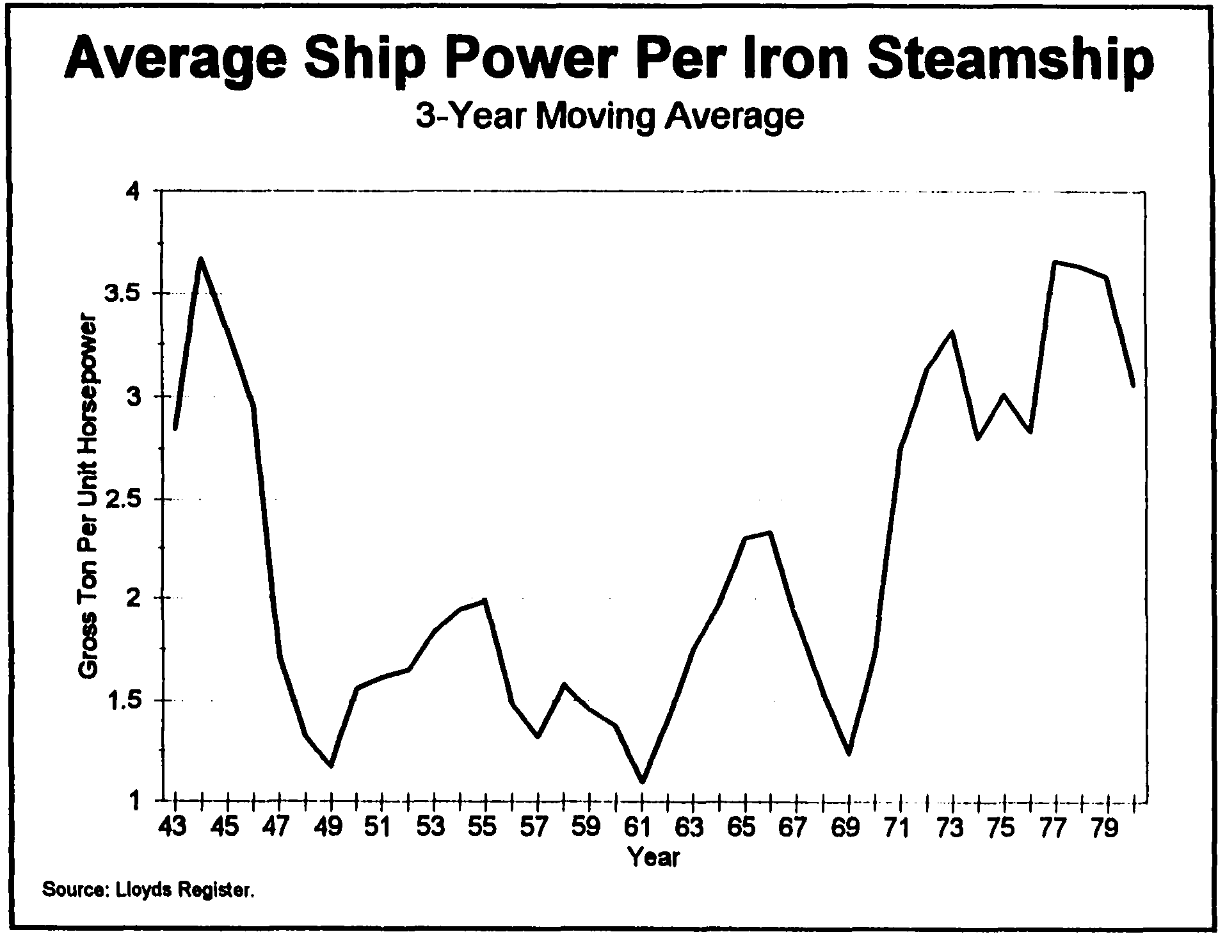


Figure IV-4: Average Ship Power Per Iron Steamship horsepower, suggesting only modest increases in ship power before 1869. After 1869, however, and around the same time the use of the Scotch boiler and surface condenser (introduced in 1862 and 1863, respectively) were widespread, ship power rises dramatically until 1873. After this year, the cyclical trend characteristic of the pre-1869 period resumes.

These graphs demonstrate that, despite the high fluctuations in horsepower and ship power, the amount of power installed on individual ships rose steadily during the period, indicating that shipbuilders were using engines commensurate with the power requirements of the individual ship. This observation suggests increasing ship power efficiency and, since this is not indicated by average horsepower alone, supports the argument made earlier that greater power efficiencies were the result of complex inter-relationships between the iron steamship's two component technologies, iron construction and steam propulsion, and their sub-systems.

4. SUMMARY AND CONCLUSIONS

British experiments in iron construction and steam propulsion began at the beginning of the nineteenth century. By the late 1830s, the innovation process had advanced to the point that the iron screw steamship was accepted by the shipping industry for trans-oceanic trade routes. This acceptance initiated a forty year innovation cycle that transformed the iron screw steamship from a ship type suitable for only a few select trade routes to the dominate trans-oceanic cargo carrier.

This revolution in ship technology was the result of successive improvements in two basic ship technological systems over the course of the 1840-1880 period. Iron construction techniques and ship designs led to cargo carriers that were much more efficient than traditional wooden ships, while a succession of improvements to the propulsion system, including engines, condensing systems, and boilers resulted in dramatic efficiency gains. Although the 1840-1880 innovation cycle concluded with the change-over to steel construction and the multiple expansion engine, modern iron construction techniques, ship designs, and propulsion systems were in place.

Significantly, however, the innovation process was not continuous. The 1840-1880 period can be broken into four genuinely distinct cycles caused by periods of economic expansion and depression within the shipbuilding and shipping industries. These cycles are important to any understanding of technological change within the shipbuilding industry for two reasons. First, changes in key technological indicators, such as average ship length or horsepower, track shipbuilding output fluctuations. Second, these changes were not continuous but rather occurred in jumps from one cycle to the next. This strongly indicates that innovations introduced in one cycle were not fully exploited in commercial terms until the following cycle.

This chapter has established the important changes that occurred in the two iron steamship component technological systems: iron construction and steam propulsion. These findings will be used in Chapter VI to direct the specification of four multiple regression models that identify the most significant technological changes that characterized the 1840-1880 iron steamship. These four sets of significant variables are then used to construct the innovation index that will be used to test for association between innovation and place.

CHAPTER V

THE 1840-1880 BRITISH IRON AND STEAM SHIPBUILDING INDUSTRY

The adoption of the iron screw steamship had a profound impact on the British shipbuilding industry. The new technologies required an expansion in shipyard scale and complexity, altered factor inputs, and created new industrial linkages. These changes relaxed the industry's traditional locational requirements and allowed for its spatial reconfiguration at a variety of scales.

This chapter examines the 1840-1880 British shipbuilding industry. It begins with a discussion of changes in shipyard operations and factor inputs that were brought about by the new shipbuilding technologies. It demonstrates that these changes altered the industry's locational requirements, primarily reflected in the industry's shift from southern centers to formerly peripheral northern centers. The industry's spatial relocation, at both the national and intra-regional levels, is then discussed. The chapter concludes with a survey of 1840-1880 British iron and steam shipbuilding regions, identifying component shipbuilding centers, their advantages and disadvantages, and their performance between 1840 and 1880.

1. INDUSTRIAL CHANGE

This section begins with an examination of changes within the shipbuilding industry. It examines changes in shipyard operations that altered the locational requirements for any particular shipyard. This is followed by a discussion of changes in factor inputs that weakened the position of established shipbuilding centers and allowed for the industry's spatial reconfiguration at a variety of scales.

1.1. Shipyard Operations and Site Requirements

In 1840, the shipbuilding industry was dominated by wooden sailing ships. A suitable site for wooden ship construction required frontage on a river channel which was wide and deep enough to launch and swing the ship; space to stock timber and erect the ship; and proximity to raw materials, skilled labor, and ship markets. Equipment was negligible and primitive. Little capital was required, so the industry was made up of a large number of highly competitive but generally small scale producers who could enter and leave production as economic conditions warranted (Jones, 1957).

Although basic ship construction steps are the same for both types of ship, iron and steam shipbuilding required massive increases in the scale and complexity of shipyard operations. New construction techniques required new and much more powerful methods for manipulating and transporting individual structural pieces, as well as more efficient layouts that maximized iron through-put from unloading to final erection. In addition to building berths and storage areas, the new shipyard was laid out differently to accommodate furnaces for heating the iron; steam-powered machines to cut, roll, and punch holes into frames and plate; and workshops for bending structural pieces. If carried out at the same location, workshops for engine- and boilerworks required even more space and capital (Abell, 1980; Hume, 1976; Walker, 1984). These changes transformed the shipyard from a small, handicraft type shop to a large industrial operation with a highly organized labor force using complex power tools (Pollard and Robertson, 1979).

As ships became larger, the construction process became more complex. As the construction process became more complicated, the shipyard required more area and more capital intensive equipment (Jones, 1957). By the late 1860s and early 1870s, when ships were becoming much larger and construction processes more complicated, shipyard productivity was increased through more efficient yard layouts, including the replacement of block and tackle with sheerless booms for lifting frames and plates, and the development of more powerful machine power tools (Pollard and Robertson, 1979; Walker, 1984).

There were also iron shipyards that operated at a much smaller scale than those described above, reflecting a more traditional approach in terms of both ship construction techniques and business strategy. Although their operations were similar in regards to machinery and yard layout, the smaller scale yards were much less capital intensive and by and large still relied on the same locational and business strategies used by the wooden shipyards. These yards were located in the smaller ports and were usually operated in conjunction with ship repair facilities. The small yards specialized in the production of small coastal steamers for the local market and could either close down or concentrate on ship repair operations during shipbuilding slumps (Waine, 1976).

1.2. Factor Inputs

Changes in shipyard operations changed the nature and relative importance of raw materials, land, labor, and capital. These changes relaxed the shipbuilding industry's traditional locational requirements and allowed for its spatial reconfiguration. While not deterministic, differences in factor prices favored new and/or formerly peripheral shipbuilding regions and disadvantaged traditional shipbuilding regions once the new shipbuilding practices became established.

1.2.1. Raw Materials

Iron, both for ship construction and ship machinery, was the industry's single most important raw material. As a result, shipbuilding activity was attracted to areas with established iron and mechanical engineering industries. The most favored locations were those near the innovative iron producing regions in Scotland and the North East Coast (Hyde, 1977). These centers were also able to attract large scale mechanical engineering industries (Hyde, 1977; Pollard and Robertson, 1979). Although regional variations in iron prices and transport costs tended to equalize over the course of the study period, northern shipbuilding centers enjoyed initial advantages because they were able to form closer business relationships with local iron producers (Jones, 1957; Pollard and Robertson, 1979; Warren, 1990).

1.2.2. Land

The early iron and steam shipbuilders were located in urban areas because of the locational advantages of access to subsidiary industries and ship and capital markets. Urban advantages eroded as the iron and steam industry became established in that congested shipping lanes and high urban land costs soon worked to create localized diseconomies of scale. These disadvantages were avoided in the newer regions by either hiving off operations or relocating entirely to low-cost satellite communities further down the urban hierarchy. This was made possible by infrastructural improvements, primarily in the form of straightening and deepening river channels and developing new industrial sites along their banks (Dougan, 1968; Pollard and Robertson, 1979; Walker; 1984). Relocation was not an option for the traditional regions, however, either because potential river improvements which might permit the development of new sites down the urban hierarchy had already been exploited or because of conflicts with the shipping industry. Firms located in these traditional regions were clearly at a serious disadvantage relative to those in the newer regions. As a result, many traditionally successful firms were forced to either relocate out of the region or left the industry altogether (Pollard, 1950; Pollard and Robertson, 1979).

1.2.3. Labor

Iron and steam transformed shipbuilding into an assembly trade with a more highly organized but less skilled labor force. Changes in labor force requirements began almost immediately with the introduction of iron and steam as shipbuilders adopted many of the labor practices used in engine- and boilerworks. Since most machine operations and new ship assembly techniques could be carried out by relatively unskilled workers, immigrants were employed in these tasks (shipwrights and apprentices, more highly skilled and higher paid, were retained because of the power of their trade organization). Since immigrants were attracted to low skilled jobs in urban areas, urban shipyards enjoyed initial advantages in labor recruitment and training. These savings in labor costs did not last, however, primarily because of the early establishment of trade unions and the development of inter-regional labor markets in the industry. At this point the advantage often swung in favor of those centers located down the urban hierarchy where housing and other amenities could be provided (Pollard, 1950; Pollard and Robertson, 1979).

1.2.4. Capital

The large fixed plant required for an iron shipyard was much more capital intensive than that for a wooden shipyard. Initially, shipbuilders received financial backing from the mechanical engineering industry and the owners of steam packet lines. Again, these sources were located in large ports. By the 1850s, which saw the expansion of the new ship into bulk cargo routes, funds became available from regional mining and iron interests that employed specialized iron steamers. Most shipyards were owned by single proprietorships or by family groups and, since the vast majority of ships were built on order from shipowners, with regular payments made during the course of the ship's construction, operating funds and capital for expansion was often raised within the firm. Capital markets formalized after the mid-1850s with shipbuilders obtaining funds from both local and regional financial institutions. Although several joint stock companies were formed between 1856 and 1865 (the second shipbuilding cycle identified in the previous chapter), survival rates were not high and this method for capital accumulation was not heavily utilized during the study period (Dougan, 1968; Pollard and Robertson, 1979; Slaven, 1992; Walker, 1984).

2. SPATIAL CHANGE

Accepting that changes in site location and factor inputs were required as the industry responded to new forces of agglomeration and economies of scale, this section examines the spatial changes within the 1840-1880 British shipbuilding industry. The discussion begins by establishing the spatial industrial system at the beginning of the study period, and then documents the changes in the system brought about by changing site requirements and factor inputs.

2.1. Circa-1840

The shipbuilding industry in 1840 was widely scattered simply because no single region had sufficient river frontage to handle all the yards needed to satisfy the country's annual demand for new shipping. The major centers dominated by wood and sail were located on the rivers Thames and Mersey, the ports of Bristol and Dublin, and smaller ports in East Anglia and on the North East Coast (Dougan, 1968; Jones, 1957; Pollard and Robertson, 1979). Of these centers, London and Liverpool, on the Thames and Mersey, respectively, built the highest rated ships and enjoyed the highest product identification (Pollard and Robertson, 1979). Although firms with several ports had experimented with iron shipbuilding, for example Bristol where the Great Western was built, iron and steam shipbuilding was still heavily concentrated in London, Liverpool, Birkenhead (also on the Mersey), and on the River Clyde in Scotland (Pollard and Robertson, 1979; Walker, 1984).

Shipbuilders in large urban ports enjoyed locational advantages over builders in the smaller ports. Ships built in these locations were rated higher than those built in smaller ports and enjoyed high product recognition. The urban location also gave access to a large ship market, and shipbuilding output was directly proportional to the trade of the port. Further, pools of skilled workers from the local building trades were readily available for both ship construction and finishing work, allowing builders in urban ports to better handle rush orders (Pollard and Robertson, 1979).

2.2. Post-1840

Iron and steam shipbuilding transformed the industry's locational requirements and allowed for the British industry's spatial restructuring at both national and regional scales. At the national level, the industry shifted out of the traditional shipbuilding regions and centers in the south to formerly peripheral regions and centers in the north. At the regional level, the industry expanded out of the original urban centers to satellite communities once the shipbuilding process became standardized and the center's agglomeration advantages began to erode.

Once iron and steam shipbuilding was established in the 1840s, the industry's primary locational concerns included convenient access to iron and mechanical engineering industries, cheap labor, ship and capital markets, and repair facilities. These concerns favored urban centers located on northern rivers. Firms at these new locations saved on raw material transport costs and realized business advantages through backward linkages to iron and machinery makers and forward linkages to shipowners. Secondary factors in the location decision were the port's volume of trade, capital markets, and engineering ability (Pollard and Robertson, 1979).

By the early 1850s, iron shipbuilding was increasingly concentrated in centers on the Clyde and North East Coast that offered cheap factor inputs; large ship markets; and subsidiary industries such as machinery, engine- and boilerworks, and repair services. Like the established wooden shipbuilding centers, the new iron concentrations enjoyed high product recognition and tended to attract shipbuilding migrants. These advantages improved the individual firm's costs and profitability, providing competitive advantages over the declining older southern regions. Other regions that successfully converted to the new ship technology were the Scottish East Coast and the River Humber (Jones, 1957; Pollard and Robertson, 1979).

The 1850s and 1860s also saw a high degree of concentration in small towns within the regional industrial system. The growth of these centers was due to intra-regional shifts as firms migrated out of congested urban shipyards and into small towns and new industrial sites. These shifts were made possible by river improvement projects that straightened and deepened river channels. The new locations allowed firms to maintain business relationships established in the original center while avoiding much higher urban land prices and congestion (Dougan, 1968; Walker, 1984). Another advantage was the firm's ability to better control workers and dominate the small towns socially, politically, and economically (Pollard and Robertson, 1979).

Intra-regional shifts occurred for both the Clyde and North East Coast regions. Shifts on the Clyde, accomplished before the beginning of the study period, were characterized by movement beyond Glasgow's corporate limits to immediately adjacent communities or further down the river. Similar shifts on the North East Coast began in the 1850s and were confined to the rivers Tyne (Newcastle) and Tees (Stockton) (Dougan, 1968; Pollard and Robertson, 1979; Walker, 1984).

3. BRITISH SHIPBUILDING REGIONS

This section presents 1840-1880 British iron and steam shipbuilding regions and their component centers (figures V-1 through V-6). Each center is assigned to one of ten shipbuilding regions. These regions, following standard regionalization schemes used by

Pollard and Robertson (1979), Todd (1985) and others, are named for either the river or sea coast on which they are located. Six of the regions are complete functional systems. Three regions include isolated ports that were not functionally a part of the region to which they are assigned (Mersey) or by combining several individual regions into one greater region (Ireland and Severn). The final region (Irish Sea) consists of isolated ports between the Mersey and Clyde regions. These centers were not functionally linked but each depended local iron supplies and industrial relationships with the Clyde.

3.1. Clyde

The Clyde was the largest and most famous shipbuilding region in the world. It was not one of Britain's traditional shipbuilding regions, however, and its success was due to its early specialization in iron and steam. The Clyde was considered to be Britain's most innovative shipbuilding region, and its list of innovative firsts include: technically and commercially successful steamboats; an exclusively iron and steam shipyard; specialized machinery, and the compound expansion engine (Hume, 1976; Jones, 1957; Walker, 1984).

Factors influencing the region's growth included the local availability of iron and coal, large pools of both skilled and unskilled labor, an established mechanical engineering industry, and local capital and ship markets. Iron for structural pieces and machinery came from the large local iron and mechanical engineering industries. Skilled labor was obtained from local mechanical engineering establishments and foundries, while unskilled labor was imported from Ireland. The river's large merchant fleet provided a ready ship market, while capital was obtained from shipowners, formal financial institutions, and shipbuilders (Hyde, 1977; Robb, 1958; Slaven, 1992; Turnock, 1982).

The distribution of Clyde shipbuilding centers is presented in Figure V-1. The region's most important center, Glasgow, was located at the Clyde's head of navigation. Next in importance were Greenock, Port Glasgow, and Dumbarton, located at the mouth of the river, and Paisley and Renfrew nearer Glasgow. Average ship size data from the Register suggests that only Greenock and Paisley specialized in particular types of ships, with the former producing large ships and the latter small coastal traders. The location of the minor centers of Bowling, Maryhill, and Whiteinch suggest relocation out of the larger, nearby centers. Campbelltown, located on the Kintyre peninsula in the Forth of Clyde, did not begin production until the very end of the study period.

3.2. Scottish East Coast

The Scottish East Coast (Figure V-1) was the Register's fourth largest producing region. Shipbuilding was a prominent industry during the eighteenth and early nineteenth centuries. The region made an early entrance into iron and steam shipbuilding, with its first wood and iron steamships being built in 1823 and 1838, respectively. However, the region is considered to have been in decline during the 1840-1880 period because of the relocation of many Aberdeen shipbuilders to both the Clyde and North East Coast and the decline of trade at the region's principal port, Leith (Bremner, 1869; Lenman, 1981; Turnock, 1982). The region's success came from its specialization in specialty ships such as coastal steamers and fishing vessels (a strategy still followed today) (Pollard and Robertson, 1979; Todd, 1985; Waine, 1976).

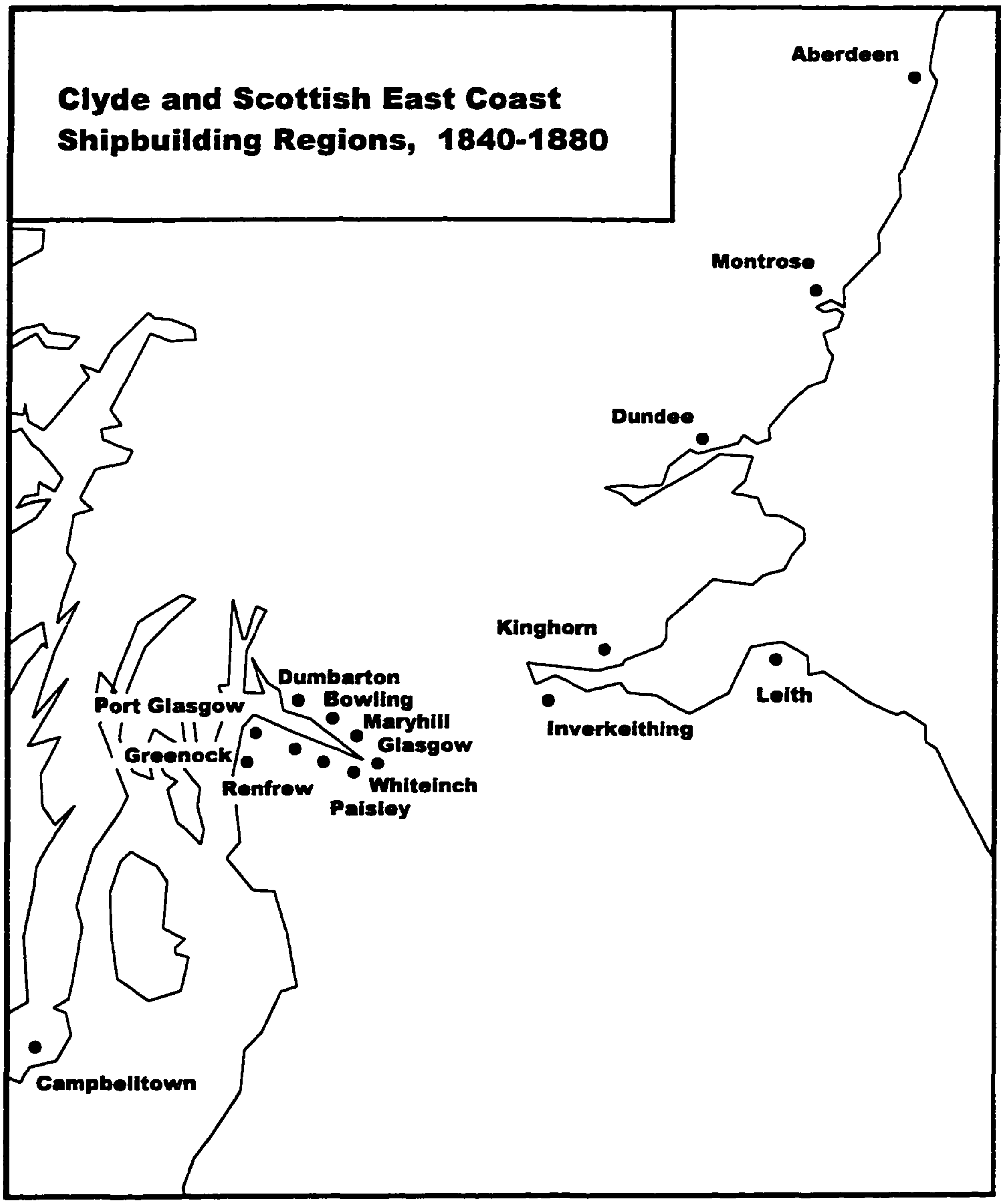


Figure V-1: Clyde and Scottish East Coast Shipbuilding Regions

Six centers were in production at one time or another during the study period. The two most important centers were Dundee and Aberdeen. Kinghorn and Inverkeithing, located on the Forth of Firth, were in production for a limited amount of time, Kinghorn appearing to specialize in large ships while Inverkeithing produced coastal steamers or smaller specialty craft. Leith, located at Edinburgh, and Montrose were very small centers (Turnock, 1982).

3.3. North East Coast

Three sub-regions, the Wear, Tyne, and Tees (Figure V-2), are combined to form a single North East Coast shipbuilding region. This regionalization scheme follows that of most shipbuilding historians. examples being Dougan (1968), Pollard and Robertson (1979), and Todd (1985). The classification is based on their dependence on the North East Coast iron and steel and coal mining industrial system (Hyde, 1977; Warren, 1990). While output for each individual region was less than fifty percent of the Clyde's, the combined output of all North East Coast centers was 31.5 percent greater than that for the Clyde.

Although the region built Britain's first iron vessels, in actuality the North East Coast did not vigorously enter into iron and steam shipbuilding until relatively late. Although authors disagree on the exact location and year, the region's first iron steamer was built on the Tyne in approximately 1840, while the first ship on the Tees was built in 1854 on and the Wear in 1858 (Dougan, 1968; Pollard and Robertson, 1979; Smith and Holden, 1953). Despite the region's late start and the small scale of its shipyards even as late as 1850, it was the first region to switch exclusively to iron and steam shipbuilding,

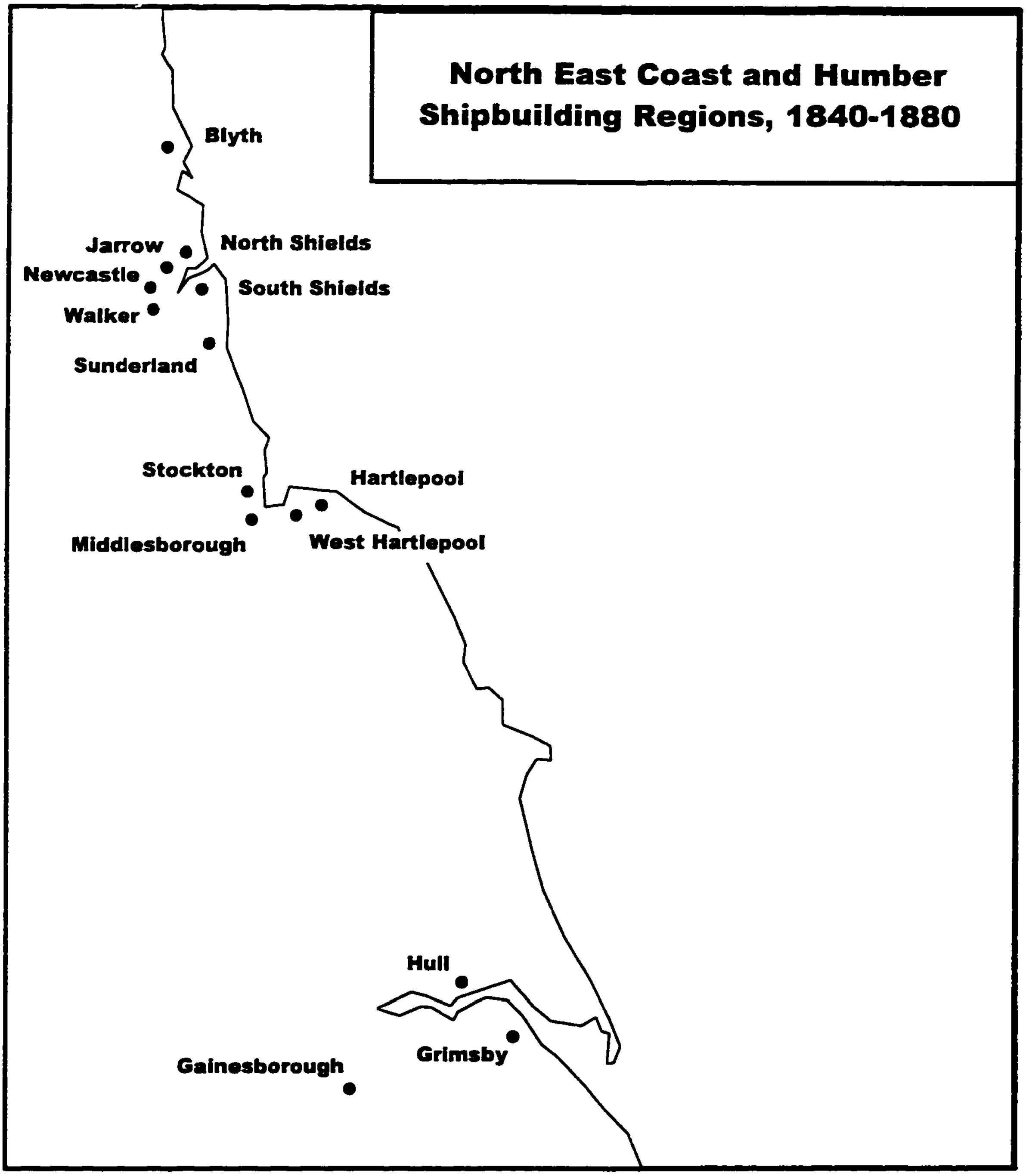


Figure V-2: North East Coast and Humber Shipbuilding Regions accomplished in 1863 (Dougan, 1968). Somewhat surprisingly, the North East Coast did not enjoy a reputation for its innovative ability at the time, though major innovations originating in the region included water ballast tanks (1840), the first bulk cargo-carrier (1852), and the double bottom water ballast tank (1860) (Dougan, 1968; Pollard and Robertson, 1979).

The region's primary locational advantages lay in access to cheap iron and machinery as well as close proximity to ship and capital markets. The region's iron industry was established soon after the introduction of Cort's puddling process (Jones, 1957), while engine works were established at Newcastle as early as 1820 (Dougan, 1968). The locational advantages in raw materials and components attracted shipbuilders from the Scottish East Coast, especially from Aberdeen, who established the region's first iron and steam shipbuilding yards on the Tyne. Demand for shipping and capital for investment in the new shipbuilding industry was provided by local iron and mining interests, who required efficient bulk cargo carriers. These ships transported coal to English (primarily London) and Continental coal markets, while iron ore was carried to the region's iron furnaces from local iron ore mines and later from mines located in Spain. The John Bowes, built in 1852, was the first iron and steam collier and revolutionized the bulk transport of both of these commodities. The region did not have an advantage in labor costs, with wages generally higher than those on the Clyde, but this disadvantage was overcome by longer working hours and the institution of piece work and sub-contracting (Dougan, 1968; Pollard and Robertson, 1979; Waine, 1976).

The Tees was the largest producer of the three sub-regions. The sub-region was centered on Stockton, which built the first iron steamer and also built the largest amount of tonnage on the North East Coast. New sites closer to the coast were developed following river improvements begun in 1852. New centers were the Hartlepools and Middlesborough, the latter the second largest center on the river (Dougan, 1968; Pollard and Robertson, 1979). Sunderland was the only center in the second largest producing sub-region, the Wear. This center was a very old shipbuilding port, specializing in wooden colliers, but it had the poorest reputation, in terms of ship quality and ship innovations, of any shipbuilding region in the study (Smith and Holden, 1953; Ville, 1990).

The final region was centered on the Tyne, specifically Newcastle and its suburbs Walker and Jarrow. Newcastle was the home of the Hawthorne Engine Works, which specialized in marine steam engines, and the Palmer Shipbuilding Company, builder of the John Bowes, (the Palmers Shipbuilding Company also operated a yard in Jarrow). River improvements begun in 1850 led to the development of the Shields: South Shields, the region's second largest producer; and, after a significant drop-off in output, North Shields.

3.4. Humber

The Humber was one of the few traditional wooden shipbuilding regions that successfully made the transition to iron and steam. Hull (Figure V-2), the region's principal center, was Britain's third largest port, trading mainly with the Baltic ports (Encyclopaedia Britannica, 1882). The center specialized in coastal steamers and bulk cargo carriers for local shipowners (Pollard and Robertson, 1979; Waine, 1976). No information is available for the minor centers of Grimsby and Gainesborough.

3.5. Thames

The Thames, centered on London, was Britain's oldest and most famous shipbuilding region (Figure V-3). Although best known for its wooden sailing ships, the Thames was one of the three pioneering iron and steam shipbuilding regions, with engine works established as early as 1810 and iron shipbuilding by 1825 (Rowland, 1970). Considered by many authors to be Britain's most innovative iron and steam shipbuilding region, the Thames claimed the country's most scientific shipbuilders and naval architects and was a leading center in the development of close tolerance metal working techniques (Banbury, 1971; Pollard and Robertson, 1979; Parkinson, 1960; Rowland, 1970).

Although London's advantages lay in its large ship and capital markets, as the industry matured it was fatally disadvantaged by high costs for raw materials, land, and labor. Transport costs kept material costs much higher than those on the Clyde and North East Coast. Congestion along the city's river front drove up land prices and major river improvement and site development schemes had all been completed before 1840. The region's greatest drawback, according to Pollard (1950), was the ability of the strong local trade unions to enforce high wage rates.

Despite its reputation for innovative ability, the Thames region declined with the increased adoption of the new ship. In 1863 the river produced 117 thousand register tons of shipping, or one quarter of all British shipbuilding output, but the industry collapsed after 1865 in the face of rapidly increasing costs (Banbury, 1971; Pollard, 1950;

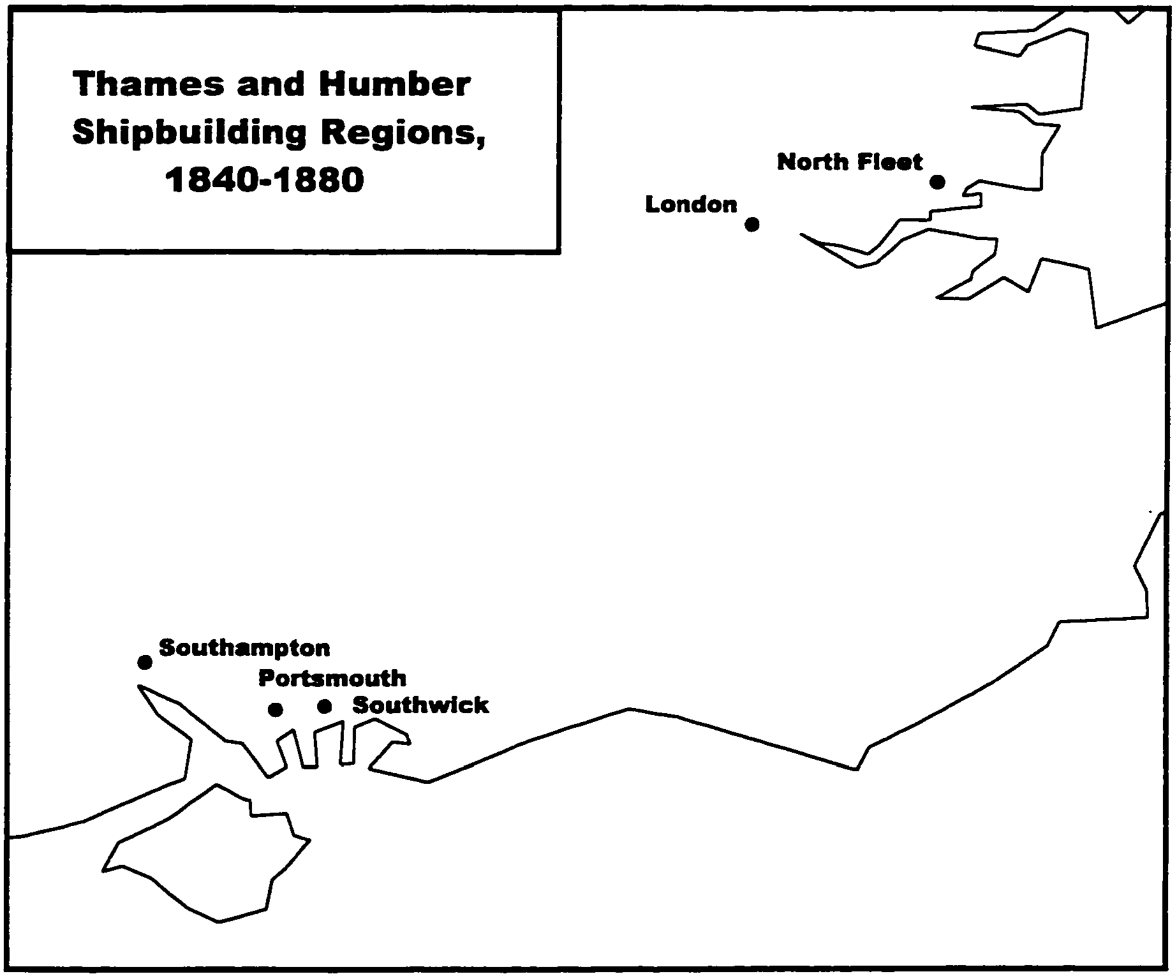


Figure V-3: Thames and Solent Shipbuilding Regions

Pollard and Robertson, 1979). The few shipyards that remained in the region after this time specialized in ships that were relatively insensitive to high production costs, such as high cost warships and passenger liners.

3.6. Solent

The Solent shipbuilding region consisted of Southampton, Southwick, and Portsmouth (Figure V-3). The Solent was an important wood and sail shipbuilding region but did not produce iron and steam ships until fairly late. This lag continued despite the fact that the Admiralty's principle dockyard was located at Portsmouth and that Southampton was one of the major ports, especially for Atlantic packet liners, on the southern coast (Encyclopaedia Britannica, 1888). Little information from the literature is available for the region's iron and steam shipbuilding industry, although Waine (1976) identifies three builders of coastal steamers. Since the Register does not include any ships until late in the study period, it would appear that the industry did not become established until after shipbuilding techniques became standardized in other regions.

3.7. Severn

The Severn shipbuilding region consists of the English port of Bristol and the Welsh ports of Llanelly, Neath, and Swansea (Figure V-4). The port of Northam, at the entrance to the Mouth of Severn, is also included in this region. The region's most significant port was Bristol, an established wooden shipbuilding center and an early iron and steam center (the Great Britain was built here in 1843). Bristol was Britain's fourth largest port (circa 1882), while the Welsh centers were important local ports and market towns (Encyclopaedia Britannica, 1882). No information is available for Northam.

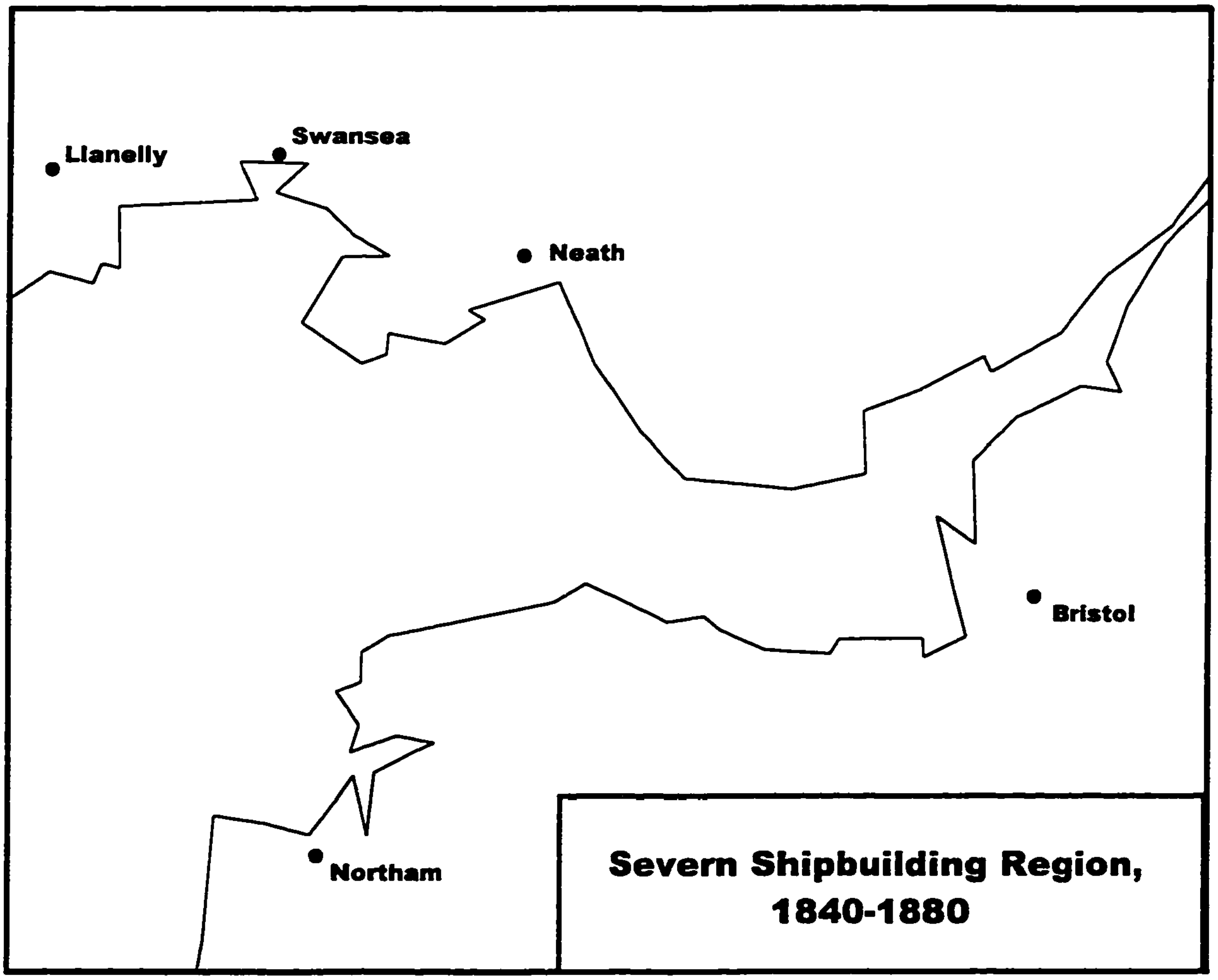


Figure V-4: Severn Shipbuilding Region

The region's locational advantages were based on local supplies of iron and machinery and demand from local shipowners operating out of the region's many ports. The Welsh ports were manufacturing centers based on coal mining, raw material processing, and iron and steel. Swansea and Neath produced iron and steel, with the latter also producing engines and machinery. Based on average ship size, these centers probably specialized in small coastal steamers and other specialty craft. This assumption is corroborated by Waine (1976), who identifies Bristol and Barnstable (Northam) as coastal steamer production centers.

3.8. Mersey

The Mersey was Britain's second largest wooden shipbuilding region after the Thames. It was one of the pioneering iron and steam shipbuilding regions, along with the Clyde and Thames. The Mersey region proper (Figure V-5) includes the centers of Liverpool, Birkenhead, Chester, and Winsford. Aberdovey, a minor Welsh port at the mouth of the River Dovey, is included although it was not related to the concentration to the north and east.

Liverpool and Birkenhead had strong reputations for innovative steamships. Liverpool dominated the region's output, with Birkenhead the second largest center. Birkenhead's one shipyard specialized in warships, explaining the sharp drop-off in output between this center and Liverpool. Chester, a minor port whose harbor was silting in (Encyclopaedia Britannica, 1875), is identified as specializing in coastal traders (Waine, 1976). Little information is available for the final two centers, Winsford and Aberdovey.

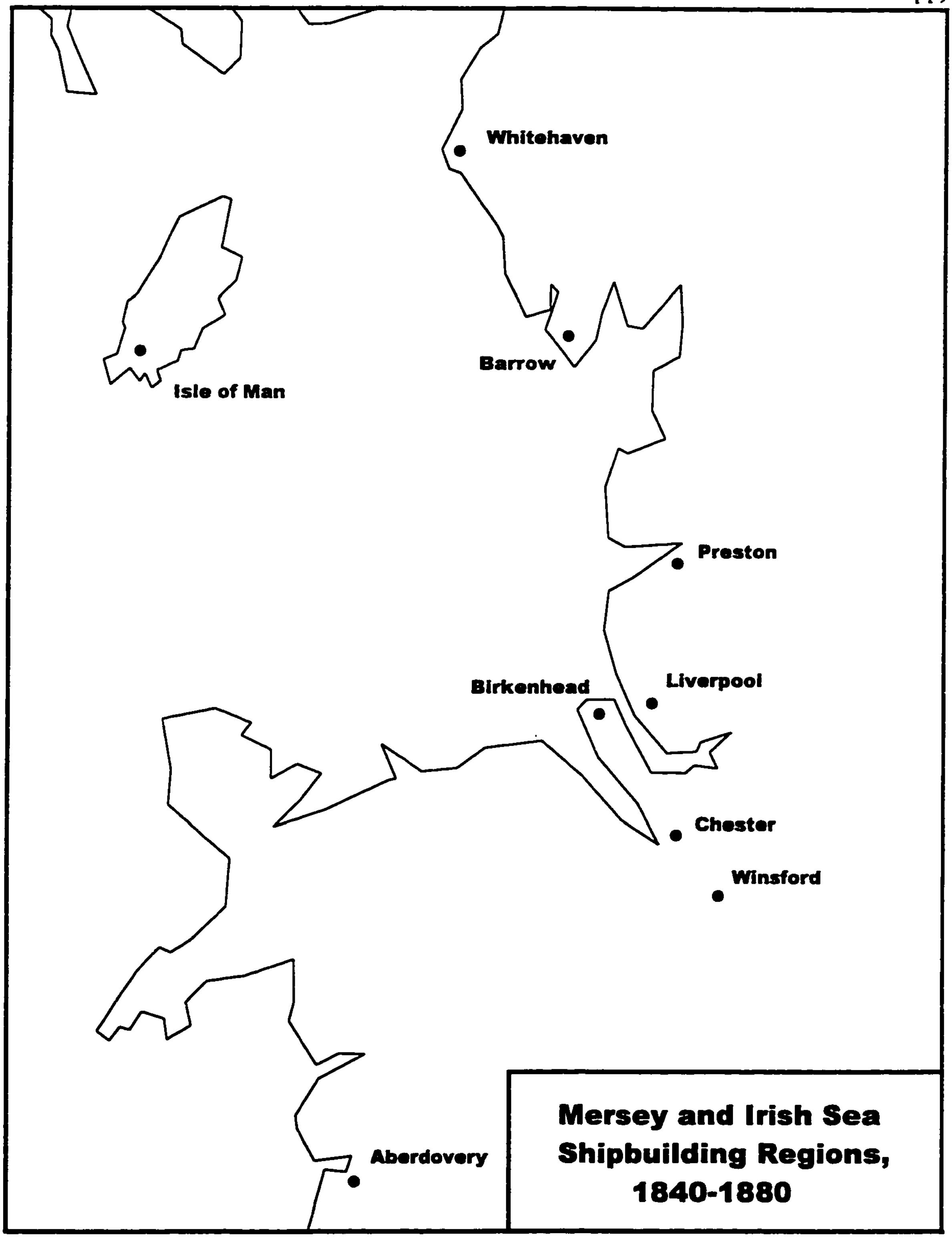


Figure V-5: Mersey and Irish Sea Shipbuilding Regions

Liverpool and Birkenhead enjoyed many of the locational advantages of the Clyde and North East Coast. Both centers had access to cheap raw materials, but labor costs were higher than the Clyde and North East Coast (but still less than the Thames). These centers, like London on the Thames, also were in proximity to large ship and capital markets (Liverpool was Britain's second largest port, serving as the Manchester's entrepot). Despite these advantages, these centers were already in decline by the beginning of the study period. According to Pollard and Robertson (1979) and corroborated by the Encyclopaedia Britannica (1875), the decline was caused by the Liverpool Corporation's refusal to provide additional river frontage for the shipbuilding industry.

3.9. Irish Sea

The four shipbuilding centers of Barrow, Preston, Whitehaven, and Isle of Man are combined to form a single Irish Sea shipbuilding region (Figure V-5). These ports do not appear to have been functionally related, other than the fact that they probably obtained raw materials from the region's revived iron and steel industry. These port's locational advantages were their access to locally produced raw materials and the proximity to the Clyde, which provided a ship market and business linkages with established yards. Labor was cheap and obtained from the Clyde and Ireland.

Barrow was the most important center in terms of subsequent growth. Developed in the early 1870s by local iron interests, it did not become a major shipbuilding center until the yard's acquisition by the Vickers armaments company in the 1890s (Encyclopaedia Britannica, 1875 and 1882; Pollard and Robertson, 1979). Preston was a trading port and mechanical engineering center (Encyclopaedia Britannica, 1882). Of the other two centers, Whitehaven was a traditional wooden shipbuilding center with linkages to Clyde shipowners (Turnock, 1982) and its fairly late development, combined with its production of large ships, suggest a functional relationship with the Clyde industry. No information is available for the Isle of Man.

3.10. Ireland

The Register's four Irish centers have been combined into one large Ireland region (Figure V-6). Each of the four was a prominent wooden shipbuilding region, but only Belfast made the successful transition to iron and steam. The Belfast industry was dominated by the Harland and Woolf company, which began operations in 1857 following the construction of a ship channel and building site. The company specialized in large ships, especially packet liners (its most famous ship was the Titanic). Belfast was disadvantaged by high raw material costs, as iron and coal had to be imported. Still, the city remained competitive because of strong national demand for its ships, an abundant supply of cheap unskilled labor, and site and harbor improvements subsidized by the city (Pollard and Robertson, 1979). Both Cork and Waterford were wooden shipbuilding centers (Todd, 1985) and were active iron and steam centers until the 1865 depression which ended the second shipbuilding cycle. (The Encyclopaedia Britannica of 1875 reports that Waterford had one operating shipyard.) Although Dublin contributed only two ships to the Register, Todd (1985) states that the harbor board subsidized a ship repair facility and Waine (1976) notes that this yard produced coastal steamers for local shipowners.

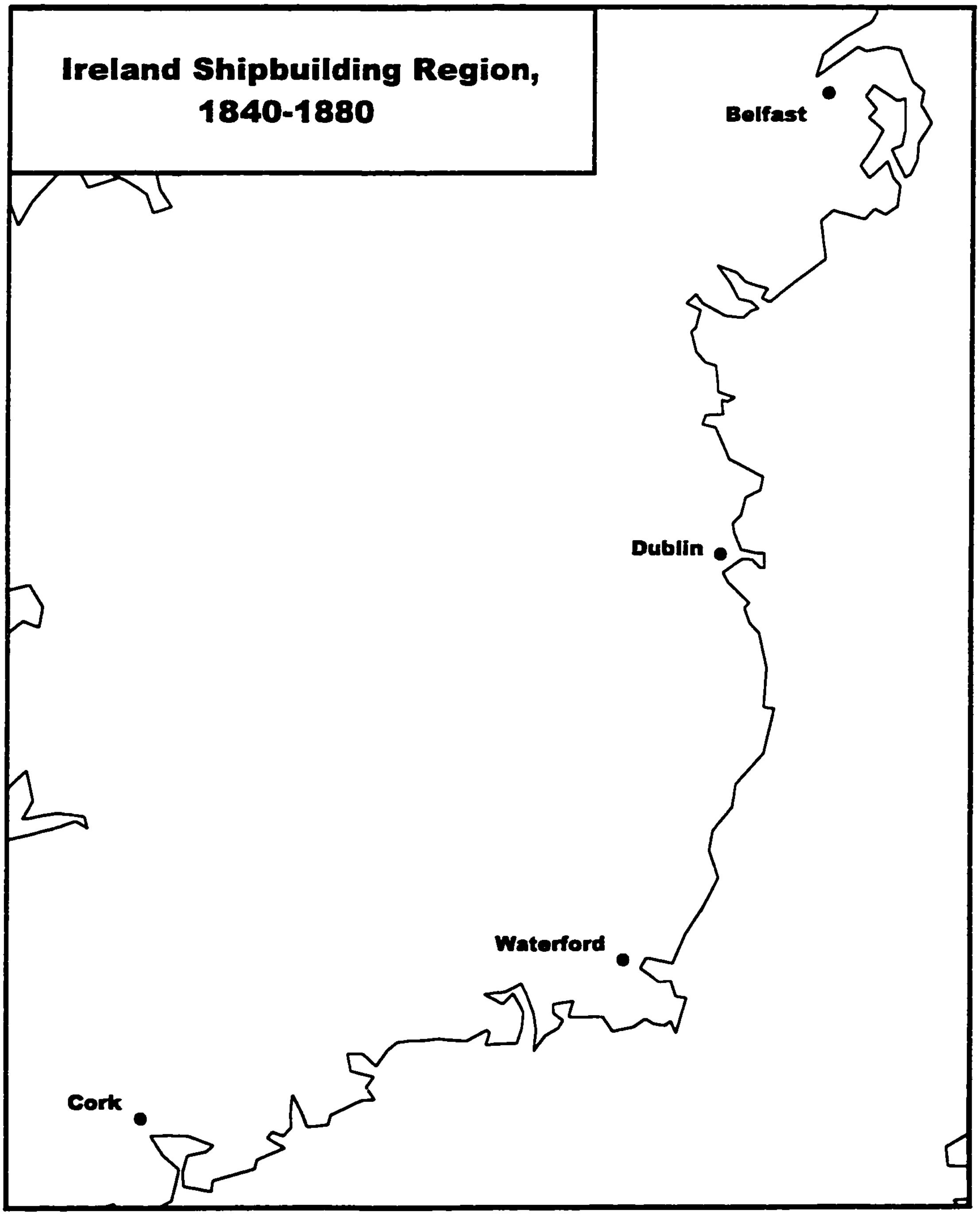


Figure V-6: Ireland Shipbuilding Region

4. SUMMARY AND CONCLUSIONS

The introduction of iron and steam shipbuilding had a profound impact on the British shipbuilding industry and its spatial structure. The new construction techniques radically increased the scale and complexity of the individual shipyard and transformed it into a large industrial operation. The new technologies also changed the relative importance and prices of factor inputs so that, in addition to iron and machinery, the new industry required more land to accommodate increased shipyard scale; cheap, unskilled labor; and access to ship and capital markets. These locational considerations favored iron and machinery producing regions on northern rivers and, at the beginning of the study period, urban areas that offered agglomeration advantages. These advantages tended to erode as the study period progressed, as witnessed by the movement out of urban concentrations and down the urban hierarchy as rivers were dredged and straightened and new industrial sites developed. The growth, expansion, and concentration of shipbuilding activity on the Clyde and North East Coast created massive industrial complexes in these two regions.

At the same time, formerly important shipbuilding centers, notably London on the Thames and Liverpool on the Mersey, declined during the study period. Despite the fact that these centers enjoyed reputations as innovative iron and steam shipbuilding centers, their disadvantages in terms of access to factor inputs was too great to overcome. Over the course of the study period, their competitive positions declined relative to the northern regions, and they were relegated to insignificance by the end of the study period.

However, shipbuilding activity continued and even expanded at minor centers in the smaller traditional shipbuilding regions. Although centers such as Belfast in Ireland and Barrow on the Irish Sea were the exception, these small scale shipyards represented a continuity with the traditional industry. These centers, operating at a disadvantage in terms of access to raw materials and urban concentrations, maintained many of the organizational and business strategies of the wooden shipyard and remained viable due to their access to local ship markets.

CHAPTER VI

SPATIAL INDUSTRIAL CHANGE

The previous chapter examined industrial and spatial changes in the British shipbuilding industry over the course of the 1840 to 1880 study period. In particular, it examined increases in the scale and complexity of shipyard operations, changes in the industry's locational requirements, and the industry's south-to-north reorientation. It also established the country's ten shipbuilding regions and their component centers.

This chapter investigates changes in the industry's spatial structure in greater detail. The first section examines the relative importance of all shipbuilding centers that produced at least one ship during the study period which was listed in the Lloyds Register. The discussion is based on a series of tables that rank each center in terms of output for each of the four shipbuilding cycles identified in Chapter IV. Each center's relative importance during each cycle is established, as well as changes in its position from one cycle to the next.

The chapter's second section presents the annual market share rankings which, when combined with the industrial viability rank to be established in the next chapter, will be used to test for the association between industrial viability and innovative ability. The market share rankings are presented in a series of tables and maps, one for each shipbuilding cycle. The tables present the annual rankings on a regional basis, while the aps locate and present the ranking of individual centers in production during each cycle's last year.

1. SPATIAL INDUSTRIAL FLUX

This section establishes the changing spatial structure of the 1840-1880 British iron and steam shipbuilding industry. The discussion is based on four tables, one for each shipbuilding cycle. Each center is ranked by its total output (in terms of gross tonnage) during a given cycle. Information provided for each center includes: the number of ships built; total tonnage; average ship size; percent change in output from the previous cycle; rank; the absolute amount and the direction of change in rank from the previous cycle; and the number of shipbuilding firms in operation. Data for the tables was synthesized from the Lloyd's Register and as such does not represent total national output.

Please note that there is a great deal of variability in average ship size. There are several reasons for this variability. First, shipbuilding centers, and regions, specialized in the type of ships they produced. Examples of specialized shipbuilding centers are Paisley and Renfrew on the Clyde which were recognized for their small coastal steamers and harbor craft. Examples of specialized regions are Hull and the Scottish East Coast, the former producing small to medium-sized cargo carriers for continental trade routes, while the latter was recognized for its coastal steamers and fishing and other specialized vessels. The second reason for the variability in average ship size deals with the fact that many shipbuilding centers produced few ships that were inspected by the Register. The reasons for this are probably due to the Lloyds neglect of remote shipbuilding locations and the fact that some shipowners and shipbuilders did not choose to have their ships inspected by Lloyds.

The discussion uses Vernon's Product Life Cycle (1966) as a conceptual framework. The model provides a spatial expression of Kuznet's (1930) argument that industries pass through a regular and predictable development cycle consisting of three periods: innovation; growth; and standardization. Each period of the Life Cycle has strong implications for the individual firm's location decision: the innovation period requiring close proximity to markets, linked industries, and capital markets; the growth stage allowing firms to expand out of their original locations to those closer to markets, and the standardization stage requiring firms to seek out the least cost location as profits diminish. As such, the Product Life Cycle provides a framework for examining the diffusion of shipbuilding activity.

1.1. Cycle 1: 1840-1855

The first cycle can be considered to be the innovation phase for the British iron and steam shipbuilding industry. The largest producing centers (Table VI-1) are located on the Clyde, Thames, and North East Coast. These regions enjoyed access to large ship and mechanical engineering industrial concentrations. These linkages are important during the Product Life Cycle's innovation period.

Glasgow and the other centers on the Clyde clearly dominated output during this cycle, followed by the Thames. North East centers appear to have occupied a second tier, with a drop-off in output occurring between South Shields (North East Coast), and Waterford (Ireland) (Aberdeen's relatively high rank is due to its production of a single

Table VI-1 : Spatial Industrial Change
Output, Rank, and Firms for Individual Centers, 1840-1855

Port	Region	Number Built	Total Output (gross tons)	Average Ship Size (gross tons)	Percent Share	Rank	Number Firms
Glasgow	Clyde	43	30345	706	35.21	1	4
Dumbarton	Clyde	23	8979	390	10.42	2	nd
Greenock	Clyde	15	8586	572	9.96	3	1
London	Thames	15	6669	445	7.74	4	nd
Port Glasgow	Clyde	9	4247	472	4.93	5	nd
Newcastle	N.E. Coast	8	3813	477	4.42	6	nd
Shields	N.E. Coast	8	3282	410	3.81	7	1
Hull	Humber	8	2696	337	3.13	8	nd
Cork	Ireland	5	2662	532	3.09	9	nd
Stockton	N.E. Coast	5	2272	454	2.64	10	nd
Birkenhead	Mersey	2	2258	1129	2.62	11	1
Liverpool	Mersey	4	1821	455	2.11	12	1
Aberdeen	S.E. Coast	1	1754	1754	2.04	13	nd
Chester	Mersey	3	1488	496	1.73	14	1
Paisley	Clyde	5	1335	267	1.55	15	1
South Shields	N.E. Coast	5	1193	239	1.38	16	nd
Waterford	Ireland	2	699	350	0.81	17	nd
Bristol	Severn	3	609	203	0.71	18	1
Jarrow	N.E. Coast	1	332	332	0.39	19	1
Walker	N.E. Coast	2	315	158	0.37	20	1
Neath	Severn	2	240	120	0.28	21	nd
Preston	Irish Sea	1	180	180	0.21	22	nd
Swansea	Severn	2	124	62	0.14	23	1
Inverkeithing	S.E. Coast	1	109	109	0.13	24	nd
Renfrew	Clyde	1	95	95	0.11	25	nd
Dundee	S.E. Coast	1	84	84	0.10	26	nd
Total		175	86187	492			14

nd - no data
Source: Lloyd's Register, 1840, 1845, 1850, 1855, 1860, 1865. 1870, 1875, 1880.

large ship). With the exception of Jarrow, Walker, and Renfrew, the small were located well away from major markets and industrial centers.

A review of Table VI-1 indicates the small number of firms. This is probably due to the fact that, first, Lloyd's did not make an effort to record builder's names and, second, there were few builders in the period that had established strong reputations. The few centers that did record builders names are concentrated in the large centers on the Clyde and North East Coast, as well as the Mersey, leaving the impression that these centers and their builders enjoyed more established reputations in iron and steam shipbuilding which undoubtedly resulted in greater sales opportunities.

1.2. Cycle 2: 1856-1865

Output more than doubled between the first (1840-1855) and second cycles (1856-1865) (Table VI-2). This growth is also reflected in the increase in the number of shipbuilding centers and firms within centers. Among all regions, the Clyde still dominated national shipbuilding output, recording four centers among the seven largest. Despite a 15 percent decline, Glasgow was still the leading center, while Greenock remained the third largest after increasing output by over one hundred percent. Newcastle was the second largest producer, increasing its output by over four hundred percent and rising from its rank of sixth in the previous cycle. Belfast, the fourth largest producer, did not even appear in the previous cycle as the Harland and Woolf Company did not begin operations until the mid 1850s. Despite experiencing absolute output gains, both Dumbarton and London experienced relative declines (dropping 4 and 3 places, respectively). Dundee and Renfrew made dramatic gains to lead the second tier of centers (output from 1890 to 7654 tons).

Table VI-2: Spatial Industrial Change
Output, Rank, and Firms for Individual Centers, 1856-1865

Port	Region	Number Built	Total Output (gross tons)	Average Ship Size (gross tons)	Percent Share	Percent Change	Rank	Rank Change	Number Firms
Glasgow	Clyde	57	25702	451	14.08	-15	1	nc	5
Newcastle	N.E. Coast	37	20074	543	11.00	427	2	+4	6
Greenock	Clyde	26	20056	771	10.99	134	3	nc	4
Belfast	Ireland	13	19727	1517	10.81	nd	4	nd	1
Port Glasgow	Clyde	35	13619	389	7.46	221	5	nc	5
Dumbarton	Clyde	14	11191	799	6.13	25	6	-4	1
London	Thames	22	11143	507	6.10	67	7	-3	9
Dundee	S.E. Coast	14	7654	547	4.19	9012	8	+18	1
Renfrew	Clyde	16	6794	425	3.72	7052	9	+16	2
West Hartlepool	N.E. Coast	8	6755	844	3.70	nd	10	nd	1
Hull	Humber	11	5225	475	2.86	94	11	-3	3
Sunderland	N.E. Coast	5	4479	896	2.45	nd	12	nd	2
Waterford	Ireland	2	3887	1944	2.13	171	13	+4	1
Liverpool	Mersey	4	3700	925	2.03	103	14	-2	3
Cork	Ireland	3	3294	1098	1.80	24	15	-6	1
Stockton	N.E. Coast	8	3121	390	1.71	37	16	-6	1
Paisley	Clyde	11	2427	221	1.33	82	17	-2	1
Bristol	Severn	4	2391	598	1.31	293	18	nc	1
Shields	N.E. Coast	4	2041	510	1.12	-61	19	-12	3
Hartlepool	N.E. Coast	4	2039	510	1.12	nd	20	nd	1
Kinghorn	S.E. Coast	3	1890	630	1.04	nd	21	nd	1
Middlesborough	N.E. Coast	2	930	465	0.51	nd	22	nd	2
Jarrow	N.E. Coast	1	899	899	0.49	171	23	-4	1
Inverkeithing	S.E. Coast	4	781	195	0.43	617	24	nc	1
Dublin	Ireland	1	736	736	0.40	nd	25	nd	1
North Shields	N.E. Coast	1	561	561	0.31	nd	26	nd	1
Isle of Man	Irish Sea	2	492	246	0.27	nd	27	nd	1
Whiteinch	Clyde	1	324	324	0.18	nd	28	nd	1
Llanelly	Severn	1	220	220	0.12	nd	29	nd	1
Grimsby	Humber	1	125	125	0.07	nd	30	nd	1
Winsford	Mersey	1	103	103	0.06	nd	31	nd	nd
Aberdovey	Mersey	1	101	101	0.06	nd	32	nd	1
Gainesborough	Humber	1	85	85	0.05	nd	33	nd	1
Total		318	182566	574					75

nd - no data
nc - no change
Source: Lloyd's Register, 1855, 1860, 1865, 1870, 1875, 1880

The table indicates that the shipbuilding industry's national spatial system was in a state of flux with some centers dropping from the list, other centers experiencing relative declines, and still others entering for the very first time. Eight centers from the previous cycle do not even appear in the next cycle. While this does not necessarily mean these centers did not build any ships (ships could have been listed with other registers), still, it does suggest a significant drop-off in output. The most significant of the centers not appearing in the second cycle are Birkenhead, probably due to the Laird's shipyard concentrating on warships, and Aberdeen which was (and still is) an important shipbuilding center. Despite absolute increases in output (only Shields experienced an absolute decline) only three firms increased their position within the industrial system. At the same time, fifteen centers make their first appearance. Prominent among these are the second tier centers of West Hartlepool, Sunderland, Hartlepool, Middlesborough, and North Shields, all located on the North East Coast. The last 9 centers, beginning with Dublin, were small scale producers and may represent repair yards building a limited number of coastal traders for the local market.

The increase in the number of shipbuilding centers and the instability in their rank order within the system relative to positions in the previous cycle indicates that the industry was in the Product Life Cycle's growth phase. Of the new centers on the North East Coast, only Sunderland was an established shipbuilding center, indicating movement out of the urban centers of Newcastle and Stockton facilitated both by river improvements and the weakening of the close ties to urban markets and support industries characteristic of the innovation phase. Although the record is incomplete, the fact that 75 firms were in operation, with multiple firms operating in the larger centers, suggests rapid expansion, another indication that the industry had entered the Product Life Cycle's growth phase.

1.3. Cycle 3: 1866-1872

Production continued to be concentrated in the north during the third cycle (Table VI-3). The centers can be sub-divided into four groups based on output: four centers producing over 26 thousand tons; four centers producing between eighteen and fourteen thousand tons; twelve centers producing between nine and one thousand tons; and twelve centers (not counting the generic "Clyde") producing less than one thousand tons. In the last group, only Belfast, Llanelly, and South Shields produced more than one ship.

Of the eight centers in the first two groups, only London was not located on either the Clyde, still the leading region, or North East Coast. The increase in total output was largely accounted for by increased output in these two regions. Greenock and Newcastle dominated national output (with more than four thousand tons apiece). Glasgow, the third largest producer, made only a marginal increase in absolute terms and still, perhaps more surprisingly, did not equal its output during the first cycle.

Of the thirteen largest centers, only Glasgow did not experience growth or at least no change in output. London was among the centers experiencing no growth. Centers experiencing the greatest gains were on the North East Coast, especially Middlesborough and Hartlepool. From Dumbarton (the fourteenth ranked center) down, however, declining centers outnumbered growth centers by 7 to 4. Eight centers from the previous cycle are no longer present, while nine new centers appear, the most prominent being

Table VI-3: Spatial Industrial Change
Output, Rank, and Firms for Individual Centers, 1866-1872

Port	Region	Number Built	Total Output (gross tons)	Average Ship Size (gross tons)	Percent Share	Percent Change	Rank	Rank Change	Number Firms
Greenock	Clyde	21	46495	2214	17.71	131.8	1	+2	4
Newcastle	N.E. Coast	51	42981	843	16.37	114.2	2	nc	7
Glasgow	Clyde	30	27083	903	10.32	5.4	3	-2	12
Renfrew	Clyde	28	25951	927	9.88	282	4	+5	2
Port Glasgow	Clyde	35	18001	514	6.86	32.2	5	nc	7
Sunderland	N.E. Coast	13	17250	1327	6.57	285.1	6	+6	7
London	Thames	14	15297	1093	5.38	37.3	7	nc	5
West Hartlepool	N.E. Coast	14	14263	1019	5.43	111.1	8	+2	2
Middlesborough	N.E. Coast	15	9021	601	3.44	870	9	+13	1
Liverpool	Mersey	8	5641	705	2.15	52.5	10	+4	6
Stockton	N.E. Coast	8	5511	689	2.10	76.6	11	+5	2
Kinghorn	S.E. Coast	4	5378	1345	2.05	184.6	12	+9	1
Hartlepool	N.E. Coast	6	5008	835	1.91	145.6	13	+7	2
Dumbarton	Clyde	5	4845	969	1.85	-56.7	14	-8	1
Dundee	S.E. Coast	7	4593	656	1.75	-40	15	-7	1
Hull	Humber	5	4528	906	1.72	-13.3	16	-5	1
Aberdeen	S.E. Coast	5	3576	715	1.36	nd	17	nd	3
Paisley	Clyde	8	1445	181	0.55	-40.5	18	-1	1
Inverkeithing	S.E. Coast	2	1191	596	0.45	52.5	19	+5	1
Southwick	Solent	1	1055	1055	0.40	nd	20	nd	1
Belfast	Ireland	2	793	397	0.30	-76.7	21	-17	1
South Shields	N.E. Coast	4	595	149	0.23	nd	22	nd	2
Llanelly	Severn	2	438	219	0.17	99.1	23	+6	1
North Fleet	Thames	1	345	345	0.13	nd	24	nd	1
Dublin	Ireland	1	234	234	0.09	-68.2	25	nc	1
Northam	Severn	1	193	193	0.07	nd	26	nd	1
Grimsby	Humber	1	190	190	0.07	52	27	+3	1
North Shields	N.E. Coast	1	129	129	0.05	-77	28	-2	1
Preston	Irish Sea	1	118	118	0.04	nd	29	nd	1
Southampton	Solent	1	108	108	0.04	nd	30	nd	1
Maryhill	Clyde	1	101	101	0.04	nd	31	nd	1
Winsford	Mersey	1	100	100	0.04	-2.9	32	-1	nd
Clyde	Clyde	1	76	76	0.03	nd	33	nd	1
Total		298	262533	881					80

nc - no change
nd - no data
Source: Lloyds Register, 1865, 1870, 1875, 1880.

Aberdeen. Other new centers included Southwick and Southampton in the Solent, North Fleet on the Thames, and Maryhill adjacent to Glasgow on the Clyde.

Although there were only five more firms operating than in the previous cycle, there was a higher number of firms per center, especially for those producing over fourteen thousand tons. Since these centers, with the exception of London, were located on the Clyde and North East Coast, this finding indicates that these massive shipbuilding concentrations formed during the 1865-1872 cycle. The decline in the number of firms operating in Glasgow combined with an increase in the number of firms operating in other Clyde centers could indicate movement out of the city to centers down the urban hierarchy. This is also suggested by the number of firm names that are common to more than one center.

The industry was clearly in the Product Life Cycle's growth phase throughout this period. This observation is based on the combination of large absolute growth rates and system instability as indicated by the dramatic rank order changes within the spatial industrial system. At the same time, the relatively small increases in the pioneering centers of Glasgow and London suggest that these centers had reached a mature stage in their development. That the industry was becoming increasingly standardized is suggested by the continued expansion down the urban hierarchy. This is further supported by an increase in the number of branch plants as indicated by the number of firms in the Register operating in more than center, as well as the industry's expansion into entirely new regions, notably Southampton on the Solent.

1.4. Cycle 4: 1873-1880

The fourth cycle was a period of phenomenal growth in the shipbuilding industry with continued concentration in the North. The phenomenal growth of the North East Coast is most likely due to the growth the region's massive iron and steel industry. Six centers experienced absolute growth of over a staggering one thousand percent, the most notable being Sunderland and Stockton (Table VI-4). Five groups of centers, based on output, can be identified. The first group is composed of Sunderland and Newcastle, the first producing 205 thousand and the second 119 thousand tons. The second group, producing from 81 to 39 thousand tons consists of two North East Coast centers and five from the Clyde, while the third group (20 to 11 thousand tons) includes North East Coast centers as well as Barrow (Irish Sea), Belfast (Ireland), and Hull (Humber), indicating rapid gains in centers not located within the shipbuilding core regions. Also note the increase in average ship size allowed for by technological changes in construction techniques and steam propulsion systems.

Industrial growth is also demonstrated by increases in the number of centers that experienced absolute production increases, the number of ships produced per center, and the number of firms per center. Although changes in rank importance suggest system instability, only five centers experienced absolute declines in output, the most important being Renfrew (-89 percent) and London (-62 percent). In addition, both the total number of firms and number of firms per center again increased from the previous cycle, although the largest gains are in the large, established centers on the North East Coast and Clyde.

Table VI-4: Spatial Industrial Change
Output, Rank, and Firms for Individual Centers, 1873-1880

Port	Region	Number Built	Total Output (gross tons)	Average Ship Size (gross tons)	Percent Share	Percent Change	Rank	Rank Change	Number Firms
Sunderland	N.E. Coast	138	204563	1482	24.21	1086	1	+5	19
Newcastle	N.E. Coast	86	118657	1380	14.04	176	2	nc	13
Stockton	N.E. Coast	54	81835	1515	9.68	1385	3	+8	2
Middlesborough	N.E. Coast	63	76500	1214	9.05	748	4	+5	4
Glasgow	Clyde	43	72376	1683	8.57	167	5	-2	11
Port Glasgow	Clyde	63	50076	795	5.93	178	6	-1	10
Greenock	Clyde	23	44968	1955	5.32	-3	7	-6	5
Dumbarton	Clyde	25	38585	1543	4.57	696	8	+6	7
Belfast	Ireland	12	20071	1673	2.38	2431	9	+12	3
South Shields	N.E. Coast	22	20070	912	2.38	3273	10	+12	3
Hull	Humber	7	15966	2281	1.89	253	11	+5	2
Barrow	Irish Sea	8	15593	1949	1.85	nd	12	nd	1
West Hartlepool	N.E. Coast	11	13845	1259	1.64	-3	13	-5	3
Hartlepool	N.E. Coast	8	10787	1348	1.28	115	14	-1	1
Aberdeen	S.E. Coast	13	9844	757	1.16	175	15	+2	3
Liverpool	Mersey	7	8858	12265	1.05	57	16	-6	5
Dundee	S.E. Coast	12	7897	658	0.93	72	17	-2	3
London	Thames	9	5869	652	0.69	-62	18	-11	6
Whitby	N.E. Coast	5	5723	1145	0.68	nd	19	nd	1
Southampton	Solent	4	5457	1364	0.65	4953	20	+10	1
Whitehaven	Irish Sea	3	3601	1200	0.43	nd	21	nd	1
Renfrew	Clyde	3	2894	965	0.34	-89	22	-18	2
North Shields	N.E. Coast	3	2553	851	0.30	1879	23	+5	2
Paisley	Clyde	5	1839	368	0.22	27	24	-6	2
Birkenhead	Mersey	2	1795	898	0.21	nd	25	nd	2
Blyth	N.E. Coast	1	1017	1017	0.12	nd	26	nd	1
Leith	S.E. Coast	1	897	897	0.11	nd	27	nd	1
Campbelltown	Clyde	2	784	392	0.09	nd	28	nd	1
Montrose	S.E. Coast	3	678	226	0.08	nd	29	nd	1
Preston	Irish Sea	2	561	281	0.07	375	30	-1	1
Bristol	Severn	2	489	245	0.06	nd	31	nd	2
Bowling	Clyde	1	143	143	0.02	nd	32	nd	1
Northam	Severn	1	121	121	0.01	-37	33	-7	1
Portsmouth	Solent	1	71	71	0.01	nd	34	nd	1
Total		643	844983	1314					122

nc - no change
nd - no data
Source: Lloyds Register, 1875, 1880.

The industry appears to have entered the standardization phase of the Product Life Cycle by the fourth innovation cycle. During this phase, competition among firms is intense as profit margins decline, while production process are so established that multiple production units can be operated to take advantage of least cost production locations or access to markets. That this was occurring is evidenced by the industry's rapid growth at Barrow and Whitehaven near the revitalized iron producing regions on the Irish Sea, and at the major shipping port of Southampton on the Solent. Further, the continued spatial expansion of the North East Coast into Blyth and Whitby reflects this trend. The Irish Sea is an example of expansion into new least cost areas, expansion on the North East Coast probably represents further attempts to escape congestion and high land costs as the spatial system infills, while growth on the Solent was an attempt to exploit larger markets. No matter what the reason, these expansions were all made possible by the standardization of the production process and subsequent relocation efforts aimed at the reduction of costs in the face of rising competition.

2. INDUSTRIAL VIABILITY

The last portion of this chapter presents the measure of industrial viability that will be used to assess the association between innovation and place. The innovative ability measure ranks each shipbuilding center's share of all ships built and registered with Lloyds during a given year. Ranking is necessary because a large number of centers accounted for only a small amount of output during any given year. To avoid this problem, each year's range of market share values is sub-divided into three equal parts, high, medium, and low, and each center is assigned to one of the three categories that corresponds to its annual market share for each cycle.

The following section presents the market share ranks for each shipbuilding center and the year in which it produced at least one ship for each of the four shipbuilding cycles. Despite it awkwardness, the term center / year combination will be used in this and subsequent discussions because it best expresses the fact that each single observation consists of both the individual center and the year it was in production. The discussion is based on a series of tables and maps. The tables present the total frequencies by region for each of the four shipbuilding cycles. For example, there were a total of 82 center / year combinations during the first shipbuilding cycle (Table VI-5), and two of the Clyde's center / year combinations were in the low market share category. The maps, conversely, identify the market share ranking for all centers in production during the last year of each cycle. The last year in the cycle was selected for these and following maps because it maintains analytical consistency from one series of maps to the next and because, since the last year in the cycle was a peak production year, it use assures that a large number of centers are available for the maps.

2.1. Cycle 1: 1840-1855

Nine shipbuilding regions were in production during the first cycle, the Solent being the only British shipbuilding region not represented (Table VI-5). The Clyde and North East Coast shipbuilding regions had the largest number of combinations with the Clyde having almost twice as many as the later region. These findings should come as no surprise given the discussion in the previous section. Following these regions were the Thames, Mersey, and Ireland, with seven center / year combinations each.

Table VI-5: Market Share Rank, 1840-1855

	Rank			
Region	Low	Medium	High	Total
Clyde	2	11	17	30
North East Coast	8	5	4	17
Thames	1	3	3	7
Mersey	3	4	0	7
Ireland	2	4	1	7
Humber	2	2	1	5
Severn	4	1	0	5
Scottish East Coast	1	1	1	3
Irish Sea	1	0	0	1
Total	24	31	27	82

The table also demonstrates the considerable degree to which the Clyde dominated the iron and steam shipbuilding market during this cycle. Its thirty center / year combinations dominated both the high and medium market share categories, accounting for almost three quarters of the high and one third of the medium share combinations. The seventeen center / year combinations on the North East Coast, conversely, consisted of low to medium share centers, with eight low and only four high share centers. The Thames was a medium to high share region, while the Mersey and Ireland were made up of low to medium share combinations. Of the remaining regions, there was no difference in ranking among the Scottish East Coast's three centers, while the Humber, Severn, and Irish Sea regions were low to medium share combinations.

Figure VI-1 reflects a fairly even spatial distribution of shipbuilding centers and clearly illustrates the concentration of high market share centers on the Clyde. Each one of this region's four centers that were in production during the year 1855 were in the highest market share category. Two of the North East Coast's four centers were medium share centers, while Shields and South Shields were high and low share centers, respectively. London, on the Thames, and Cork in Ireland were low and medium share centers, respectively, while two of the Mersey's three centers were medium share and Chester was a low share center.

2.2. Cycle 2: 1856-1865

The only regions not represented during the second cycle was again the Solent (Table VI-6). The nine regions that were in production fall into four groups based on the number of center / year combinations. The first group is again made up of the Clyde (45 center / year combinations) and the North East Coast (27). The Scottish East Coast (13) and Ireland (12) constitute the second group. Next are the Thames and Humber, with eight and seven center / year combinations, respectively. The smallest group is made up of the Mersey, Severn, and Irish Sea regions.

The spatial shifts which characterized this cycle are quickly apparent. Unlike the previous cycle, no single region dominated the high market share category. Share rankings were evenly distributed on the Clyde, with the largest number of high (19) and low (14) share combinations, and both categories were larger than the medium share

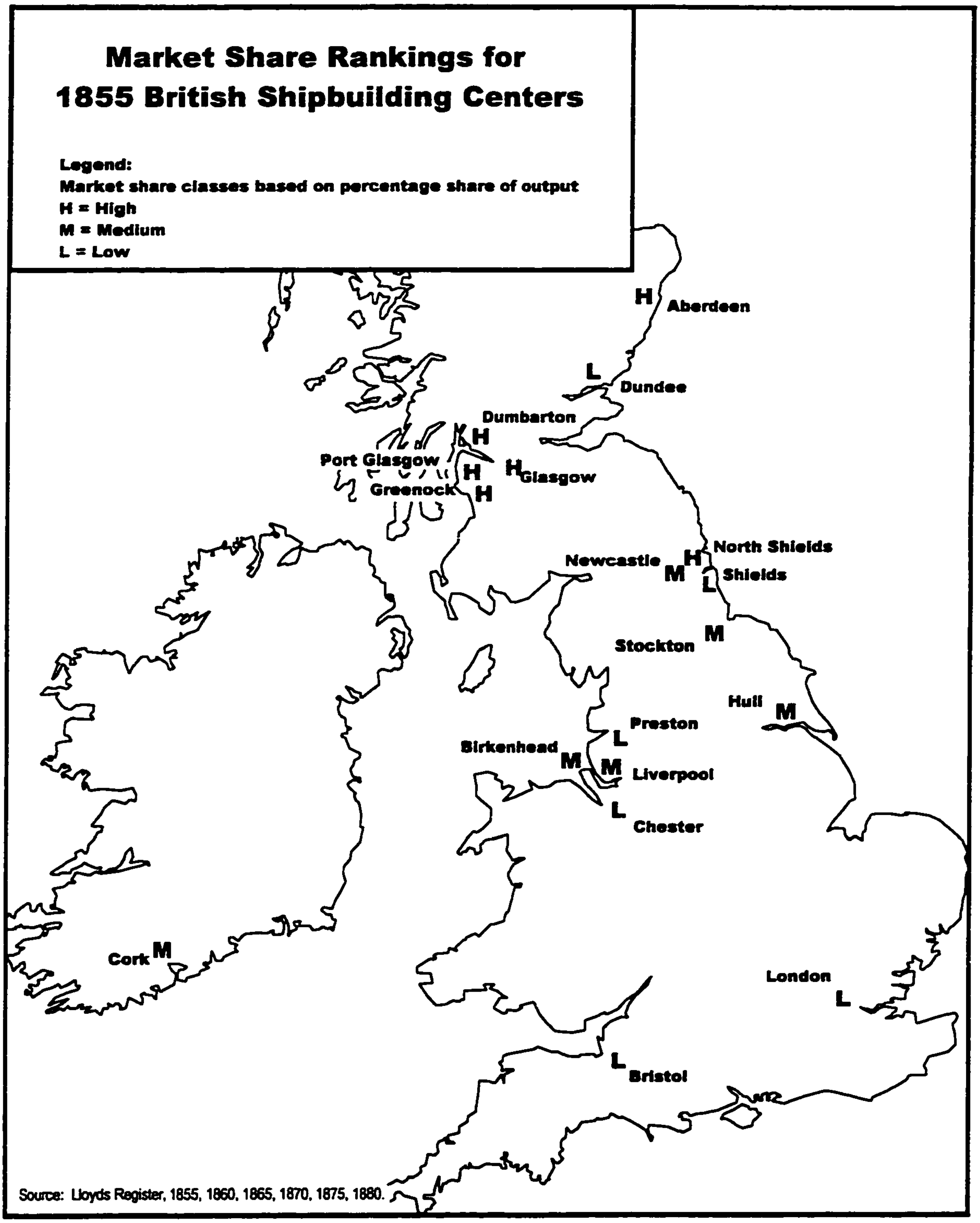


Figure VI-1: Market Share Rankings: 1855

Table VI-6: Market Share Rank, 1856-1865				
	Rank			
Region	Low	Medium	High	Total
Clyde	14	12	19	45
North East Coast	5	13	9	27
Scottish East Coast	5	8	0	13
Ireland	2	3	7	12
Thames	2	4	2	8
Humber	3	0	1	7
Mersey	3	0	1	4
Severn	1	0	2	3
Irish Sea	2	0	0	2
Total	37	43	41	121

combinations. The North East Coast was characterized by the relatively large number of medium share combinations relative to the other two categories. In the second group, the Scottish East Coast can be characterized as a medium to low share region while Ireland was a high share region. The Thames and Humber, in the third group, were medium and low share regions, respectively, and the last group consisted of low share centers with the exception of the Severn, which was a high market share region.

Figure VI-2 corroborates the market characterizations identified from the tables. The Clyde's four centers were dominated by high share production centers, with only one center, Port Glasgow, in the medium share category. On the North East Coast, Newcastle was a high share center, Middlesborough a low share center, and the remaining two

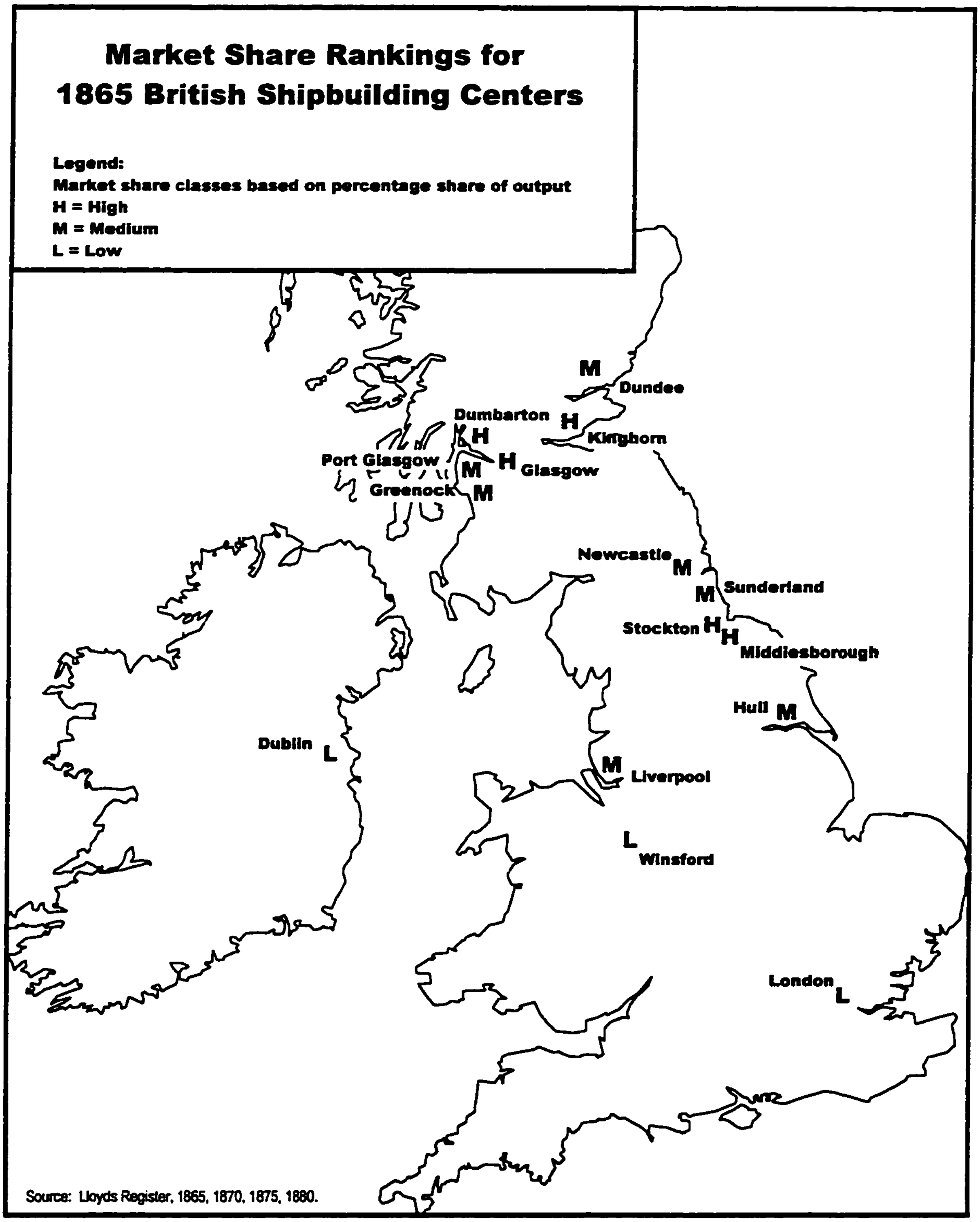


Figure VI-2: Market Share Rankings: 1865

centers were in the medium share rank. Three centers on Scottish East Coast and Ireland were in production in 1865, and all of these centers were ranked in the low share category, while London on the Thames and Hull on the Humber were medium share centers. The Mersey was the only one of the remaining regions represented, with Liverpool and Winsford high and low market share centers, respectively.

2.3. Cycle 3: 1865-1872

The Irish Sea was the only region not represented during the 1866-1872 shipbuilding cycle. Although the Clyde was still the largest shipbuilding region, the North East Coast began to challenge the former region during this cycle, as demonstrated by the number of center / year combinations shown in Table VI-7. The North East Coast accounted for thirty-four of the cycle's center / year combinations compared to the Clyde's thirty-six. Repeating the pattern established in the previous cycles, the Scottish East Coast alone occupied a second tier, being represented by fourteen center / year combinations. There was a significant drop-off from the latter region to the remaining regions, with the number of combinations in these regions ranging from the Thames' six to the Solent's two.

Continuing the trend established in the previous cycles, the Clyde continued to dominate the high market share category. However, it is important to note that the categories were not evenly distributed in the region, with twenty center / year combinations in the highest rank, eleven in the lowest, but only five in the medium share category. The North East Coast was still characterized by fairly equal distribution of medium and high market share combinations, and the distribution of combinations among

Table VI-7: Market Share Rank, 1866-1872

Region	Rank Low	Medium	High	Total
Clyde	11	5	20	36
North East Coast	7	15	12	34
Scottish East Coast	4	9	1	14
Thames	2	3	1	6
Mersey	2	3	0	5
Severn	3	1	0	4
Humber	1	1	1	3
Ireland	2	1	0	3
Solent	2	0	0	2
Total	34	38	35	107

the three categories was little changed from the previous cycle. The Scottish East Coast was a medium share region, as were the Thames and Mersey. Of the remaining regions, however, all were characterized by their low market share rankings.

The northern shipbuilding regions dominated the British shipbuilding industrial system by the end of the third cycle. The concentration of activity in these two regions can be clearly seen in Figure VI-3: aside from these two shipbuilding concentrations, only four centers were in production south of the North East Coast. While the two Scottish East Coast centers fell into the low share category, the Clyde's five centers all placed in either the high (3) or medium (2) categories. Eight centers were concentrated in the North East Coast, which was dominated by four high share centers. Of the centers south

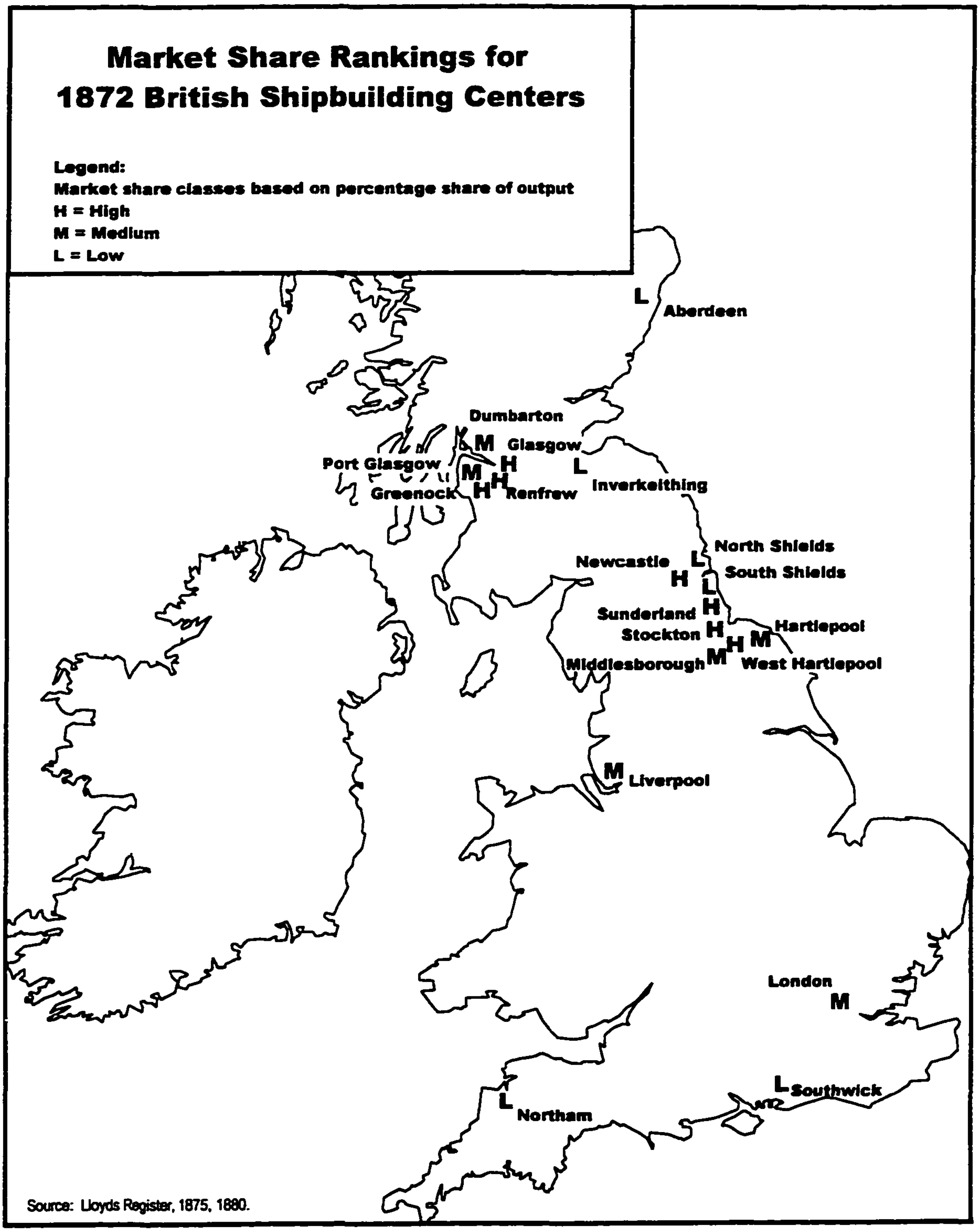


Figure VI-3: Market Share Rankings: 1872

of the North East Coast, London and Liverpool were medium share centers, while Northam and Southwick were low share centers.

2.4. Cycle 4: 1873-1880

By the fourth cycle the North East Coast surpassed the Clyde as Britain's dominant shipbuilding region, accounting for fifty-one of the cycle's center / year combinations (Table VI-8). The Clyde accounted for thirty-four of these combinations, down from thirty-six in the previous cycle. The Scottish East Coast was again the third largest region and was followed by the remaining seven regions that were clustered in a range of combinations from a high of eight (Irish Sea) to a low of two (Humber and Severn regions).

Table VI-8: Market Share Rank, 1873-1880

	Rank			
Region	Low	Medium	High	Total
North East Coast	6	18	27	51
Clyde	7	13	14	34
Scottish East Coast	10	4	0	14
Irish Sea	4	3	1	8
Mersey	2	4	0	6
Thames	3	1	0	4
Ireland	0	2	1	3
Solent	2	1	0	3
Humber	2	0	0	2
Severn	2	0	0	2
Total	38	46	43	127

Not only was the North East Coast the dominant region, but it also had the largest number of centers, twenty-seven, in the high market share category. Of the region's other center / year combinations, eighteen were ranked in the medium category and only six in the low category. In addition to its decline in center / year combinations, the Clyde also experienced a shift out of the high and into the medium share categories. The Scottish East Coast was dominated by low share centers. Ireland was characterized by its medium to high share centers, the Irish Sea by medium centers, and the Mersey by medium to low share centers. All other regions were characterized by their rankings in the low market share category.

The south to north spatial shift in shipbuilding output, as well as the industry's increasing concentration ou the North East Coast and Clyde can be seen in Figure VI-4. Liverpool is the only center south of the North East Coast that contributed a ship to the Lloyds Register in 1880. Six centers were in production on both the North East Coast and Clyde in 1880 and the three market share categories are fairly evenly distributed. The only difference between the regions is that the North East Coast has one more and one less center in the high and low share categories, respectively, than does the Clyde. The two centers on the Scottish East Coast were again ranked in the low share category, while the two remaining centers, Liverpool and Belfast, were both ranked in the medium market share category.

3. SUMMARY AND CONCLUSIONS

This chapter has examined the changing spatial structure of the 1840-1880 British iron and steam shipbuilding industry. It has documented the industry's spatial relocation,

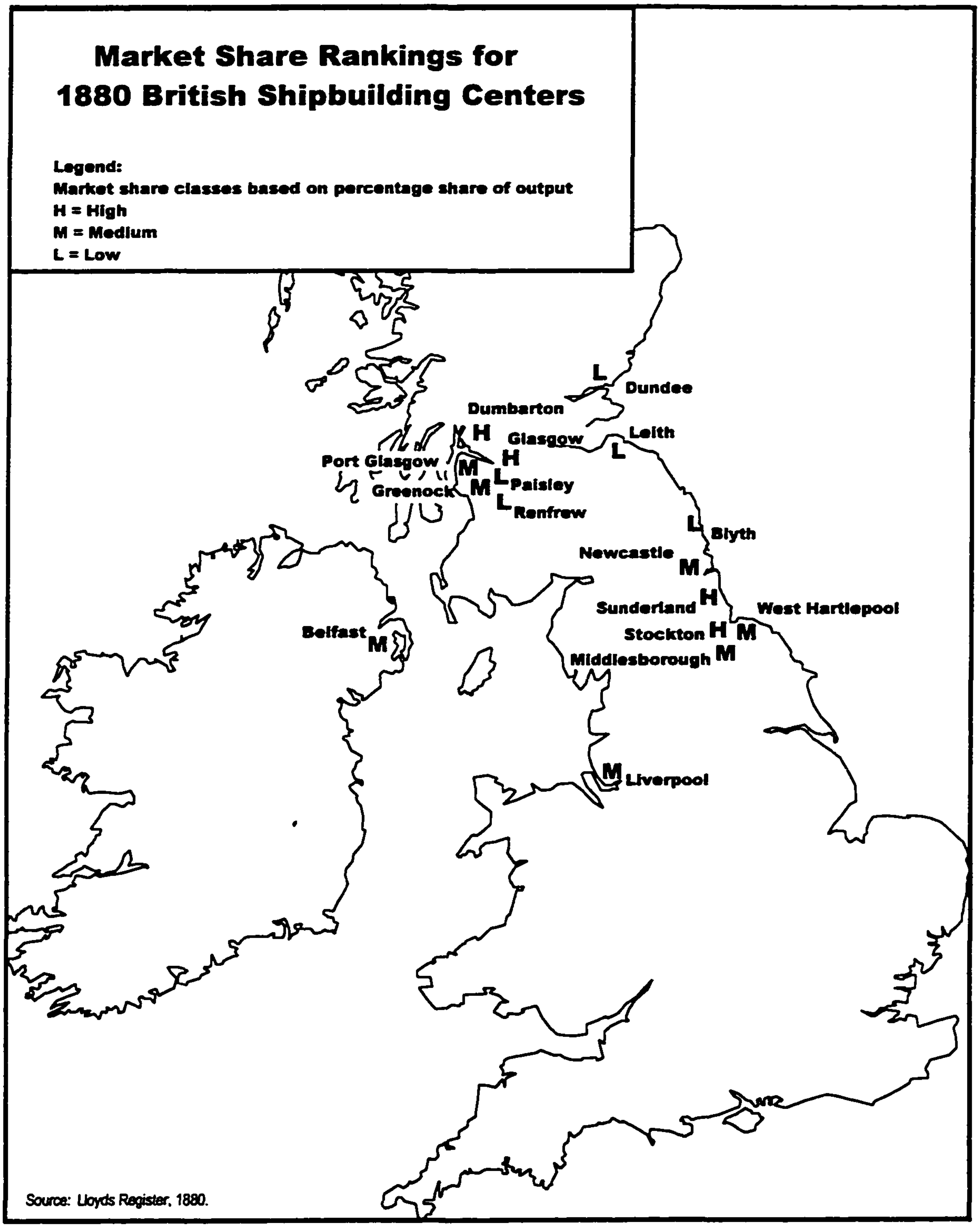


Figure VI-4: Market Share Rankings: 1880

ranging from the national to intra-regional levels. Using a conceptual framework provided by the Product Life Cycle, this chapter has examined the spatial restructuring process for each of the four shipbuilding cycles. During the first cycle, the Product Life Cycle's innovation phase, iron and steam shipbuilding was already concentrated in the northern iron and machinery producing regions of the Clyde and North East Coast. In addition, favored locations tended to be urban centers that offered access to labor, capital, and ship markets. The industry's continued concentration in the north, as well as its expansion out of the urban centers favored in the first cycle, was apparent during the Product Life Cycle's growth phase that corresponded to the second and third shipbuilding cycles (1856-1872). By the fourth shipbuilding cycle, 1873-1880, the industry had entered the final standardization phase of the Product Life Cycle. This period was characterized by the massive shipbuilding concentrations in the north and the development of medium to large scale shipbuilding enterprises in formerly peripheral regions on the Irish Sea (Barrow) and in Ireland (Belfast).

The concentration of market share in northern shipbuilding regions, first on the Clyde and later on the North East Coast, was phenomenal. The Clyde dominated both the absolute number of shipbuilding center / year combinations developed for the industrial viability variable, as well as the number of these combinations in the high and medium market share categories. The Clyde's dominance extended into the second cycle, but declined and then stabilized for the rest of the study period.

Although the North East Coast was the second largest region in terms of the absolute number of combinations, it can not be characterized as a high share region until the third and fourth cycles. During the last two cycles, this region overtook the Clyde to become Britain's largest shipbuilding region in both the absolute number of combinations and in its dominance of the high market share category.

Still, despite this dominance, it is important to note that smaller regions and centers remained competitive and experienced growth. By the end of the period, large scale production centers were established in formerly minor regions. However, traditional shipbuilding regions, especially the Thames and Mersey, experienced relative declines throughout the study period. The performance of all the small regions in the market share categories was characterized by the small absolute number of combinations and their concentration in the low and medium share categories.

CHAPTER VII

TECHNOLOGICAL CHANGE AND BRITISH SHIPBUILDING CENTERS

The last measure required to assess the relationship between innovation and place is a measure of the innovative ability of individual shipbuilding centers. This index is developed in two stages. The first stage specifies a series of multiple regression models to identify technological innovations that made a significant contribution to increasing ship size, the single most important change in iron steamships that occurred throughout the study period. The first section of this chapter introduces these models and identifies significant variables which can be used to construct the index.

The second stage in developing the innovative ability index uses these significant variables to rank each shipbuilding center for every year in which it produced at least one ship registered with Lloyds. Since the regression models' independent variables have minimal multicollinearity (based on correlation coefficients), each variable included in the index represents a unique technological component of the iron steamship. As a result, each ship's scores on these variables can be summed to develop a measure of that ship's level of technological sophistication vis-a-vis all other centers in each sub-period. A mean score for all ships built at a center during a given year, therefore, provides a measure of that center's level of technological sophistication. This mean score can then be used to develop a ranking system that identifies technologically leading and lagging shipbuilding centers and which, when combined with the industrial viability measure presented in the previous chapter, allows for the statistical testing of the association between innovation and place. These rankings are presented and discussed in this chapter's second section.

1. MODELING TECHNOLOGICAL CHANGE

This section specifies technological change models for each shipbuilding cycle. It begins with a model for the entire study period using available data to demonstrate that, though such a model provides a good description of 1840-1880 technological change, this single model is really not appropriate for the entire study period. A series of models are then specified that better capture the changes that occurred during the individual cycles by incorporating more variables as the Lloyds Register's record keeping improves and more data become available.

1.1. The 1840-1880 Model

The nineteenth century witnessed unprecedented changes to the ship. Experiments during the century's first four decades established the iron steamship as a viable alternative to the traditional wooden sailing ship. Changes introduced between 1840 and 1880 resulted in continuous increases in ship size and power. By 1880, these changes had laid the foundation for the modern ship and rendered the traditional wooden sailing ship virtually obsolete.

This success was the result of improvements in the two component technological systems, iron construction and steam propulsion, as well as interrelationships between the two technologies whereby a change in one led to improved performance and innovation in the other. Improvements in iron construction techniques resulted in increased ship size and cargo-carrying capacity and allowed for modern ship designs. Improvements in marine steam engine plants, including boilers and condensers, created ever more powerful and more efficient engines which remained the industry standard until the diesel engine's introduction.

1.1.1. Model

With these changes in mind, the analysis begins by specifying a model for the 1840-1880 period. Since shipbuilding historians agree that the greatest changes to ships during the study period were increased ship size and power, a model is specified to test the hypothesis that ship size, measured by gross tonnage, is a function of the year the ship was built and its motive power. As such, the model describes the technological innovations that made a significant contribution to increasing ship size. This hypothesis is articulated in the following regression model:

$$\text{Gross Tons} = a + b1 * \text{Year} + b2 * \text{Ship Power}$$

Again, and as discussed earlier, the dependent variable is gross tonnage, a measure of the ship's total permanently enclosed volume or absolute size. This is the only tonnage measurement available for the entire period. Since both net and gross tonnage are common measurements used to describe merchant ships, these variables are key descriptors of the ship and both are appropriate measures for the dependent variable. A more complete discussion of all variables used this and subsequent models was introduced earlier in Chapter III.

The independent variables are the year in which the ship was built and gross tonnage per unit of horsepower. The variable Year incorporates change over time so the variable is expected to have a positive coefficient which reflects the increasing demand for larger ships over time. The second independent variable is gross tonnage per unit of horsepower, or ship power. This variable is derived by dividing gross tonnage by the engine's indicated horsepower. This derived variable is a measure of the number of tons propelled by one unit of horsepower or, simply put, the ship's motive power. Although gross tonnage is used to derive the dependent variable ship power, the two variables are only moderately correlated (r = .528 at p = .0001), reflecting significant differences in power generation technology among ships and, hence, this variable's suitability for inclusion in the model. Since ship power increased throughout the study period. its coefficient is expected to be also positive.

The final specifications of the model and their associated test statistics are given in Table VII-1. The overall fit of the model is adequate given the complexities of this problem, with an adjusted R^2 of .29 and a highly significant F-statistic (306.17 at p = .00001). While the adjusted R^2 explains less than one third of the total variance, the model is theoretically sound and highly significant, as indicated by the fact that the signs of the coefficients are as predicted and the associated high level of significance for each independent variable.

While the model provides a good fit to the data, it has two serious drawbacks. First, it is very simplistic in that it contains only two independent variables. While these are the most important variables identified in the literature, a more complete description of iron steamship change can be specified as more technical descriptors become available over the course of the study period. The second drawback is that the model does not describe changes for the entire study period well, as indicated by the distribution of the

Table VII-1: 1840-1880 Model Results and Statistics Dependent Variable: Gross Tons			
	Coefficient	Beta	Significance
Intercept	-696.71	0.00001	0.00001
Year	12.73	0.1498	0.00001
Ship Power (Gross Tons)	118.67	0.4314	0.00001
n = 1487			
Adjusted R Square	0.291		
F- Ratio	306.17		0.00001

residuals within the individual shipbuilding cycles. If the model represents the entire study period, then the mean residual for each sub-period should sum to zero indicating no difference in the explanatory power of the independent variables across the cycles. When the mean residuals for each cycle are summed and averaged, however (Table VII-2), it is clear that this is not the case: the model underpredicted ship size for the first and fourth cycles while it overpredicted ship size for cycles 2 and 3.

Table VII-2: Mean and Summed Residuals by Shipbuilding Cycle

Statistic	Cycle 1: 1843-1855	Cycle 2: 1856-1865	Cycle 3: 1866-1872	Cycle 4: 1873-1880
Mean	58.05	-5.11	-44.84	8.53
Sum	9694	-1630.58	13946	5882.59
n	167	319	311	690

Based on the temporal pattern found during the residual analysis, it is clear that iron steamship change differed from cycle to cycle. This is not surprising when we consider the cyclical nature of changes in ship size, engine horsepower, and ship power established in Chapter IV. Therefore, to adequately understand the technical components of the steamship and their change through time requires the specification of a model for *each* individual shipbuilding cycle to improve our understanding of how these variables interact.

1.2. Cycle 1: 1840-1855

The first shipbuilding cycle, from 1840 to 1855, was a period of growth and experimentation within the shipbuilding industry. Output increased, especially after 1850 when the iron steamship made significant inroads in the European cargo routes (Hughes and Reiter, 1958). New keel framing systems associated with double bottom water ballasting increased longitudinal strength and allowed for greater ship length and tonnage (Dougan, 1968; Waine, 1976). Specialized bulk cargo-carriers were also introduced during the cycle (Dougan, 1868; Waine, 1976), along with the addition of deck structures (the bridge) and additional decks and partial decks (Waine, 1976). Experimentation also continued to make existing engines more suitable for the screw propeller, finally culminating in the introduction of the double expansion engine near the end of the cycle (Jones, 1958).

1.2.1. Model

A model predicting iron steamship technological change for the first cycle, 1840-1855, is now specified. Since the data are limited to the same variables as those available for use during the entire 1840-1880 period, the model remains unchanged:

Gross Tonnage = a + b1*Year + b2 * Ship Power

Again, ship size, in terms of gross tonnage, depends on the year the ship was built and its motive power. Likewise, both independent variables are again expected to have positive coefficients. Regression statistics are reported in Table VII-3.

Once again, the model provides a reasonably good fit to the data. The regression coefficients are of the expected signs and are significant, while the significance level associated with the F-statistic is quite good. Although the model explains only .13 percent of the total variance, down from an R^2 of .29 for the entire period, this is not surprising given the fact that only one technological measurement, ship power, is used to describe what is still, in practical terms, a highly experimental ship.

Table VII-3: 1840-1855 Model Results and Statistics
Dependent Variable: Gross Tons

	Coefficient	Beta	Significance
Intercept	-1815.78		0.0016
Year	39.99	0.275	0.0008
Ship Power (Gross Tons)	59.65	0.168	0.0381
n = 167			
Adjusted R Square	0.134		
F- Ratio	13.86		0.00001

The 1840-1855 steamship described by the model had a registered gross tonnage of 494 tons and its engine plant propelled 3.99 gross tons for each unit of engine horsepower. Gross tonnage increased rapidly during this cycle, at an average of 40 tons per year. Every unit increase in ship power resulted in an average increase of 60 gross tons.

1.3. Cycle 2: 1856 - 1865

The second shipbuilding cycle was an important period in the development of the iron steamship. The year 1855 witnessed three critical developments that directly impacted iron ship construction. First, the shipping community accepted iron as a shipbuilding material because of its technical and economic advantages over wood. Second, the Register established its first iron ship construction guidelines for ships classified with the society. Finally, Parliament passed the Moorsom Act which redefined the methods for calculating gross and net tonnage.

Perhaps the most important event of the entire study period occurred immediately before the start of this cycle with the re-introduction of the compound engine. This engine, designed to power the screw propeller, was followed three years later by an improved stern bearing that eliminated leakage where the propeller shaft exited the hull. These changes, introduced during the first cycle, coincided with the outbreak of the Crimean War, and the resulting shipbuilding boom accelerated their adoption during the second cycle.

The improved engine plant, when combined with the benefits of higher length-to-beam ratios, allowed for larger ships without corresponding increases in engine power. Changes in ship design included greater use of multiple decks, partial decks, and superstructures as shipbuilders sought to minimize net tonnage but not carrying capacity.

These changes took advantage of net and gross tonnage exemptions allowed by the Moorsom Act and later amendments.

1.3.1. Variables

In addition to the variables that were available for the first cycle's model, the Register began to consistently record net tonnage in 1853. Net tonnage is the ship's gross tonnage less the amount of ship volume used to carry cargo, and is a measure of the ship's cargo-carrying capacity. This improvement in record keeping makes possible a more detailed model. Using net and gross tonnage, an additional variable is constructed that measures cargo-carrying efficiency, expressed a percent of the ship's total permanently enclosed volume. This variable, the Net:Gross Ratio, is constructed by dividing net tons by gross tons.

A theoretical model is specified that states that a ship's gross tonnage depended on the year it was built, the ship's power, and the new variable: the Net:Gross Ratio. As in the previous model, the regression coefficients for these variables are expected to be positive to reflect increased average ship size and engine power. It is also expected that a negative coefficient will result for the Net:Gross Ratio under the assumption that experimental ship designs resulted in gross tonnage increasing at a faster rate than net tonnage. This assumption is based on Waine's (1976) argument that 1) shipowners demanded ships with minimal net tonnage relative to gross tonnage to minimize tax and cargo-handling costs, and that 2) this demand was satisfied by incorporating spaces that could hold cargo but were not permanently enclosed and so could be excluded from net tonnage calculations. This model is specified as:

Gross Tons = Year + Ship Power + Net:Gross Ratio

As can be seen in Table VII-4, the model does not provide a good fit to the data but, still, it is significant. R^2 is only .16, but the F-statistic is significant. The regression coefficients for Year and Ship Power are both significant and of the expected sign, but the Net:Gross Ratio is neither significant nor of the expected sign. The model suggests that ship design changes did not contribute to changes in ship tonnage.

Table VII-4: 1856-1865 Theoretical Model Results and Statistics
Dependent Variable: Gross Tons

	Coefficient	Beta	Significance
Intercept	-1456.94	0.137	0.0114
Year	23.68	0.137	0.0106
Net:Gross	93.29	0.011	0.8343
Ship Power (Gross Tons)	123.60	0.371	0.00001
n = 315			
Adjusted R Square	0.158		
F- Ratio	20.32		0.00001

Since this result is contrary to Waine's argument, the model is respecified by substituting net tonnage for gross tonnage for both the dependent and ship power variables under the assumption that shipowners were more concerned with a ship's cargo-carrying capacity than they possibly were with its absolute volume. Qualitatively, this argument seems sound and precedent for this specification is found in the literature. Net tonnage is used to calculate the ship power variable in order to keep it consistent with the dependent variable. Therefore, net tonnage is a more appropriate descriptor of the ship. The new model then becomes:

Net Tons = Year + Ship Power + Net: Gross Ratio

The new model reflects an improvement over the first (Table VII-5). Both R^2 and the F-statistic improve slightly (to .18 and 23.7, respectively). All regression coefficients, including that for the Net:Gross Ratio, are now significant, although the Net:Gross Ratio is still not of the expected sign. The improved performance of the model indicates that cargo-carrying capacity is a more precise, and so more appropriate, descriptor of 1856-1865 iron -steamship technological change.

Table VII-5: 1856-1865 Model Results and Statistics
Dependent Variable: New Tons

	Coefficient	Beta	Significance
Intercept	-1416.324		0.0007
Year	15.31	0.122	0.0212
Net:Gross	755.2	0.127	0.0189
Ship Power (Gross Tons)	85.18	0.350	0.0001
n = 315			
Adjusted R Square	0.183		
F- Ratio	23.74		0.0001

The mean 1856-1865 steamship was registered at 434.14 net tons. Net tonnage increased by 7.55 tons with every .01 unit increase in the Net:Gross Ratio. This is contrary to expectations that ship size would decline as the ratio increased. The

Net:Gross Ratio makes an important contribution to the steamship, but not through the addition of more exempted spaces. Had additional exempted spaces suitable for carrying cargo been added, then the ratio's value would have declined reflecting the fact that net tonnage declined or stayed the same relative to gross tonnage and, hence, the negative coefficient. The increase in gross tonnage relative to net tonnage indicates an increase in register cargo space, suggesting that the compound engine's fuel consumption and engine size efficiencies were reducing the amount of space being exempted for coal bunkers and machinery and so providing more ship volume for cargo.

1.4. Cycle 3: 1866-1872

The 1866-1872 cycle can be considered to have been a consolidation period in ship construction. Although shipbuilders continued to build larger ships, no significant changes in construction techniques are recorded for this period. Instead, shipbuilders began to experiment with new ship designs and adjusted length-to-beam ratios, with the latter reaching highs of between 10:1 and 11:1 during the cycle. That shipbuilding techniques had become standardized is suggested by the fact that shipbuilders were sending their ships back to the shipyard for lengthening (Parliamentary Papers, 1961) rather than selling them off to foreign buyers and purchasing newer and improved ships (Jones, 1958; Pollard and Robertson, 1979). Lengthening was accomplished by disassembling the ship at its midsection and inserting new hull sections.

The most important innovations in the marine steam engine plant during the 1866-1872 cycle were the adoption of the Scotch boiler and surface condenser. Following the pattern set by the compound engine, these innovations were introduced at the end of the previous cycle (1862 for the Scotch boiler and 1863 for the surface condenser) but not fully adopted until the 1866-1872 cycle. Unlike the compound engine, whose introduction coincided with a war-time merchant fleet build-up, the adoption of these innovations was much slower and they did not come into common use until after 1870.

1.4.1. Variables

The Register consistently recorded ship dimensions beginning in 1861. As a result, an additional aggregate variable, the Length-to-Beam ratio, can now be included in the analysis. This ratio, computed by dividing ship length by width, measures changes in hull form resulting from the application of the principle that increasing ship length relative to its width reduces water friction against the hull. This allows for larger ships but not a corresponding increase in engine power. According to Pollard and Robertson (1979), increasing the length-to-beam ratio was heavily utilized to improve engine and cargo-carrying efficiency.

1.4.2. Model

The theoretical model differs from the previous model only in that it includes the Length-to-Beam ratio. All other variables remain the same. The model is specified as:

New Tons = Year + Ship Power + Net:Gross + Length-to-Beam

Again, the coefficient for the variable Year is expected to be positive because ship size continued to increase. The Length-to-Beam coefficient is also hypothesized to be positive as shipbuilders sought to maximize ship power efficiencies by increasing the ratio, especially for larger ships. Conversely, the coefficients for ship power and the Net:Gross ratio is expected to have either very small positive or negative values, indicating that engine plants and ship designs were becoming so efficient that increases in ship size did not require corresponding increases in ship power or engine size. Finally, the Net:Gross coefficient is hypothesized to be negative because of an increasing divergence between net and gross tons as shipbuilders included more decks, partial decks, and other unenclosed spaces not included in net tonnage calculations.

The resulting model is the best so far. It explains over 50 percent of the variance among the variables (adjusted $R^2 = .52$) with a highly significant F-statistic of 85.6 (Table VII-6). However, and somewhat surprisingly, the regression coefficients for Year and Net:Gross are not significant, indicating that these variables were not significant for predicting ship tonnage.

Table VII-6: 1866-1872 Theoretical Model Results and Statistics
Dependent Variable: New Tons

	Coefficient	Beta	Significance
Intercept	-4301.17		0.0005
Year	30.41	0.080	0.0727
Net:Gross	-551.26	-0.057	0.2084
Ship Power (Gross)	48.88	0.155	0.002
Length-to-Beam	435.24	0.653	0.00001
n = 310			
Adjusted R Square	0.523		
F- Ratio	85.61		0.00001

The model is now respecified to achieve the best fit while retaining as many explanatory variables as possible. After running all possible combinations of variables, the model that best fit the two conditions is:

Gross Tons = Net:Gross + Length-to-Beam + Ship Power (Net Tons)

Regression statistics are reported in Table VII-7.

Table VII-7: 1866-1872 Model Results and Statistics
Dependent Variable: Gross Tons

	Coefficient	Beta	Significance
Intercept	-1876.33		0.00001
Ship Power (Net)	92.56	0.225	0.00001
Net:Gross	-1220.11	-0.125	0.009
Length-to-Beam	441.41	0.663	0.00001
n = 310			
Adjusted R Square	0.522		
F- Ratio	113.58		0.00001

After the respecification, the results remain consistent. The R^2 is unchanged and the F-statistic remains highly significant. The differences between the two models are that, first, Gross Tons replaces Net Tons as the dependent variable; second, the variable Ship Power is computed using net rather than gross tons; and third, the variable Year has been dropped from the model altogether. The fact that the variable Year was not significant is surprising. That the year in which the ship was built is not important strongly suggests that the pace of technological change slackened during this period and underscores the fact that iron and steam shipbuilding techniques had become standardized at this time.

The three variables that explain ship size, in terms of gross tons, are Ship Power, the Net:Gross ratio, and the Length-to-Beam ratio. Per unit increases in both Ship Power and the Length-to-Beam Ratio resulted in increases of 92.56 and 441.41 gross tons, respectively. As expected, but unlike its performance in the previous cycle, a negative relationship existed between the Net:Gross ratio and ship size: an increase of .01 units in this ratio resulted in a decrease in ship size of 12.2 tons.

The performance of the Length-to-Beam and Net:Gross ratio variables substantiate the arguments made by Pollard and Robertson and Waine concerning changes in hull form and ship designs. The Length-to-Beam ratio made the largest contribution of the three variables in explaining ship size. The negative relationship between the Net:Gross ratio and ship size demonstrates that the percent of net tonnage as a percent of gross tonnage declined, demonstrating that shipbuilders were increasing absolute ship size but not registered cargo-carrying capacity. Although the divergence between net and gross tonnage could be due to increases in machinery and engine plant size that were exempt from net tonnage calculations, this is highly unlikely given the emphasis placed on making the engine plant more space efficient. A more likely explanation is that shipbuilders were making use of deductions that allowed for non-permanently enclosed spaces through the addition of decks and partial decks as provided for in the Moorsom Act of 1854. Non-permanently enclosed spaces could be used to carry cargo but were not included in the calculation of taxes, cargo-handling fees, and other expenses.

1.5. Cycle 4: 1873-1880

A review of the historical literature identifies few changes in either ship construction or engine plants during the final cycle incorporating the years from 1873 to

1880. This suggests that the period was one of stabilization and standardization and that further improvements came through the fine-tuning of existing techniques. Changes in ship construction centered around a trend toward the stabilization of the Length-to-Beam ratio at around 8:1 (Pollard and Robertson, 1979) and the increasing use of additional and partial decks (Waine, 1976). Improvements in the engine centered around raising boiler pressures, made possible by improvements to the Scotch boiler adopted during the preceding cycle (Rowland, 1970).

1.5.1. Variables

The Register began recording engine specifications by 1870, allowing for the addition of two new variables to the analysis. These variables are boiler pressure and engine size. The estimate of boiler pressure reported in the Register is the boiler's rated operating pressure rather than the amount of pressure operating on the cylinder head (based on experiments attempting to calculate horsepower using the Register's engine specifications). The engine size variable is a ratio that unitizes register tonnage, either gross or net, to engine cylinder volume (in^3) computed from the Register's cylinder diameter and piston stroke length specifications.

1.5.2. Model

The theoretical model includes the variables used in the final model for the 1866-1872 cycle but also incorporates these two new variables, Boiler Pressure and Cylinder Volume:Gross Tons. Gross tons is used as the unitizing value for the cylinder volume ratio because this is also the dependent variable. The model is specified as:

Gross Tons = Ship Power (Net) + Net:Gross + Length-to-Beam +

Boiler Pressure + Cylinder Volume:Gross Tons

Positive coefficients are expected for the variables Ship Power and Boiler Pressure reflecting continued improvements in engine plant efficiencies. A positive coefficient is also expected for the Length-to-Beam ratio. Conversely, the coefficients for both Net:Gross and Cylinder Volume:Gross Tons should be negative: the first because of additional exempted spaces within the ship; the second because of scale efficiencies in the engine plant, coupled with the effects of the Length-to-Beam ratio, allowed for more cargo to be carried without a corresponding increase in engine plant size.

Model statistics, reported in Table VII-8, show that the model provides a very good fit to the data. Adjusted R^2 is .63 and the F-statistic is highly significant. However, the regression coefficient for the Net:Gross ratio is not significant, while that for the Cylinder Volume:Gross Tons ratio, while significant, surprisingly is not of the expected sign.

The model is respecified in order to include the Net:Gross ratio and see if this would change the sign for the Cylinder Volume:Gross Tons ratio. As in the previous model, the condition for selecting the best model is to retain as many explanatory variables as possible without jeopardizing explanatory power. After running all possible combinations of variables, the best model in respect to explanatory power is as follows:

Net Tons = Year + Net:Gross + Ship Power (Net) + Length-to-Beam +

Cylinder Volume:Gross Tons + Boiler Pressure

Table VII-8: 1873-1880 Theoretical Model Results and Statistics Dependent Variable: Gross Tons			
	Coefficient	Beta	Significance
Intercept	-4512.39		0.00001
Ship Power (Net)	125.23	0.284	0.00001
Net:Gross	110.20	0.008	0.7593
Length-to-Beam	540.07	0.638	0.00001
Boiler Pressure	10.97	0.152688	0.00001
Cylinder Volume:Gross	0.16	0.111	0.0001
n = 608			
Adjusted R Square	0.631		
F- Ratio	249.02		0.00001

These changes slightly improve Adjusted R^2 from the .63 of the theoretical model to .66 due to the additional variables (Table VII-9). The F-statistic remains highly significant. The new model also results in two important changes. The first change is the renewed emphasis on cargo-carrying capacity in explaining the steamship, as demonstrated by the substitution of Gross Tons (absolute ship size) for Net Tons as the dependent variable. This change suggests that shipbuilders were more concerned with maximizing the ship's cargo-carrying capacity, and so its earning potential, rather than absolute size. The second change is the re-emergence of the variable Year which demonstrates that, unlike the 1866-1872 cycle, technological change over time was an important component of the 1873-1880 iron steamship.

Table VII-9: 1873-1880 Model Results and Statistics for Dependent Variable Net Tons

	Coefficient	Beta	Significance
Intercept	-5420.88		0.00001
Year	12.96	0.058	0.0442
Net:Gross	2151.5	0.225	0.00001
Ship Power (Net)	72.98	0.225	0.00001
Length-to-Beam	358.89	0.627	0.00001
Cylinder Volume:Net	0.08	0.195	0.00001
Boiler Pressure	8.55	0.133	0.00001
n = 608			
Adjusted R Square	0.663		
F- Ratio	199.64		0.00001

Both average ship size and power increased between the third and fourth cycles. The average ship was registered at 1285.63 gross tons and 839.61 net tons, while ship volume propelled by one unit of horsepower increased by 8.41 (gross) and 5.46 (net). These changes represent rates of increase of approximately 27.7 and 20.75 percent, respectively, with the slower rate of increase for ship power indicating that engines were becoming more efficient in terms of power. This is because increases in ship size did not require corresponding increases in ship power. In addition, the average values for the Net:Gross and Length-to-Beam ratios did not change from the third to fourth cycle.

The average 1873-1880 steamship was registered at 840 net tons. Net tonnage increased 12 tons each year. Every unit increase in ship power, in terms of volume of cargo propelled by engine plant, resulted in 73 additional net tons. While the average

Net:Gross ratio remained stable between the third and fourth cycles, net tonnage increased 21.51 tons for every .01 unit change in the ratio. This is counter to expectations of a negative relationship between the variables, and suggests that a limit had been reached to the amount of additional space that could be exempted from the net tonnage calculations. Based on the size of its beta coefficient, the Length-to-Beam ratio was again the single largest contributor with respect to explaining ship cargo-carrying capacity, with a unit increase in the ratio resulting in a corresponding increase in cargo-carrying capacity of 359 tons. Contrary to expectations of a negative relationship between the Cylinder Volume:Net Tons ratio and cargo-carrying capacity (expected if engine size efficiencies were being realized), a one unit increase in the ratio resulted in an increase of only .08 net tons. This a very small value since the average ratio was 1984.4:1, but the coefficient is highly significant. The final variable, Boiler Pressure, did perform as expected, with one unit change leading to an additional 8.55 tons of cargo-carrying capacity.

This discussion of the final model for the fourth shipbuilding cycle concludes the technological change modeling process. Using data available from the Register, these models have identified those innovations that made a significant contribution, in a statistical sense, to increasing ship size. With the significance of their importance proven, the variables from these models can now be used to construct the innovative ability variable that identifies technologically leading and lagging shipbuilding centers.

2. INNOVATIVE ABILITY INDEX

The independent variables for each of the four models are now used to develop a synthetic measure of each shipbuilding center's innovative ability during each year it was in production. This variable is developed by scoring each ship built during a given cycle by its level of technological sophistication relative to all other ships. This is accomplished by assigning each independent variable, which measures an important technological innovation, from each cycle a score ranging from one (1) to five (5) based on quintiles which reflect the position of each ship on that variable's range of values for all ships. A score of 1 indicates that the ship incorporated the lowest possible level of technological sophistication for that particular innovation (the lowest quintile), while a score of 5 indicates that it incorporated the highest level (the highest quintile). The variable scores are then summed to produce an "innovative index" for each ship. Since the majority of ships were built on order from the shipowner, it should be recognized that the index score can be influenced by design considerations such as trade route and owner preferences.

The mean innovative index score for all ships built at any center during any given year is then calculated to serve as a benchmark for all ships. The final step is to rank each center and year into one of two categories based on whether or not the center and year combination's mean innovative index score was above or below the mean score for all ships built during the cycle. A high rank indicates that the center was, in practical terms, a technological leader relative to the cycle's mean ship, while a low rank indicates that it was a technological laggard.

The use of such composite indices in studies of technological innovation with multiple forms has precedent in economics research. An example is the study by Akridge (1989) that assesses the effectiveness of a sample of multiproduct agribusiness firms in minimizing costs. The study estimates the frontier multiproduct cost function and then develops an index to use as a benchmark against which the performance of individual firms is compared. A second example is the study by Baltagi, et al. (1995) who estimate a general index of technical change within the US airline industry to identify cost changes due to technological change and cost changes due to deregulation.

The following section presents these innovative rankings for each of the four cycles. Again, each observation is a combination of an individual center and the year in which it produced at least one ship listed in the Register. The discussion is based on a series of tables and maps. The tables present the total number of center / year combinations by region for each cycle, while the maps provide the rank for each center producing a ship during the last year of each cycle.

2.1. Cycle 1: 1840-1855

Technologically leading shipbuilding center / year combinations outnumbered lagging combinations during the first cycle (Table VII-10). Leaders accounted for 57 percent of the eighty-two total frequencies. The Humber was the most innovative region with all its centers being technological leaders. Contrary to the assessment of nineteenth century observers and shipbuilding historians (Parliamentary Papers, 1969; Pollard and Robertson, 1979), the North East Coast was a technologically leading region while the Clyde was evenly divided among technologically leading and lagging center / year combinations. The Mersey and Thames, both considered innovative centers (Banbury, 1971; Pollard and Robertson, 1979), can be so characterized: both having five of their seven total combinations ranked as technological leaders. This confirms the assessment of previous research discussed in Chapter V. While the innovative performance of the

Severn and Scottish East Coast was mixed, the remaining regions, especially Ireland, can not be considered to have been innovative.

Table VII-10: Innovative Ability Rank, 1840-1855

	Rank		
Region	Low	High	Total
Clyde	15	15	30
North East Coast	5	12	17
Thames	2	5	7
Mersey	2	5	7
Ireland	6	1	7
Humber	0	5	5
Severn	3	2	5
Scottish East Coast	1	2	3
Irish Sea	1	0	1
Total	35	47	82

The map of 1855 centers, Figure VII-1, is dominated by technological leaders. Of the eighteen centers, only one center (Preston, the single observation on the Irish Sea) was not a technologically leading center. The map, when compared to the regional performances in Table VII-10, suggests that innovations associated with the single independent variable ship power had been assimilated by the industry.

2.2. Cycle 2: 1856-1865

Technologically lagging center / year combinations outnumbered leaders during the second cycle, with seventy-one of the total combinations being non-innovative (Table

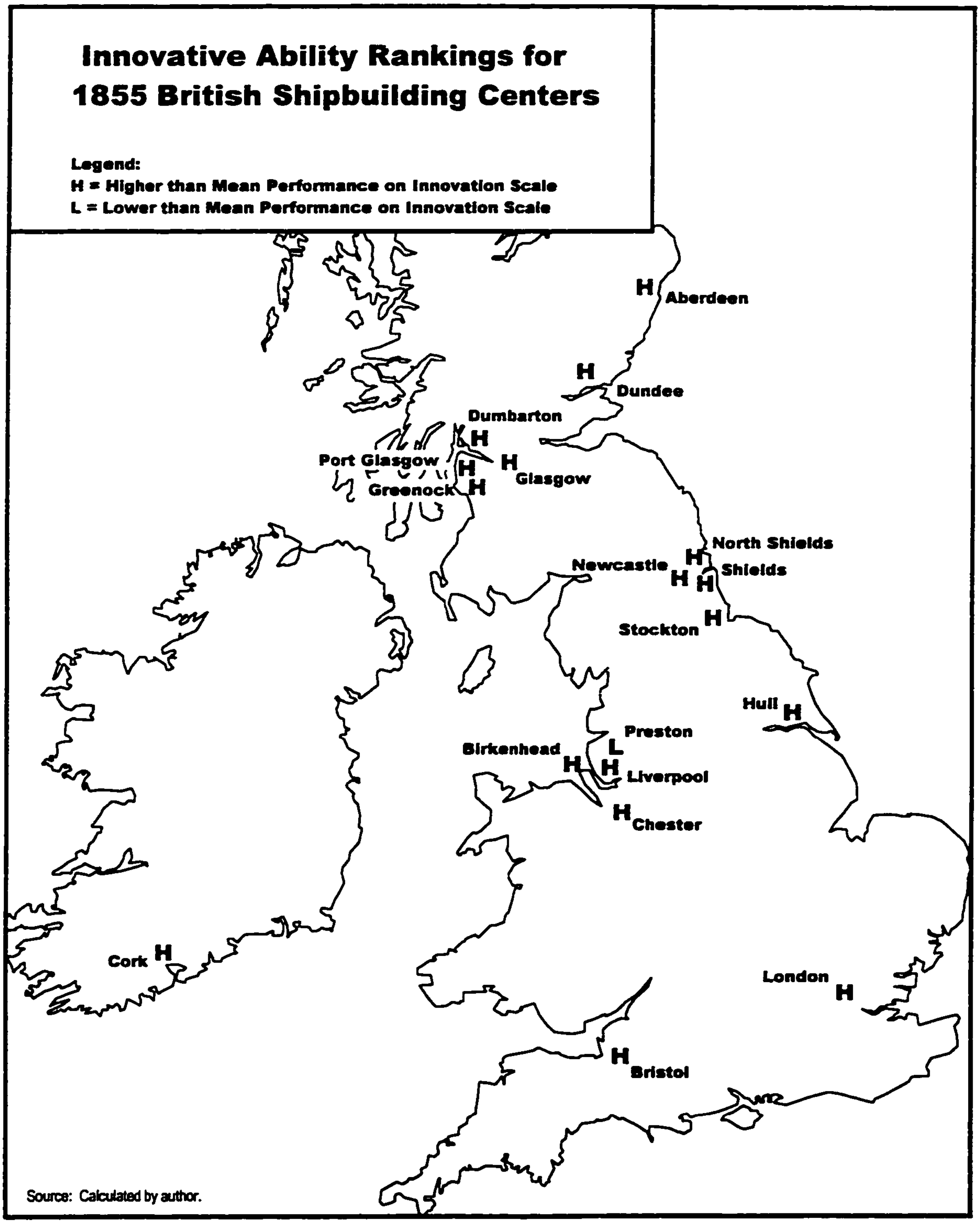


Figure VII-1: Innovative Ability Rankings: 1855

VII-11). The North East Coast was again the most innovative region. The only other region that can be characterized as being innovative was Ireland, where five of its seven combinations were in the high innovative ability category. This region's performance is due to Belfast's Harland and Woolf Company, a firm which enjoyed a strong reputation as an innovative shipbuilding firm. The Clyde, Thames, and Mersey regions can all be considered non-innovative, although the Clyde to a lesser extent that the other two.

Table VII-11: Innovative Ability Rank, 1856-1865

	Rank		
Region	Low	High	Total
Clyde	29	16	45
North East Coast	10	17	27
Scottish East Coast	8	5	13
Ireland	5	7	12
Thames	6	2	8
Humber	6	1	7
Mersey	3	1	4
Severn	2	1	3
Irish Sea	2	0	2
Total	71	50	121

Of the fifteen centers in production during 1865 (Figure VII-2), ten were technological leaders. All four of the centers on the North East Coast were innovative. The only innovative center on the Clyde was Dumbarton, where the multiple expansion engine was introduced. Unexpectedly, Glasgow is included among this region's non-

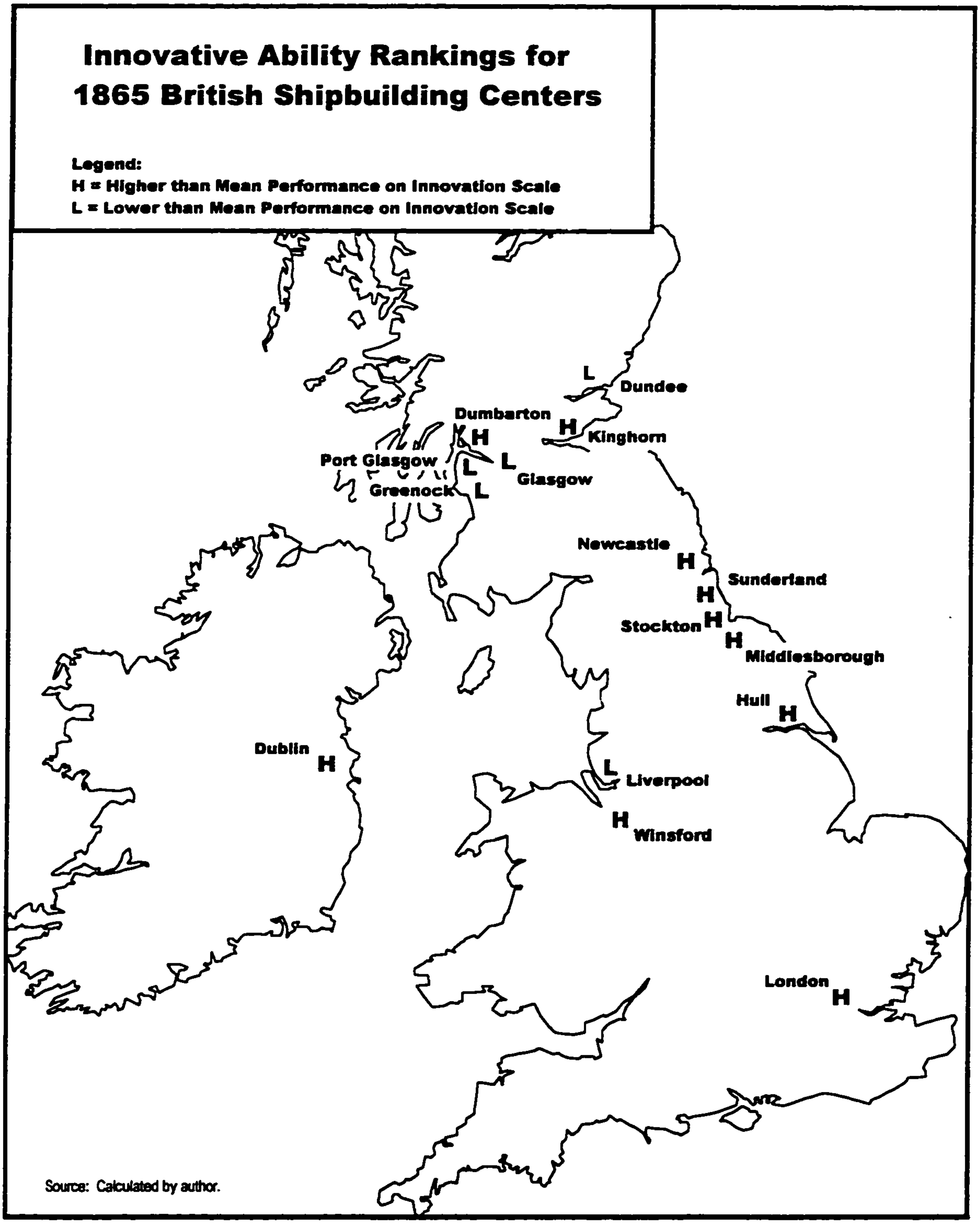


Figure VII-2: Innovative Ability Rankings: 1865

innovative centers. The only other non-innovative centers were Liverpool on the Merseyand Dundee on the Scottish East Coast. London is included among the innovative centers.

2.3. Cycle 3: 1866-1872

Repeating the pattern in the previous cycle, technologically lagging center / year combinations were in the majority (Table VII-12). The best performing region during this cycle was the Scottish East Coast were there were as many leaders as laggards (although the same can be said for the Solent, this region had only two combinations). In all the other regions, including the North East Coast and Clyde, technological laggards outnumbered leaders. The Severn was the worst performing region with no technological leaders among its four center / year combinations.

Table VII-12: Innovative Ability Rank, 1866-1872

	Rank		
Region	Low	High	Total
Clyde	21	15	36
North East Coast	20	14	34
Scottish East Coast	7	7	14
Thames	4	2	6
Mersey	3	2	5
Severn	4	0	4
Humber	2	1	3
Ireland	2	1	3
Solent	1	1	2
Total	64	43	107

The nineteen shipbuilding centers shown in Figure VII-3 suggest that the technologies represented by the independent variables in the third cycle's model had been widely assimilated by the British shipbuilding industry. Only five centers were non-innovative centers. The Clyde and North East Coast each accounted for two of these centers (Renfrew and Port Glasgow on the Clyde, the two Shields on the North Each Coast), while the final non-innovative center was the isolated Northam. Both Liverpool, on the Mersey, and London on the Thames were innovative centers.

2.4. Cycle 4: 1873-1880

Unlike the previous two cycle, the fourth cycle had more innovative center / year combinations than non-innovative combinations. Both the North East Coast and the Clyde can be characterized as technological leading regions with 66 and 56 percent of their shipbuilding combinations being in the technologically leading category. All combinations in the Ireland and Humber regions were innovative, and 63 percent (5 of 8) of the combinations on the Irish Sea were innovative. The regions that performed poorly were the Scottish East Coast, Severn, and Thames, while the Mersey had as many leading as lagging combinations.

Of the fifteen centers shown in Figure VII-4, only two were non-innovative. These centers were Greenock and Paisley on the Clyde. Again, the high proportion of innovative to non-innovative centers suggests that the significant technological changes identified by the cycle's model had been widely diffused within the industry by end of the fourth, and last, shipbuilding cycle.

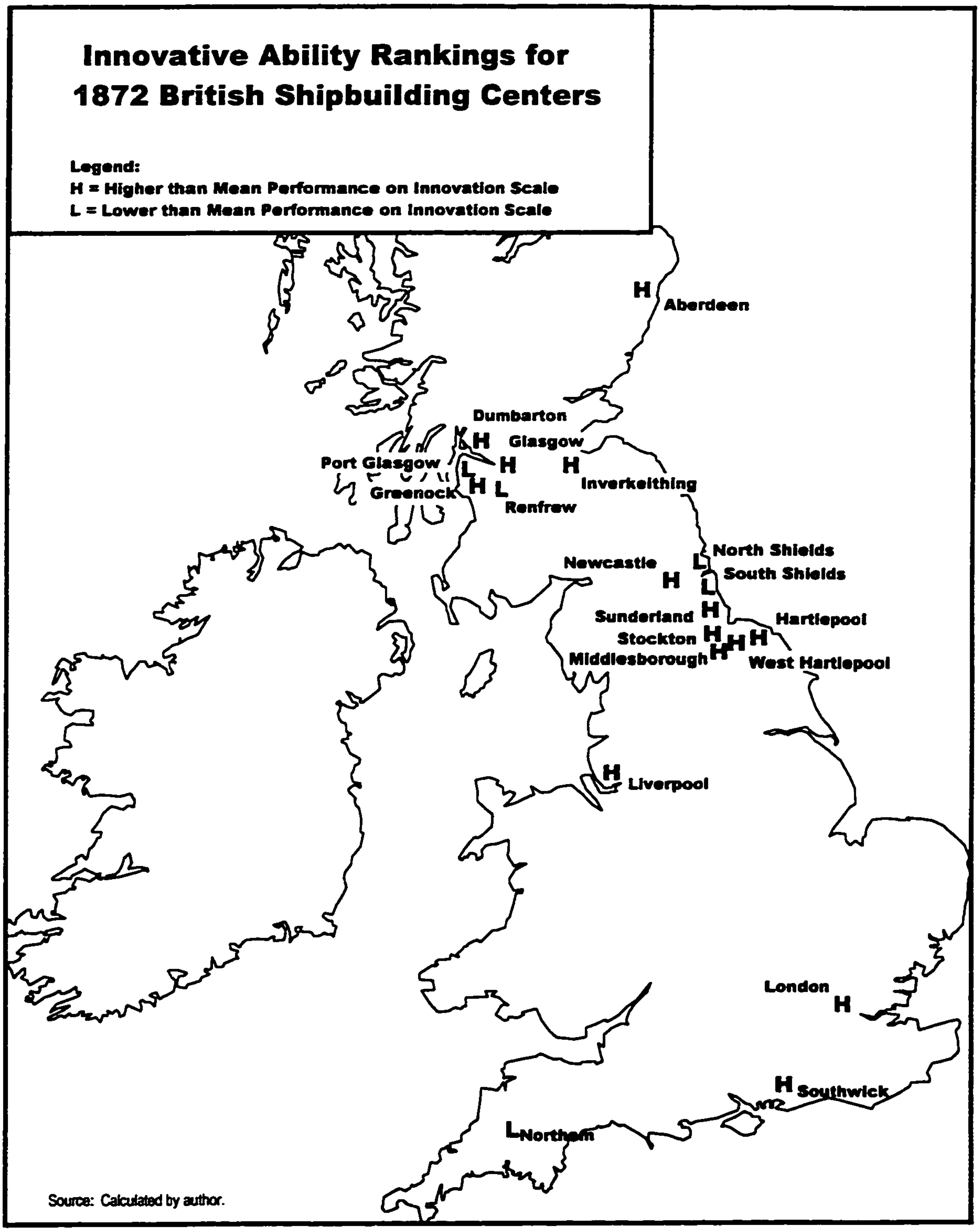


Figure VII-3: Innovative Ability Rankings: 1872

Table VII-13: Innovative Ability Rank, 1873-1880			
		Rank	
Region	Low	High	Total
North East Coast	17	34	51
Clyde	15	19	34
Scottish East Coast	11	3	14
Irish Sea	3	5	8
Mersey	3	3	6
Thames	3	1	4
Ireland	0	3	3
Solent	2	1	3
Humber	0	2	2
Severn	2	0	2
Total	56	71	127

3. SUMMARY AND CONCLUSIONS

This chapter has developed a measure of the innovative ability of each individual shipbuilding center and year in which that center produced at least one ship certified and registered with Lloyds. This has been accomplished by estimating a series of regression models that describe iron steamships and their technological change over time for each of four shipbuilding cycles. It then uses the independent variables from these models to construct an innovation index that aggregates all ships built at an individual center during each year it was in production and assigning the center / year combination a ranking of high, indicating a technologically leading center, or low to indicate a technologically lagging center.

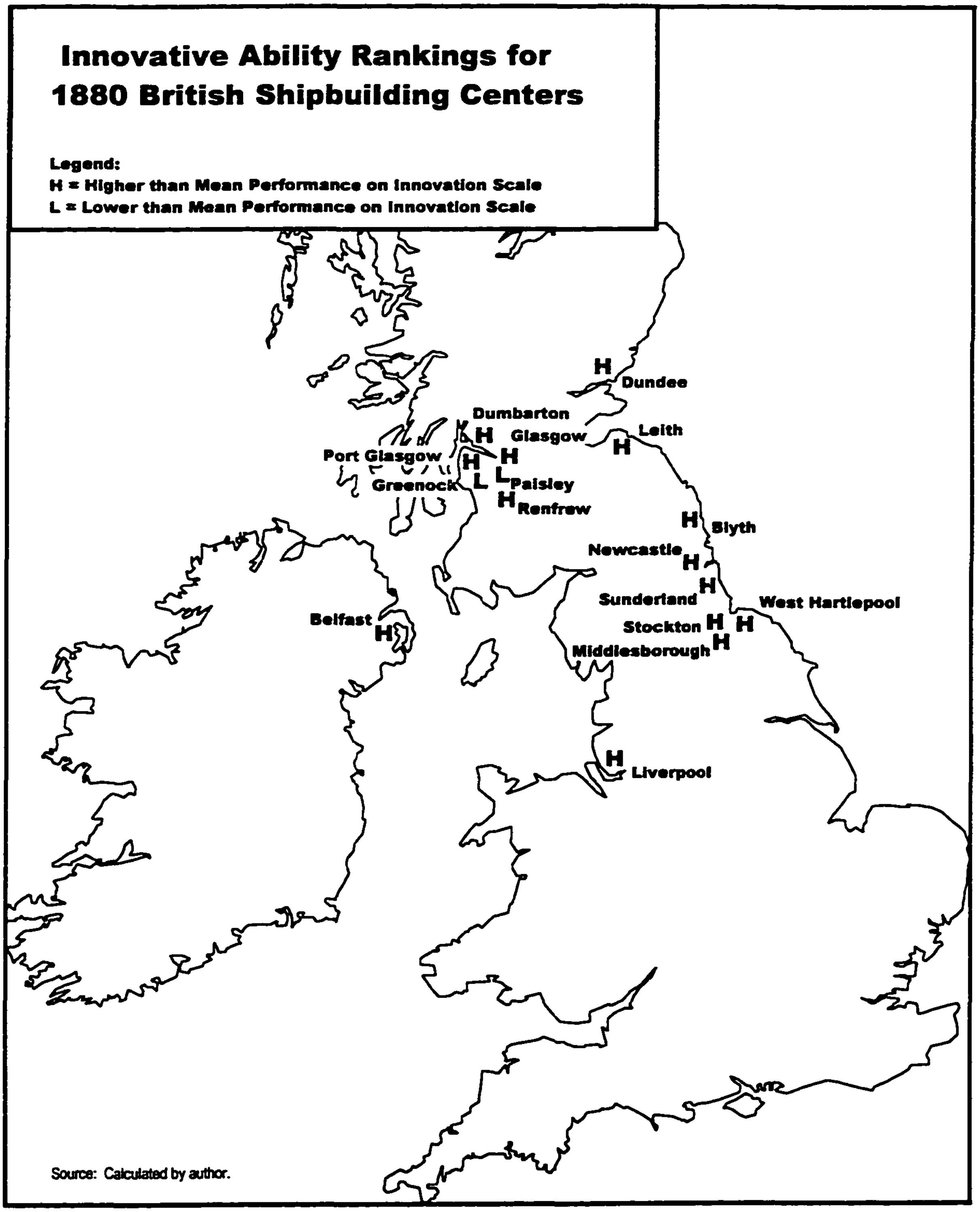


Figure VII-4: Innovative Ability Rankings: 1880

Four regression models, one for each of the four shipbuilding cycles identified in Chapter IV, were estimated using variables as they became available over the course of the study period. Although initial R^2s were low, this is understandable given the lack of data available for the early part of the study period and the complexity of these technologies. Still, test statistics for the models for the first two cycles were significant and theoretically correct. The last two models incorporated more variables and provided much higher levels of explanatory power while maintaining their significance and theoretical correctness.

These models reveal a great deal of information about iron steamship technological change. Generally, the behavior of the models and the variables incorporated in them confirm historical interpretations of steamship technological change while quantifying its rate and direction. In addition, the behavior of the variables from one cycle to the next provides insights into shipbuilders' technological concerns when designing ships and the economic considerations of shipowners.

Several insights are gained when we consider the type of register tonnage measurement used for the dependent variables and ship power variables. The highest amount of explanatory power for the second cycle model was obtained using net tonnage as the dependent variable and net tonnage per unit of horsepower for the Ship Power variable. Since net tonnage measures the ship's cargo-carrying capacity, its use suggests that ships were being built to maximize earning potential in response to the primary concern of the shipping industry.

However, the dependent variables were reversed for the 1866-1872 cycle. While this could be a data artifact, it could also indicate that technological change was directed toward maximizing ship size while maintaining the concern for cargo-carrying potential (as indicated by the continued use of net tonnage to derive the ship power variable). It is especially interesting that the variable Year did not significantly load in this model. By the fourth cycle, however, and when the variable Year again becomes significant, the "best fit" dependent variable returned to net tonnage, or cargo-carrying capacity rather than absolute ship size. Again, this change was in response to the shipping industry's concern for ships that maximized earning potential.

The last section in the chapter presented the innovative ability rankings constructed using the statistically significant independent variables from the four regression models for each shipbuilding center / year combination. These data were presented through a series of tables showing the innovative performance at the regional level and a series of maps that identified the performance of all centers that were in production during the last year of each shipbuilding cycle. The rankings for each center / year combination are now carried into the final stage of this analysis that, in conjunction with the market share rankings developed in the previous chapter, assesses the association between industrial viability and innovative ability.

In many respects, the results reflected by these regional innovative ability rankings do not substantiate the opinions of shipbuilding historians as to which regions were and were not innovative. Based on the calculated innovative index put forward in this research, the North East Coast can be characterized as Britain's most innovative shipbuilding region. This finding is contrary to the consensus historical interpretation (with the notable exceptions of those volumes that deal exclusively with the North East Coast industry) which considers the Clyde, Thames, and Mersey regions to have been the most innovative. However, the assessment based on the innovative index reveals that the performance of the Clyde and Mersey was mixed while the Thames innovative ability declined after the first cycle.

CHAPTER VIII

THE RELATIONSHIP BETWEEN INDUSTRIAL VIABILITY AND INNOVATIVE ABILITY

The final portion of this study will examine the relationship between every 1840-1880 British iron and steam shipbuilding center's industrial viability and its innovative ability. The analysis uses a chi-square contingency table testing procedure to determine whether or not a statistical association exists between a shipbuilding center's annual market share rank and its position as either a technologically leading or lagging shipbuilding center. In practical terms, the question to be answered is whether or not individual shipbuilding centers reaped an economic reward for building innovative iron steamships. Following the logic of the implicit relationship between innovation and place, this analysis assumes that a center's ability to compete successfully in the market place was related to the production of innovative ships.

This chapter is organized in the following manner. The first section presents the analytical framework that will be used to carry out the test. It briefly outlines the chi-square contingency table test, the variables used for this test, and the methods that will be used to test for, and then assess, the association. The second section conducts a separate test for each of the four shipbuilding cycles and assesses the relationship between innovative ability and industrial viability.

1. ANALYTICAL FRAMEWORK

The test for the association between a shipbuilding center's innovative ability and its ability to compete within the national shipbuilding industrial system is conducted using a chi-square contingency table test. To carry out the test, the market share rank variable developed and introduced in Chapter V is combined with the innovative ability rank variable developed in the previous chapter. This section presents the framework that will be used to assess this relationship.

1.1. Chi-square Contingency Table Test

The chi-square contingency table test is a non-parametric statistical procedure that tests for an association between two sets of categorical variables. The variable categories are used to construct a contingency table in which the categories for one variable represent rows in the table and the categories for the second variable form the columns. Each joint occurrence, or frequency, of the two variables is then entered into one of the cells formed by the intersection of the rows and columns. The test compares the cells' observed joint frequencies to their expected joint frequencies, with the expected frequencies calculated based on the proportions between the total row and column frequencies (Conover, 1980). Nonparametric statistical techniques have been used to investigate technological change, as in Chavas and Cox's "A Nonparametric Analysis of Agricultural Technology" (1988).

The test's null hypothesis is that the two variables are independent or, more specifically, that they are not associated. In this case, there will be little or no statistically significant differences between the observed and expected frequencies in each cell of the contingency table. The alternative hypothesis is that the variables are not independent or, alternatively, that an association does in fact exist. The test is carried out by calculating a chi-square statistic. If the chi-square statistic is insignificant then any differences between the observed and expected frequencies is due entirely to chance and the null hypothesis of no association must be accepted. If the statistic is significant, then the differences are real and the alternative hypothesis of an association is accepted.

1.2. Variables and Categories

For the test between industrial viability and innovative ability, each shipbuilding center for each year it produced at least one ship listed in the Register has been ranked in terms of its market share and innovative ability. There are three ranks for the market share variable based on the amount of annual output the shipbuilding center produced relative to all other centers. A center is given a high score if it was in the top 33 percent of all centers in production for that year, a medium score if it was in the middle 33 percent, and a low score if it was in the bottom 33 percent.

The innovative ability variable ranks centers as to whether the combination of technological innovations incorporated in the ship or ships built at that center for that year were above the mean value of the index for all ships built during a given shipbuilding cycle. A high rank indicates that the technological innovations for the ship or ships built at a given center during a given year exceeded the mean level of technological innovations in all ships, indicating that it was a "technological leader," while a low rank indicates that technological innovations were below the mean and that the center was a "technological laggard."

Again, it should be remembered that ships were built on order for shipowners, so that the innovative ability index value also clearly reflects shipowner preferences and, as such, can be influenced by a shipowner's technical specifications. If the shipowners' specifications included non-innovative technical components. then they are reflected in the final ranking. This influence is especially strong for centers that produced only one ship during a given year.

This method of analysis results in a three-by-two contingency table with the market share categories forming the rows and the innovative ability rankings the columns. The six possible joint occurrences of the two variables are:

Low/Low	- Low market share and low innovative ability
Low/High	- Low market share and high innovative ability
Medium/Low	- Medium market share and low innovative ability
Medium/High	- Medium market share and low innovative ability
High/Low	- High market share and low innovative ability
High/High	- High market share and high innovative ability

There are four contingency tables and four sets of association which reflect the sub-division of the study period into four separate shipbuilding cycles.

1.3. Analytical Procedure

The analysis of the tables is conducted in the following manner. First, the test for association is carried out. The null hypothesis for each test is that no relationship exists between the two variables and that market share and innovative ability are not associated. In the event of an insignificant chi-square statistic, the null hypothesis is accepted. In the event of a significant chi-square, the alternative hypothesis of an association between market share and innovative ability is accepted.

If the chi-square statistic is significant, the strength and direction of the association is measured. Since the contingency table is rectangular, rather than square, this is accomplished using Kendall's Tau-c measure of association. Tau-c, and other measures of association between two ordinal-level variables makes possible a check of every possible pair of cases in the table to determine if their relative ordering on the first variable is the same (concordant) or if the ordering is reversed (discordant). If a preponderance of the cases are ordered in the same direction on both variables, then the final statistic will be positive and the association is positive. If not, then the final value of the test statistic is negative and the association is negative. The Tau-c statistic is interpreted in a manner similar to a correlation coefficient, with values ranging from a negative one (-1), indicating a perfect negative association, to a positive one (+1) indicating perfect positive correlation (Hettmansperger, 1984).

The final step, employed only if the chi-square statistic is significant, is to identify which of the six possible categories in the contingency table were the most influential to the association and why. This is accomplished by assessing the relative contribution of the individual table cells to the absolute value of the chi-square statistic. If one or more table categories made a higher relative contribution than the other table categories, then those categories are examined in more detail to identify the characteristic or characteristics of those shipbuilding center / year combinations which might make them more influential than the other possible combinations.

2. THE ASSOCIATION BETWEEN INNOVATION AND PLACE

With the analytical framework established, a report on the actual association between innovation and place can precede. The test is conducted for each shipbuilding cycle in succession. The discussion for each cycle is organized in the following manner. First, the variables' joint occurrence is presented and discussed through a table that provides regional breakdowns for the six categories and supported by a map that identifies individual shipbuilding centers and their performance during the last year in the cycle. Next, the results of the contingency table test are presented. If no association exists, the discussion must end at that point. If there is an association, its strength and direction are assessed and the influential categories across rows and columns are identified and discussed.

2.1. Cycle 1: 1840-1855

The first cycle represents the innovation phase of Vernon's Product Life Cycle. During this phase, production tends to be concentrated in a relatively few locations. That this concentration occurred in the shipbuilding industry is demonstrated by the number of shipbuilding center / year frequencies in the medium and high market share categories on the Clyde (Table VIII-1). However, this concentration was not necessarily due to the region's greater innovative ability. Granted that the innovative ability measure consists of only one variable (ship power), there were just as many center / year frequencies appearing in the two low innovation categories as were found in the high innovation categories. There does appear to be a positive relationship between innovative ability and market share for the North East Coast, Thames, and Mersey shipbuilding regions, however, where more frequencies occur in the high and medium share categories. A similar pattern does not exist for the other regions.

For the purposes of illustration, Figure VIII-1 locates the shipbuilding centers and their performance in the six categories during the year 1855, the last year in the cycle. Only four categories are represented. The highest category, high market share and high innovative ability, is dominated by the Clyde, with all four of its centers in this category. as well as the two Shields on the North East Coast and Aberdeen on the Scottish East Coast. The medium share/high innovative ability category is made up of Newcastle and Stockton on the North East Coast, Liverpool and Chester on the Mersey, and Hull (Humber) and Cork (Ireland). Four centers, including London, are in the low share/high innovative ability category, while Preston on the Irish Sea is the only center in the low share/low innovative ability category. Based on the map, and recognizing the exception of London. there does appear to have been a relationship between market share and innovative ability in 1855.

Table VIII-1: Regional Contingency Table Categories
Cycle 1: 1843 - 1855

	Categories						
Region	Low Low	Low High	Medium Low	Medium High	High Low	High High	Total
Clyde	1	1	5	6	9	8	30
N. E. Coast	3	5	1	4	1	3	17
Thames	0	1	1	2	1	2	7
Mersey	1	2	1	3	0	0	7
Ireland	2	0	3	1	1	0	7
Humber	0	0	0	2	2	1	5
Severn	3	1	0	1	0	0	5
S. E. Coast	0	1	1	0	0	1	3
Irish Sea	1	0	0	0	0	0	1
Total	11	11	12	19	14	15	82
Percent Total	13.4	15.9	14.6	23.2	14.6	18.3	100

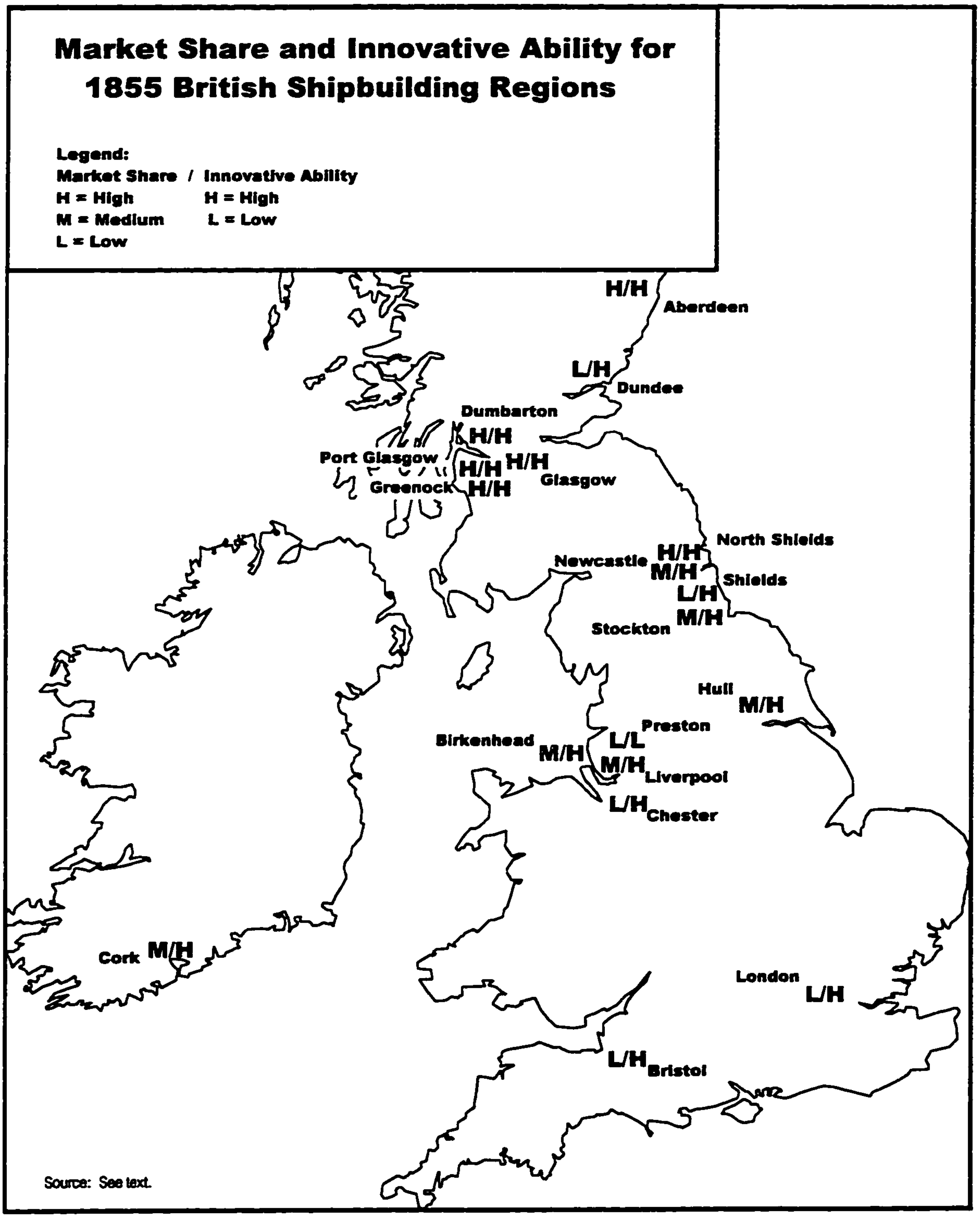


Figure VIII-1: Market Share and Innovative Ability Rankings: 1855

Despite the apparent positive association between market share and innovative ability, the chi-square contingency table test resulted in a non-significant chi-square statistic. The table and test statistics are presented in Table VIII-2. Based on the results of this test (χ^2 = .33, df = 2, p = .847), the null hypothesis that there is no association between market share and innovative ability is accepted.

Table VIII-2: Chi-square Contingency Table Test Results
Cycle 1: 1843 - 1855

		Market Share			
Innovative Ability		Low	Medium	High	Total
Low	Observed Expected	11 10.2	12 13.2	12 11.5	35
High	Observed Expected	13 13.8	19 17.8	15 15.5	47
Total		24	31	27	82

χ^2 = .33 df = 2 p = .847

Obviously, the first cycle was a period of high innovation: after all, the first trans-oceanic iron steamship had been introduced only three years before. Three possible reasons for this lack of association can be identified. The first, of course, is that a model based on only two available variables from the Register is not powerful enough to capture technological change. There were only two independent variables used to specify the regression model and, as discussed earlier, its explanatory power is low. Second, but related to the first reason, innovation was going on at such a high rate that the single variable used to construct the innovation index, ship power, does not capture the full range of innovations that were actually of significance during the period. Finally, the reason could lie in the fact that there simply was not that strong an association between market share and innovative ability, so that the Clyde's dominance of market share can be explained in terms of its initial and locational advantages: its pioneering role in iron and steam shipbuilding and its established linkages to the iron and machinery industries and ship markets.

2.2. Cycle 2

The industry had clearly entered the growth phase of the Product Life Cycle during the second cycle (1856-1865). As established earlier, the Clyde was again the dominant region, but the North East Coast experienced significant growth as did, but to a lesser extent, the Scottish East Coast, Ireland, Thames, and Humber regions. From an examination of Table VIII-3, it does not appear that the market share of any of the regions is associated with innovative ability. On the Clyde, the majority of frequencies occur in the low innovative ability categories. With the exception of the North East Coast, all the other regions are characterized by the joint occurrence of low to medium market share and low innovative ability. Although twice as many of the North East Coast's high share center / year combinations were in the high innovative category, the highest proportion of its frequencies was in the medium market share / high innovation category.

Figure VIII-2 maps the variables' joint occurrence for all centers that were in production in 1865; it shows that the majority of these centers fell into the medium market share / high innovative ability and low market share / high innovative ability categories.

Table VIII-3: Regional Contingency Table Categories
Cycle 2: 1856-1865

Region	Low Low	Low High	Medium Low	Medium High	High Low	High High	Total
Clyde	10	4	8	4	11	8	45
N. E. Coast	1	4	3	10	6	3	27
S. E. Coast	3	2	5	3	0	0	13
Ireland	0	2	1	2	4	3	12
Thames	2	0	3	1	1	1	8
Humber	3	0	2	1	1	0	7
Mersey	2	1	0	0	1	0	4
Severn	0	1	2	0	0	0	3
Irish Sea	2	0	0	0	0	0	2
Total Percent Total	23 19.0	14 18.2	24 21.5	21 11.6	24 17.4	15 12.4	121 100

Although all six categories are represented by the fifteen centers, only Newcastle on the North East Coast and Dumbarton on the Clyde placed in the high share / high innovative ability category, while four centers (two on the North East Coast, and two on the Humber and Thames) were in the medium share / high innovative ability category. Four centers were in the low share / high innovative ability category. The remaining five centers fell into either one of the three market share / low innovative ability categories. The majority of the centers on the Clyde were in the low innovation category, with Glasgow and Greenock in the high share / low innovation category and Port Glasgow in the medium share / low innovation category.

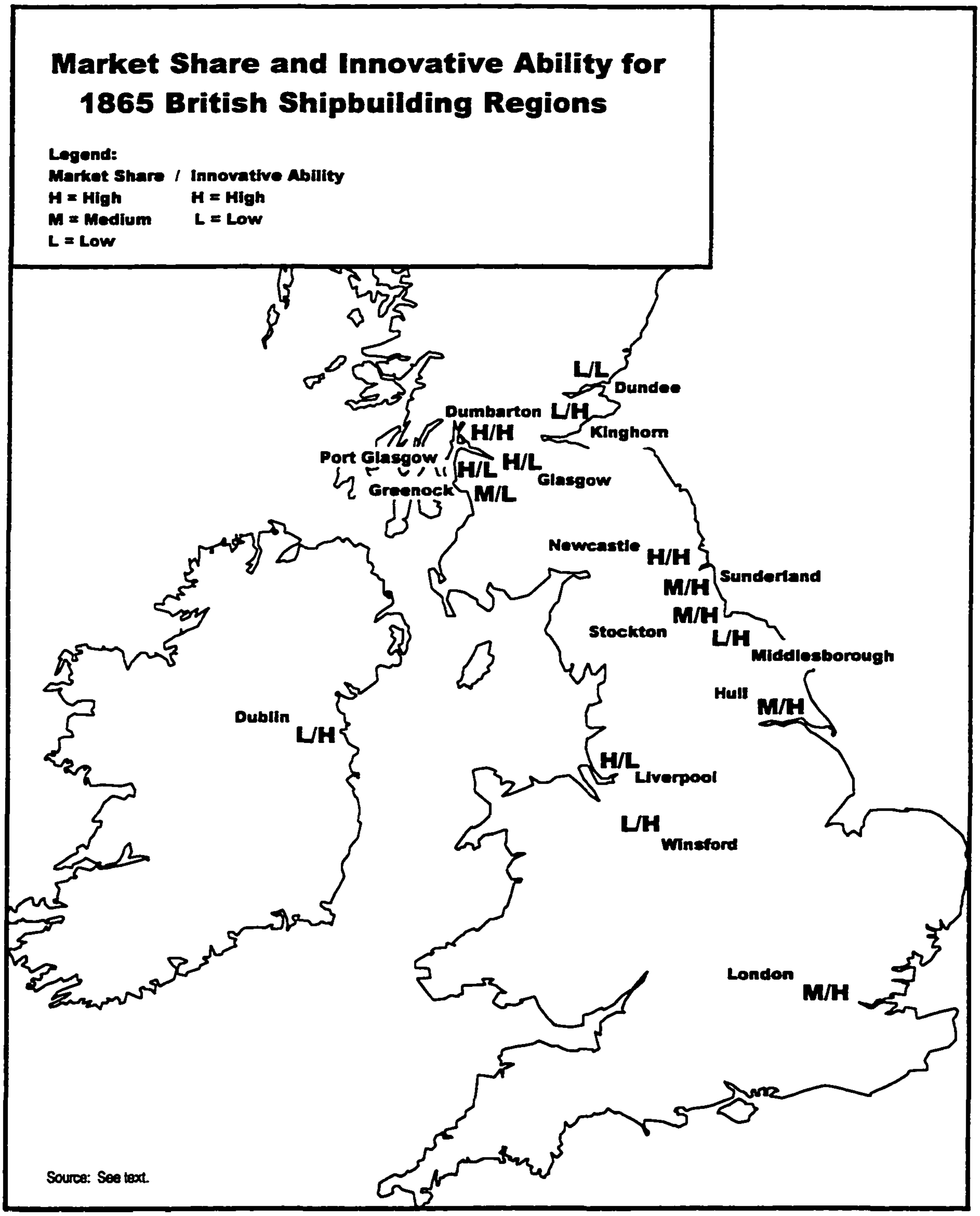


Figure VIII-2: Market Share and Innovative Ability Rankings: 1865

Once again, and despite an apparent negative association between market share and innovative ability, the chi-square contingency table test resulted in a non-significant chi-square statistic (Table VIII-4). The test resulted in a χ^2 statistic of .33 (df = 2, p = .847), so that the null hypothesis of no association between the two variables is accepted. The possible explanations for the lack of association are the same as those given for the first cycle.

Table VIII-4: Chi-square Contingency Table Test Results:
Cycle 2: 1856 - 1865

Innovative Ability		Market Share Low	Medium	High	Total
Low	Observed Expected	23 21.7	22 25.2	26 24.1	71
High	Observed Expected	14 15.3	21 17.8	15 16.9	50
Total		37	43	41	121
$\chi^2 = 1.57$	df=2	p =.457			

2.3. Cycle 3

The Clyde was again Britain's dominant shipbuilding region during the 1866-1872 period as the industry remained in the Product Life Cycle's growth stage. The second and third largest regions were the North East Coast and, after a significant drop-off, the Scottish East Coast (Table VIII-5). The distribution of categories on the Clyde is characterized by the number of shipbuilding center / year combinations at the two extremes: twelve frequencies in the high share / high innovative ability category; nine in the low share / low innovation category; and the remaining frequencies distributed among the other four categories. The North East Coast shows a better distribution among all categories, but the six frequencies in the low share / low innovative ability category stand out. Of the remaining regions, the Scottish East Coast, Thames, and Humber are the only other regions represented in the high share / high innovative ability category. Nevertheless, these regions are all characterized by the absolute number of frequencies in the low share / low innovative ability category. These results suggest a negative association between market share and innovative ability.

Table VIII-5: Regional Contingency Table Categories
Cycle 3: 1866-1872

	Categories						
Region	Low Low	Low High	Medium Low	Medium High	High Low	High High	Total
Clyde	9	2	4	1	8	12	36
N. E. Coast	6	1	7	8	7	5	34
S. E. Coast	2	2	5	4	0	1	14
Thames	2	0	2	1	0	1	6
Mersey	2	0	1	2	0	0	5
Severn	3	0	1	0	0	0	4
Humber	1	0	1	0	0	1	3
Ireland	2	0	0	1	0	0	3
Solent	1	1	0	0	0	0	2
Total	28	6	21	17	15	20	107
Percent Total	26.2	5.6	19.6	15.9	14.0	18.7	100

The map of 1872 shipbuilding centers (Figure VIII-3) shows that, for this year at least, high and medium share centers were the most innovative. Eleven of the nineteen total centers were in these two categories. Five centers were in the highest category (two from the Clyde and three from the North East Coast), while six centers were in the medium share / high innovative ability categories (one Clyde, three North East Coast, and one each from the Mersey and Thames). The two remaining Clyde centers were in the high and medium share / low innovative ability categories, while the two remaining North East Coast centers were in the lowest category. Both centers on the Scottish East Coast and Southwick, on the Solent, were in the low share / high innovative ability category, while the final low share / low innovative ability center is at Northam on the Severn.

Unlike the previous two cycles, a significant association between market share and innovative ability was identified. The existence of this association is indicated by the significant chi-square statistic ($\chi^2 = 11.69$, df = 2, p = .003) . The contingency table and test results are given in Table VIII-6.

In addition to the information presented in the previous contingency tables, two further pieces of information are included in this and the following table. The first is Kendall's Tau-c statistic, a measure of the strength of the association and its direction. The second addition is the reporting of the relative contribution of each individual cell to the overall chi-square statistic to identify the most important categories in explaining the association.

Based on the Tau-c statistic, a positive association was identified, albeit moderate to weak, across categories ($\tau_c = .344$; p = .0003). This indicates that there was a positive

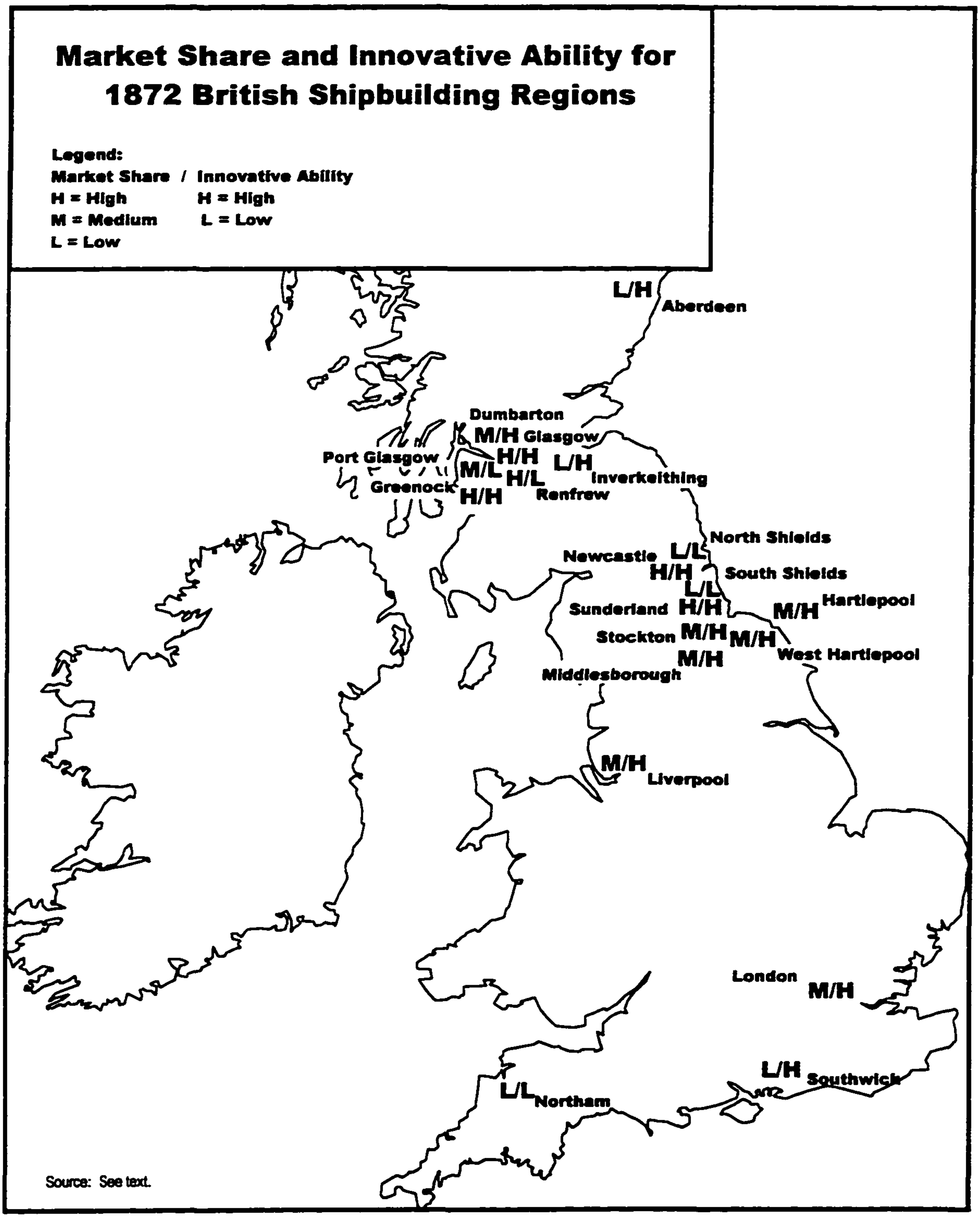


Figure VIII-3: Market Share and Innovative Ability Rankings: 1872

relationship between a center's market share and its innovative ability. Bearing in mind its low value, the statistic indicates that centers that ranked high on the innovative index were also ranked highly on market share, while centers that were low on the innovative index were also low in terms of market share. Therefore, the Tau-c statistic confirms the implicit assumption that innovative shipbuilding centers enjoyed a competitive advantage over non-innovative shipbuilding centers.

Table VIII-6: Chi-square Contingency Table Test Results:
Cycle 3: 1866 - 1872

		Market Share			
Innovative Ability		Low	Medium	High	Total
Low	Observed Expected Contribution to Total χ^2	28 20.3 25	21 22.7 1	15 20.9 14	64
High	Observed Expected Contribution to Total χ^2	6 13.7 37	17 15.3 2	20 14.1 21	43
Total		34	38	35	107
$\chi^2 = 11.69$; df = 2; p = .003		Kendall's Tau c = .344; p = .0003			

The reasons that the association first appears in the third shipbuilding cycle are probably twofold. The first is statistical: the independent variables in the multiple regression model, which were used to develop the innovation index, were much more powerful in explaining increasing ship size than those in the previous model. This results in a much better representation of the changes in the individual technological components incorporated in these ships. The second probable reason is that the shipbuilding industry had become more competitive: initial advantages, especially for the Clyde, were eroding and shipbuilders were building more efficient, and so more innovative, ships to attract shipowning customers.

An examination of the differences between the observed and expected frequencies for the individual categories reveals important information about the relationship between market share and innovative ability. The table shows that there was no difference between observed and expected frequencies in either the two medium share categories, indicating that there was no association between market share and innovative ability for these combinations. Conversely, the high share / high innovation categories performed better than would be expected, while the low share high innovation categories did not perform as well. This demonstrates that, for the high share centers, innovative centers received more orders for ships than could be expected were there no relationship between innovation and place.

However, the performance of the two low share frequencies are the most interesting in that they contribute the largest amount to the absolute value of the chi-square statistic: 39 percent for the low market share / low innovative ability category and 25 percent for the high market share / high innovative ability category. This is larger than that for the high share / high innovative ability category's 21 percent. This is because these two categories had the highest and lowest number of frequencies, respectively, of the six classes. In addition, these categories combined contribution to total chi-square was enough to produce a significant statistic.

2.4. Cycle 4

The North East Coast surpassed the Clyde as Britain's largest shipbuilding region during the 1873-1880 period as the industry entered the standardization phase of the Product Life Cycle. This region was characterized during the fourth cycle by a pattern where each high share category had twice as many frequencies as the corresponding low share frequency (Table VIII-7). Based on this observation, it appears that there was a strong relationship between innovation and economic viability in this region. The Clyde was again characterized by the low share/low innovative ability and high share / high innovative ability category extremes. The most notable change for this region from the third cycle was the increase in the number of frequencies in the two medium share categories, suggesting that perhaps output was becoming more equally distributed among the region's centers. Only two other regions, the Irish Sea and Ireland, were represented in the high market share / high innovative ability category. Most centers on the Scottish East Coast were in the low share / low innovative category, and the majority of centers in the remaining regions were in either the low share / low innovation or medium share / high innovation categories.

The sixteen centers that were in production at the end of the study period are shown in Figure VIII-4. The majority of these centers, fourteen out of sixteen, were assigned the high innovation category across the three market share ranks. The exceptions were Greenock and Paisley on the Clyde, which were medium share / low innovation and low share / low innovation centers. Five of the six North East Coast centers were in either the high share / high innovation (3) or medium share / high innovation categories (3), while the number of centers on the Clyde in these same categories were two and one. Both centers on the Scottish East Coast were in the low share / high innovation category. This is also true for Renfrew, the last Clyde center. Both Belfast in Ireland and Liverpool on the Mersey were in the medium market share / high innovative ability category.

Table VIII-7: Regional Contingency Categories, 1873-1880

Region	Categories: Low Low	Low High	Medium Low	Medium High	High Low	High High	Total
N. E. Coast	2	4	6	12	9	18	51
Clyde	5	2	6	7	4	10	34
S. E. Coast	8	2	3	1	0	0	14
Irish Sea	3	1	0	3	0	1	8
Mersey	1	1	2	2	0	0	6
Thames	2	1	0	1	0	0	4
Ireland	0	0	0	2	0	1	3
Solent	2	0	0	1	0	0	3
Humber	0	2	0	0	0	0	2
Severn	2	0	0	0	0	0	2
Total	25	13	17	29	13	30	127
Percent Total	19.7	10.2	13.4	22.8	10.2	23.6	100

The chi-square test again indicates that there was an association between market share and innovative ability. The contingency table and related statistics are given in Table VIII-8. The chi-square statistic is significant ($\chi^2 = 11.57$, df = 2, p = .003), and the

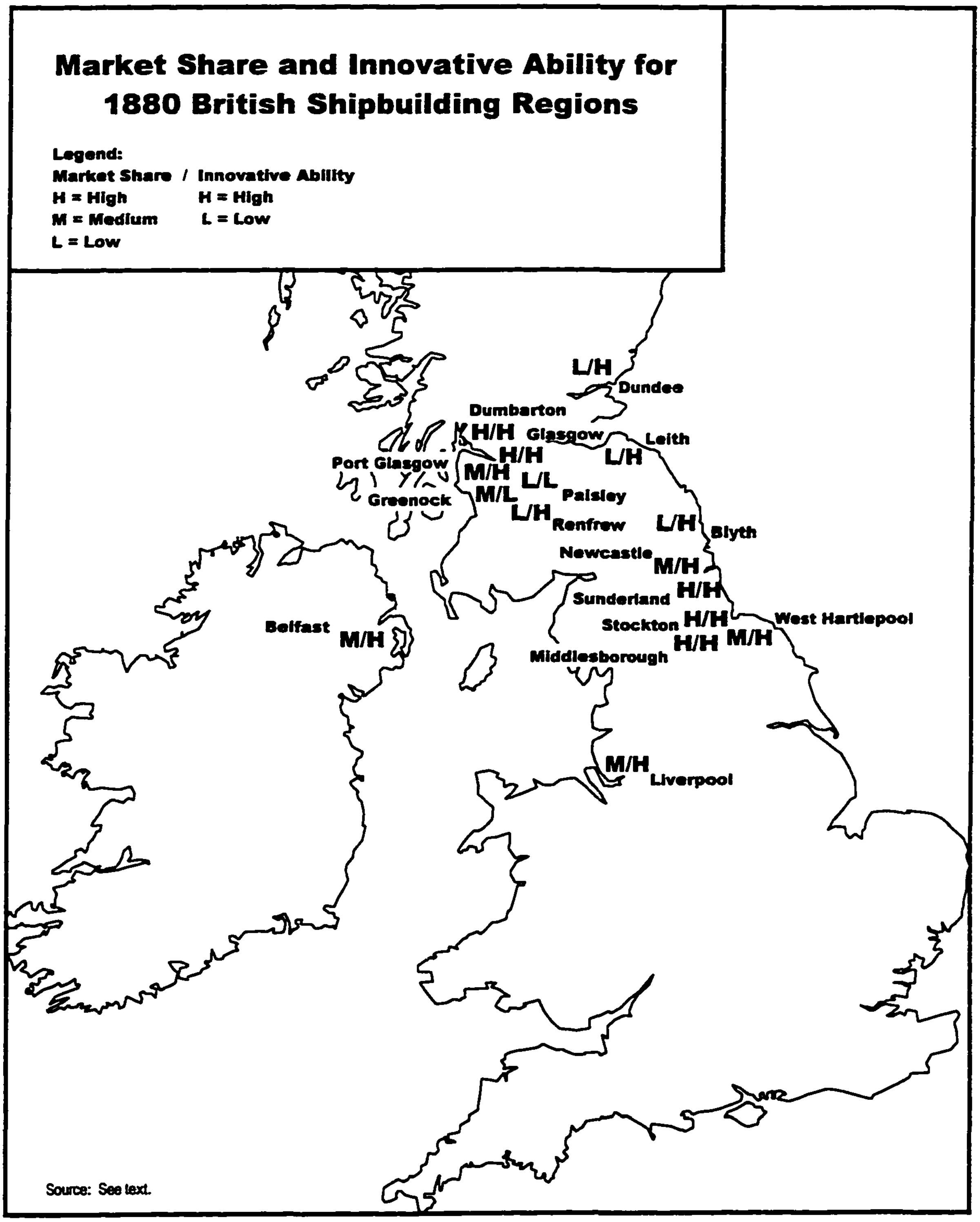


Figure VIII-4: Market Share and Innovative Ability Rankings: 1880

Kendall's Tau c statistic again shows a positive association between market share and innovative ability (τ_c = .302; p = .001).

Table VIII-8: Chi-square Contingency Table Test Results:
Cycle 4: 1873 - 1880

Innovative Ability		Market Share Low	Medium	High	Total
Low	Observed	25	17	13	55
	Expected	16.5	19.9	18.6	
	Contribution to Total χ^2	38	4	15	
High	Observed	13	29	30	72
	Expected	21.5	26.1	24.4	
	Contribution to Total χ^2	29	3	11	
Total		38	46	43	127

χ^2 = 11.57; df = 2; p = .003 Kendall's Tau c = .302; p = .001

A comparison of observed and expected frequencies and individual category contribution to total chi-square reveals the same pattern as in the previous cycle. The medium market share categories were again little different that expected. Frequencies in the high share / high innovative category were greater than expected and the high share / low innovative category frequencies were less than expected. However, these differences between the high share categories was not as great as in the third cycle.

Once again, the differences between the observed and expected frequencies for the low market share categories are the most important in accounting for the statistical association between innovative ability and industrial viability. Frequencies for the low innovation centers were fifty-two percent greater than expected, while frequencies for the high innovation centers were forty percent less than expected. And again, their combined contribution to total chi-square was enough to produce a significant statistic.

2.5. High and Low Market Share Comparison

The chi-square contingency table test analysis revealed a positive association between industrial viability and innovative during the third and fourth shipbuilding cycles only. However, the Tau-c statistic reveals that the positive associations were only weak to moderate. Further, the most important categories in accounting for this association between industrial viability and innovative ability were the two low market share categories and that the high market share categories made only a marginal contribution. This suggests that innovative ability, while important, was not a precondition for industrial viability during the last two shipbuilding cycles.

The results of the chi-square analysis, especially the performance of the low market share categories, run counter to implicit assumptions regarding the importance of innovation to a production center's industrial viability. Therefore, this section examines the low share and high share categories in greater detail. This is accomplished by comparing the mean values for the innovative index variables and shipbuilding output for the four categories against the values for all centers during the respective cycle and against each other.

The analysis begins with the third shipbuilding cycle. The innovative index variables, as identified in Chapter VI, are Ship Power (in terms of net tons), and the Net:Gross and Length-to-Beam ratios. The output data are the number and the average size, in gross tons, of ships built at each shipbuilding center / year combination. Comparisons of these data are presented in Table VIII-9.

Table VIII-9: Comparison of Mean Innovation Index Values and Shipbuilding Output for Low and High Market Share Categories
Cycle 3: 1866-1872

	Contingency Table Classes					
Variable	Low / Low [1]	Low / High [2]	All Ships Built	High / Low [3]	High / High [4]	Variable
Ship Power [a]	2.85	5.85	4.07	4.06	4.67	Ship Power [a]
Length to Beam [b]	5.87	7.39	6.96	7	7.87	Length to Beam [b]
Net:Gross [c]	0.61	0.64	0.65	0.68	0.65	Net:Gross [c]
Mean Tons	193.15	832.67	748.59	799.37	1463.66	Mean Tons
Number Built	1.21	1	2.75	5.73	4.5	Number Built
Total Frequency	28	6	107	15	20	Total Frequency

[1] Low Share / Low Innovative Ability
[2] Low Share / High Innovative Ability
[3] High Share / Low Innovative Ability
[4] High Share / High Innovative Ability

[a] net tons / engine horsepower
[b] ship length / width
[c] net tons / gross tons

As the table demonstrates, the low market share / low innovative combinations and the high share / high innovative combinations represented the two extremes of the British shipbuilding industry. On one hand, there were a relatively large number of combinations producing ships that were much smaller and technologically inferior to those produced in the high share / high innovative ability combinations. However, the latter category dominated shipbuilding output because of the large size (and number) of ships they produced in any given year. The only similarity between the other two combinations was that they produced ships of approximately the same size, with the low share / high innovative combinations performing no differently or better than the high share / high innovative combinations. The fact that there were only six of these combinations indicates that they were not representative of the larger industry and, perhaps, represent years in which was down for some reason.

Differences between the two low share categories become more apparent when differences in output are examined. Shipbuilding centers in both low market share categories produced ships that were smaller than the industry average but, still, the ships built at low innovation centers were much smaller (193 versus 833 gross tons). In terms of the number of ships produced, none of the high innovation centers produced more than one ship per year while the low innovation centers averaged 1.2 ships per year. The fact that the low innovation centers were characterized by the production of multiple ships per year that were much smaller than average suggests that these centers occupied a distinct market niche specializing in small, technologically backward ships. This is a significant finding that will be discussed later in this chapter. The low number of ships produced at the Low market share / high innovative ability centers reinforces the supposition that these centers experienced off years in terms of output.

Table VIII-10 presents the same comparisons for the fourth shipbuilding cycle. The variables incorporated in the innovative ability index for this cycle increased to five, the additional variables being rated Boiler Pressure and the Cylinder Volume:Net Tonnage ratio (Volume:Net in the table). The output variables are the same as those used in the previous discussion.

Table VIII-10: Comparison of Mean Innovation Index Values and Shipbuilding Output for Low and High Market Share Categories
Cycle 4: 1873-1880

Variable	Low / Low[1]	Low / High[2]	All Ships Built	High / Low[3]	High / High[4]	Variable
	Contingency Table Classes					
Ship Power [a]	3.45	6.11	5.12	4.99	5.60	Ship Power [a]
Length to Beam [b]	6.59	7.46	7.47	7.42	7.93	Length to Beam [b]
Net:Gross [c]	0.60	0.66	0.63	0.63	.65	Net:Gross [c]
Pressure [d]	66.30	74.46	70.41	67.43	72.49	Pressure [d]
Volume:Net [e]	2527.46	1959.90	2129.00	2079.20	2003.69	Volume:Net [e]
Mean Tons	377.19	1161.17	1177.20	1054.21	1721.09	Mean Tons
Number Built	1.48	1.31	4.94	7.92	10.83	Number Built
Total Frequency	25	13	127	13	30	Total Frequency

[1] Low Share / Low Innovative Ability
[2] Low Share / High Innovative Ability
[3] High Share / Low Innovative Ability
[4] High Share / High Innovative Ability

[a] net tons / engine horsepower
[b] ship length / width
[c] net tons / gross tons
[d] rated boiler pressure
[e] engine cylinder volume / net tons

The table again shows the extent of the disparities between the low share / low innovative and high share / high innovation shipbuilding center / year combinations. The low share / low innovation combinations were still characterized by the small size of the average ship (although average ship size almost doubled) and their poor technological performance relative to not only the high innovative combinations, but in fact to all ships. The absolute number of high share / high innovation combinations increased by fifty percent between this and the third cycle, reflecting the dominant position, in terms of output, of a relatively few centers as established in Chapter VI. The only point to be raised for the other two categories is how well the low share / high innovative ability combinations compared in the innovation index variables relative to the high share / high innovative combinations. Rather than representing centers that experienced off years in production as in the previous cycle, by the fourth cycle these low market share centers appear to represent shipbuilding centers that were not rewarded, at least in terms of increased orders, for their ability to build innovative ships.

The results of this comparison reveals a very distinct dichotomy within the British iron and steam shipbuilding industry. At one extreme were the large shipbuilding centers, located primarily in the North East Coast and Clyde regions, that dominated the British shipbuilding industry. The success of these centers, based on the historical interpretations and an examination of the contingency tables (but not from the results of the statistical test), would appear to owe their success as much to their access to factor inputs and major ship markets as to their innovative ability.

At the other extreme were small centers, many but not all located in smaller shipbuilding regions. These centers occupied a very minor but distinct market niche, specializing in small, "technologically backward" iron steamships. Based on an examination of the ships produced at these low share / low innovation centers, it is safe to say that they specialized in small coastal trading steamers. According to Waine (1976), much of the coasting trade at the smaller ports was conducted by local shipowners. Ships built at these centers during both cycles were much smaller than average, allowing them to use small, remote ports. Their small length-to-beam ratios, constrained because of their length, would also allow them maintain their stability during adverse sailing conditions in deep water.

Based on these observations, it should not be surprising to find shipbuilding centers specializing in the production of these technologically lagging ships to fit the requirements of small, local shipowners in peripheral ports. This would account for the low innovative centers that specialized in these ships, as well as for the existence of low market share / low innovative centers in the minor shipbuilding regions. Specializing centers were located on the Clyde (Bowling and Paisley) and the Scottish East Coast (Dundee and Montrose) and on the North East Coast (North Shields and South Shields), as well as at Liverpool on the Mersey during the third cycle and at London on the Thames during the fourth. In addition, the output at centers located in the minor regions was heavily concentrated in small, technologically lagging ships.

Since the small coastal steamers were built for shipowners in localized coasting trades, it is possible that the technological backwardness of these ships was due to the indifference of shipowners to the technological changes occurring in the larger shipbuilding and shipowning industries. These owners, and shipbuilders, could have been more conservative, preferring established and safer technologies, so that they tended to forgo improved propulsion systems in favor of established systems as indicated by their poor performance in the Net:Gross, Cylinder Volume:Net Tons, and Boiler Pressure variables. Ships that incorporated these improved technologies could also have been more expensive relative to the older technologies, and the smaller shipowner may not have felt the extra cost justified their use. It could also be that the coastal steamer market, because of its small share of the total market, was not large enough to warrant the same level of innovative activity as that for larger ships.

3. SUMMARY AND CONCLUSIONS

This chapter presents tests of the presence of an association between market share and innovative ability. This was accomplished using the chi-square contingency table procedure for each shipbuilding cycle in order to test for the association of and to assess the relationship between market share and innovative ability. The results of this analysis reveal an association between industrial viability and innovative ability during the third and fourth shipbuilding cycles only. It further reveals that although the associations are moderately to weakly positive, it appears that, in general, the higher a center's innovative ability then the higher its market share.

At the same time, the analysis reveals that the most important contributors to this association are the two low market share categories and that the contribution of the high share categories was secondary. This finding runs counter to implicit assumptions in the literature which link innovation to the industrial viability of the production center. Of centers in the two low share categories, the most interesting were those centers that were able to remain economically viable despite the fact that the ships they produced were, in relative terms, technologically backward. These centers, the evidence suggests, specialized in the production of small coastal steamers; in which case the shipowners for whom these ships were built may have been indifferent to technological change and the shipbuilders in these centers held too small a market share to warrant the levels of innovative activity evident in the larger markets.

CHAPTER IX

DISCUSSION AND CONCLUSIONS

Transformations of the industrial landscape, especially in the world's industrialized countries, has heightened interest in the impacts of technological change on the economic viability of industrial centers and regions. This interest has manifested itself in an increase in the number of studies that investigate the interaction between technological change, economic competitiveness, and the economic viability of industrial regions and individual production centers. The one feature common to these studies is their implicit assumption that a direct and positive relationship exists between innovative ability and industrial viability: that the more innovative a place, then the greater its economic competitiveness.

Unfortunately, the field of economic geography has not explicitly examined technological change in detail and then attempted to relate those changes back to the individual firms within the industrial system. Two reasons for this failure can be identified. First, the majority of these studies either assume that one industry is more innovative than others or they rely on proxy measures, such as employment growth or the number of patents issued, to identify innovative industries. Second, theoretical constructs within the discipline of geography do not allow for the analysis of the interaction between large scale economic spatial systems and their individual spatial components. The result is that actual technological change and the full extent of its impacts are not explicitly incorporated into the examination of technologically-induced spatial change.

The over-riding purpose of this dissertation has been to address this neglect. Using real data for an industry which seems to fit the Product Life Cycle during the years in question, it has measured technological change and then related those changes back to the spatial industrial restructuring process. This was accomplished through a case study of the 1840-1880 British iron and steam shipbuilding industry. This industry introduced and perfected the ocean-going iron screw steamship and experienced a profound spatial reorientation in the process while accounting for remarkable growth in related measures such as employment, productivity, and profitability.

1. ANALYTICAL FRAMEWORK

The methodological framework developed for this study offers an analytical procedure to assess the interaction between technological change and the economic viability of individual production centers within larger spatial industrial systems. Measuring technological change and its linkages to the performance of individual centers within an industrial system, however, create serious problems for researchers. These problems require a multi-stage methodology that establishes and locates technological changes and then subsequently relates those changes back to a center's industrial viability.

Any geographical study of technological change and spatial industrial change requires the development of two key site- and temporally-specific variables that measure industrial viability and innovative ability. Industrial viability, regardless of the measure used, represents a center's growth or stability within the larger related industrial system, while innovative ability is a locationally specific attribute which reflects the proclivity of any particular place for initiating or rapidly adopting technological change. The generation of legitimate measures for these two variables allow for the assessment of the performance of any production center within the larger industrial system for any year in which the firms within the region were in operation.

1.1. Industrial Viability

The industrial viability index is based on each center's annual market share. This study utilized total national shipbuilding output reported in the Lloyds Register of British and Foreign Shipping. Since the vast majority of ships built during the study period were ordered directly by shipowners and were not built on speculation, a shipbuilding enter's annual share of national output can legitimately be viewed as a measure of its market share. As a result, the market share index was constructed by dividing each center's annual output of ships registered with Lloyds by all ships built and registered during that given year. Each center's market share was then classified and assigned to one of three relative categorical ranks--high, medium, or low--based on their proportions of the production scale for each and every year.

1.2. Innovative Ability

The corresponding innovative ability index was constructed from actual iron steamship measurements also obtained from the Register. Important technological changes were identified from the historical literature on the nineteenth century British shipbuilding industry. Technical measurements obtained from the Lloyds Register were then used to construct variables that measured these technological changes. At the same time, the 1840-1880 study period was sub-divided into four shipbuilding cycles that also correspond to industrial innovation cycles first described by Kuznets (1930).

Once the technical variables were identified, a series of multiple regression models, one for each cycle, were used to identify those variables that made statistically significant contributions to explaining the increasing size of iron steamships. In a sense, this tested the qualitative assumptions reflected in the work of previous scholarship. Those variables which were identified as significant were then used to construct a series of innovation indices that scored each ship based on its component technologies. These indices were collapsed into a simple measure of innovative ability which could be ranked for each shipbuilding center and for each year it produced at least one ship. A center with a mean innovation index for a given year that was greater than the mean index value for the entire cycle was considered, technologically, to be a leader and assigned to the high category. A technological laggard, conversely, was one whose mean innovative index score was below the cycle mean. These centers were assigned to the low category.

1.3. Testing For The Relationship Between Industrial Viability and Innovative Ability

Once the two site-specific variables were constructed, the relationship between innovation and place was conducted. This was accomplished using a series of chi-square contingency table tests to assess the relationship between industrial viability and innovative ability. The three market share categories were combined with the two innovative ability categories to produce a three-by-two contingency table. The analysis was conducted by first testing for the existence of an association between the six categories in the table. Next, Kendall's Tau-c statistic was used to measure the association between the categories and the direction of that association. Finally, the relative contribution of each category to the total chi-square statistic was used to identify important categories for further and more detailed analysis.

2. SIGNIFICANT FINDINGS

The analytical framework employed in this research provided a procedure for assessing the relationship between innovation and place. At the same time, it allowed for an investigation into one of, if not the, most important industries that keyed Britain's nineteenth century dominance of the world economy. The findings of this analysis provide important insights into key aspects of technological change. These insights apply not only to the nineteenth century British shipbuilding industry, but to contemporary issues related to industrial restructuring as well. The most significant of these findings are discussed in the following section.

2.1. Cycles

The first of the findings discussed concerns the identification of separate sub-cycles within the larger 1840-1880 technological change cycle. British shipbuilding output during the 1840-1880 study period consisted of four separate and distinct shipbuilding cycles. These cycles are characterized by alternating periods of rising output followed by market saturation and glut. As their correspondence to cyclical fluctuations in interest rates demonstrated, these cycles fit within larger British economic cycles, referred to in Britain as trade cycles and which are analogous to the industrial cycles first identified by Kuznets (1930). The existence of these cycles confirm the observations of shipbuilding historians and researchers of the contemporary industry regarding the volatility in output associated with this industry.

More importantly in regard to the process of technological change, however, is the way in which major shipbuilding innovations fit within these cycles. As important ship component innovations were identified and dated from the historical literature, this study revealed that important innovations were introduced at either the beginning or end of each shipbuilding output cycle and that the innovation was not fully incorporated until the following cycle. The existence of these innovation cycles demonstrates that the innovation process was clearly not continuous, but was accomplished through net gains from one cycle to the next. Further, the performance of the technical indicators revealed that their changes tracked those for shipbuilding output, indicating that the innovation process was related to periods of economic expansion and depression within the shipbuilding and shipping industries. This strongly indicates that innovations introduced in one sub-cycle were not fully exploited in commercial terms until the following sub-cycle. This particular finding offers concrete evidence and support for similar arguments made by Schumpeter (1939 and 1950) and Hyde (1977).

2.2. Technological Change Models

Perhaps the most satisfying, and certainly the most challenging, aspect of this research was the identification of the variables required to construct the innovative ability index. As should be clear by now, one of this study's primary goals has been to directly incorporate changing technology into economic geographic research. To accomplish this required extensive reading in the historical and economic historical literature to identify and date important innovations. It also required a full summer in Scotland developing and compiling the required database.

The measure of innovative ability was constructed from variables identified by multiple regression analysis. This technique allowed for the testing of hypotheses about the contributions of individual iron construction and steam propulsion innovations identified in the literature using actual technical measurements available in the Lloyds Register. The Register is not an exhaustive source for all the measurements needed to assess the technical components of the iron steamship and their change through time, nor is it realistic to expect it to be such a source of data given the very different goals associated with its creation and continuation as a resource. However, the sub-division of the study period into four distinct technological change cycles and the use of the two stage model specification approach resulted in sets of technical measurements that were statistically proven to be theoretically correct and significant. For the last two cycles, these variables were proven to be very powerful in explaining increasing ship size.

This approach provides valuable insights into the underlying rationale behind iron steamship technological change. Specifically, it reveals the economic considerations of shipowners which, in turn, guided shipbuilders' technological concerns in ship design and construction. These insights are provided by the behavior of the register tonnage measurements for both absolute size (gross tonnage) and cargo-carrying capacity (net tonnage).

In the model for the 1856-1865 shipbuilding cycle, the highest amount of explanatory power was obtained using net tonnage as the dependent variable and net tonnage per unit of horsepower for the independent variable Ship Power. Since net tonnage measures the ship's cargo-carrying capacity, the importance of this variable suggests that ships were being designed to maximize earning potential. This, after all, was the primary concern of the shipping industry at this time.

By the 1866-1872 cycle, however, the dependent variable that maximized model explanatory power was gross tonnage: the ship's absolute volume. When we recall that this was the only cycle in which the variable Year was significant, it strongly suggests that the period represents one of technological consolidation, that the pace of change had slowed. The innovation process continued, however, as indicated by introduction of the surface condenser and Scotch boiler during this period. These facts, plus the performance of net tonnage in deriving the variable for Ship Power, suggest that the innovation process was directed toward maintaining its cargo-carrying potential while maximizing engine power.

By the fourth cycle, when the variable Year was again significant, the dependent variable returned to net tonnage, or cargo-carrying capacity rather than absolute size. This reversal strongly suggests a renewed emphasis on innovations that maximized earning potential and explicitly reflects the economic concerns of the shipping industry.

2.3. Regional Innovative Ability

The primary purpose of the innovative ability index, constructed from the statistically significant independent variables of the multiple regression models, was to develop a variable to test for the association between market share and innovative ability. The index also serves another purpose. When the resulting regional innovative ability rankings are compared, they allow for the assessment of the accuracy of popularly held opinions about the relative technological sophistication of individual shipbuilding regions.

Contrary to the consensus of both contemporaries and shipbuilding historians (except for regional champions), the North East Coast compared very well to regions which are considered to be technologically superior. In fact, and again based on the rankings, this region can be characterized as the most innovative during the entire 1840-1880 study period. At the same time, the results indicated that the technological performance of the Clyde, considered to be the country's most innovative region, did not actually compare favorably to the North East Coast. At the least, if the Clyde was the most innovative region, then its technological contributions are not reflected in the technical measurements available from the Register. Nor do the Thames and Mersey regions, also considered highly innovative, compare favorably; the performance of the Mersey was mixed across cycles, while the Thames's innovative ability most certainly declined after the first cycle.

2.4. The Relationship Between Innovation and Place

The ultimate goal of this dissertation was to test the assumption that there is a positive association between an individual production center's innovative ability and its ability to compete successfully within its larger industrial system. This assumption is implicit in most studies in the field of economic geography. To explore this issue, statistical tests for association between the two site-specific variables were conducted. This determined whether or not a shipbuilding center was rewarded economically for its ability to produce technologically superior ships for each of the four shipbuilding cycles within the larger study period.

The results of these tests indicated that there was no association between market share and innovative ability during the first two periods, from 1840 to 1855, but that one did in fact exist during the two later periods covering the years 1856 to 1880. Since the first two periods were obviously ones of high innovative activity, two possible reasons for the lack of an association can be identified.

The first reason for the lack of association is that the two models do not capture the actual innovations that were attracting orders for ships. These two cycles represent innovation periods during which the component technologies incorporated in the iron steamship were still evolving and during which innovative activity was occurring at a high rate. That this was indeed the case is suggested by the Register's failure to recognize the importance of many technical measurements until later in the study period. This lack of recognition results in a serious lack of data with which to construct the innovative ability index. Recall that the models for these two cycles included only two and three independent variables, respectively, and that their explanatory power was low.

The second possible reason could be that there simply was not that strong an association between market share and innovative ability. If this was the case, then initial and later locational advantages in terms of factor inputs and access to ship and capital markets were more important to success than was innovative ability. Again recall that the variables used to construct the second cycle's innovation index were basically the same as those used for the third cycle, which produced a much more powerful model. Therefore, data constraints do not necessarily account for the lack of a statistical association during the second cycle. This leads to the plausible conclusion that initial advantages were just as important (and perhaps more so), relative to innovative ability, for a center's industrial viability during the first two cycles. This is especially true when explaining the dominance of the Clyde, the region that in many ways pioneered the new ship and its component technologies. The importance of access to factor inputs during the second cycle is indicated by the continued dominance of the shipbuilding centers on the Clyde, despite their low innovative rankings, and the rapid rise of the North East Coast during the second cycle. Both of these regions were located in new iron and machinery producing regions.

By the time of the last two cycles, 1866-1872 and 1873-1880, there is a clear and significant association between innovative ability and industrial viability. Further, there was a positive relationship, albeit moderate to weak, between the two. The reason for this shift, from no association to a positive association, is most likely due to the industry's transition from the innovative or early growth stages of the Product Life Cycle to full-blown growth and the standardization stages of the cycle.

During the third and fourth shipbuilding cycles, the iron steamship overtook the traditional wooden sailing ship to become the British merchant fleet's dominant cargo carrier. At the same time, the industry made the transition from the innovation (first shipbuilding cycle) stage to the growth (second and third shipbuilding cycles) and standardization stages (fourth shipbuilding cycle) of the Product Life Cycle. Shipbuilders and shipowners, by now thoroughly familiar with the new ship, were more concerned with incorporating greater power and cargo-carrying efficiencies for ships designed for particular trade routes. Those centers best able to produce the ships required by their particular shipowning customers, or those centers that specialized in particular ship types, did indeed enjoy economic advantages over their less innovative competitors. This is the reason why the low market share shipbuilding centers were so important in contributing to the association revealed in the chi-square tests for the third and fourth shipbuilding cycles. Although innovative centers outperformed less innovative centers in the high market share categories, the statistical association was due to centers that had the smallest share of the market irrespective of their innovative ability.

2.5. Continued Viability of Low Innovation Centers

In addition to testing for an association and then measuring its strength and direction, the contingency tables provided a means for identifying those categories that made the greatest contribution to the overall strength of the identified association. Analysis revealed that centers assigned to the low and high market share categories made the greatest contribution to the overall association. Further, the centers in low share categories, whether innovative or not, made the largest contribution to this relationship. Based on these results, the mean values for the innovative index variables and shipbuilding output were compared to explore differences and similarities between the four categories.

The subsequent analysis revealed a sharp dichotomy within the shipbuilding industry from 1840 to 1880. At one extreme were the large shipbuilding centers, located mostly in the North East Coast and Clyde regions, that dominated the British shipbuilding industry. Due to their relatively low contribution to the association, it can be speculated that these center's owed their success as much to their locational advantages, in terms of access to factor inputs and major ship markets, as to their innovative ability.

At the other extreme were small centers, many of which were located in the small peripheral shipbuilding regions. In truth, the ships built at these centers do not compare favorably with ships built at the major shipbuilding centers: they were much smaller and much less efficient. The obvious conclusion is that the British shipbuilding industry operated at two distinct levels: one specializing in larger, trans-oceanic cargo-carriers; the other specializing in the small steamers that carried the bulk of the British seaboard trade. However, the centers that built these smaller, technologically conservative ships were just as numerous as the larger centers and often immediately adjacent to them, as witnessed by the proximity of Renfrew and Paisley to Glasgow on the Clyde and the two Shields to Stockton on the North East Coast. The reasons for these ships' technological lag are probably due to either the indifference of their owners to the technological advances in the larger industry or, alternatively, that the market was either not large or lucrative enough to justify the same levels of innovative activity displayed in the larger ships.

This dichotomy can be seen today in the contemporary shipbuilding industry located on the US Gulf Coast. At one level are the large shipyards at coastal ports from Biloxi, Mississippi to New Orleans and further west. These shipyards produce large, ocean-going freighters, container ships, and off-shore oil rigs. At the same time, and at a distinctly smaller scale of operations, are the small yards on the region's rivers and bayous. These yards, often associated with ship repair and refitting facilities, produce towboats used in the inland and ocean-going barge fleets. These yards remain in operation precisely because the demand from local fleet owners is large enough to warrant the additional costs of assembling the needed raw materials and machinery while innovations are deemed unnecessary. While they are probably not as innovative as the larger yards, they are obviously viable as clearly proven by their continued presence.

3. CONTRIBUTION OF RESEARCH

This dissertation has examined the relationship between industrial viability and innovative ability in the 1840-1880 British iron and steam shipbuilding industry. This industry has provided an excellent opportunity to examine this relationship because of the importance which shipbuilding analysts and historians place on technological change in the industry's periodic spatial restructuring. In addition to the insights it provides into the spatial impacts of technological change on the British shipbuilding industry, the study also makes two major contributions to the fields of economic geography, historical geography, and economic history.

First, it presents an analytical framework that directly incorporates technological change into the examination of technologically-induced spatial change. Rather than simply examining the relationship between technological change and industrial regions using proxy measures, this study posits a possible approach for assessing the relationship between actual innovations and individual production centers--the place where innovations emerge and where spatial changes are most directly felt. Such an approach reconciles the broad macro-scale concerns of the new economic development theories with the place-specific focus of the more traditional regional scientists. This reconciliation would seem important because technological change is both initiated at and imposed upon individual production centers which compose the larger spatial industrial system. The development of two site-specific variables, industrial viability and innovative ability, allows for the assessment of the interaction between the larger economic structure and the individual production center. Implicit in this research is the hope that others might build on these efforts to create measures more suitable for contemporary industries.

The benefits of the analytical approach presented in this study are not confined to studies of the contemporary industrial landscape, however. This is especially true for the fields of historical geography and economic history. Historical geographical scholarship can be especially enriched by an analytical approach that recognizes the inter-relationship between the overall economic structure and the individual place. The same can be said for studies in economic history concerned with the individual firm. For both disciplines, understanding the full consequences of change requires the recognition that change is initiated at and imposed upon individual places and firms. At the same time, research by historical geographers and economic historians can often profit from the adoption of more rigorous analytical methods: as the North East Coast's performance on the innovative ability index revealed, subjective historical interpretations do not always bear up to objective analysis.

At a broader level, this study bridges the two fundamental theoretical constructs within the field of economic geography. At one level, it has placed technological change within the context of the larger industrial system and the economic forces that shape it, while retaining a concern for place. While the two constructs are often presented as antithetical, this study demonstrates that they can be joined to offer a better understanding of the spatial impacts of technological change. The result is a more realistic analysis of the spatial restructuring process and a more effective analytical approach.

REFERENCES CITED

Abell, Westcott, The Shipwright's Trade, Conway Maritime Press; London, 1981.

Ackridge, Jay T., "Measuring Productive Efficiency in Multiple Product Agribusiness Firms: A Dual Approach," American Journal of Agricultural Economics, Vol. 71, no. 1 (February 1989), pp. 116-125.

Acs, Zoltan J., and Donald B. Andretsch, eds., Innovations and Technological Change: An International Comparison, University of Michigan Press; Ann Arbor, 1991.

Bailey, Martin Neil and Alek K. Chakrabarti, Innovation and the Productivity Crisis, The Brookings Institution; Washington, DC, 1988.

Baltagi, Badi H, James M. Griffin, and Daniel P. Rich, "Airline Deregulation: The Cost Pieces of the Puzzle," International Economic Review, Vol. 36, no. 1 (February 1995), pp. 245-260.

Banbury, Philip, Shipbuilders of the Thames and Medway, David & Charles; Newton Abbey, 1971.

Barkley, David L., "The Decentralization of High Technology Manufacturing to Nonmetropolitan Areas," Growth and Change, Vol. 9, no.1, 1988, 13-30.

Berry, Brian J.L., Long Wave Rhythms in Economic Development and Political Behavior, Johns Hopkins University Press; Baltimore, 1991.

----- Edgar C. Conkling, and D. Michael Ray, The Global Economy in Transition, 2nd ed., Prentice Hall; Upper Saddle River, NJ, 1997.

Blake, George, Lloyd's Register of Shipping, 1760-1960, Lloyd's Register of Shipping; Crawley, Sussex, UK, 1961.

Bremner, David, The Industries of Scotland: Their Rise, Progress and Present Condition, Augustus M. Kelly; New York, 1969.

Brock, P.W., and Basil Greenhill, Steam and Sail: in Britain and North America, David and Charles; Newton Abbot, UK, 1973.

Ceh, S. L. Brian, "The Recent Evolution of Canadian Inventive Enterprises," The Professional Geographer, vol. 49, no. 1 (February, 1997). pp. 64-76.

The Century Dictionary and Cyclopedia, Century Company; New York, 1913.

Chavas, Jean-Paul, and Thomas L. Cox, "A Nonparametric Analysis of Agricultural Technology," American Journal of Agricultural Economics, Vol. 70, no. 2 (May 1988), pp. 304-310.

Clark, Gordon, "US Regional Transformations in the Context of International Economic Competition," in Lloyd Rodwin and Hidehiko Sazanami, eds., Deindustrialization and Regional Economic Transformations: the Experience of the United States, Unwin Hyman; Boston, 1989.

Clark, W.A.V. and P.L. Hoskings, Statistical Methods for Geographers, John Wiley and Sons, Inc.; New York, 1986.

Conover, W.J., Practical Non-Parametric Statistics, 2nd ed., John Wiley and Sons. Inc.; New York, 1980.

Cornish, Susan L., "Product Innovation and the Spatial Dynamics of Market Intelligence," Economic Geography, Vol. 73, no. 2 (April 1997), pp. 143-165.

Delaney, Edward J, "Technology Search and Firm Bounds in Biotechnology: New Firms as Agents of Change," Growth and Change, Vol. 24, no. 2 (Spring 1993), pp 206-228.

Dougan, David, The History of North East Shipbuilding, George Allen and Unwin Ltd.; London , 1968.

Dunn, Laurence, The Book of Ships, Time-Life Books; New York, 1968.

Encyclopaedia Britannica, Adam and Charles Black; Edinburgh, 1875.

Encyclopaedia Britannica, Adam and Charles Black; Edinburgh, 1882.

Encyclopaedia Britannica, Adam and Charles Black; Edinburgh, 1886.

Faberberg, Jan, Bart Verspagan, and Marjolein Caniels, "Technology, Growth, and Unemployment Across European Regions," Regional Studies, Vol. 31, no. 5 (July 1997), pp. 457-466.

Feldman, Maryann P. and Richard Florida, "The Geographic Sources of Innovation: Technological Infrastructure and Product Innovation in the United States," Annals of the Association of American Geographers, Vol. 84, no. 2 (June 1994), pp. 211-221.

Fitzroy, Felix R. and Kornelius Kraft, "Firm Size, Growth, and Innovation: Some Evidence From West Germany", in Zoltan J. Acs and Donald B. Andretsch, eds., Innovations and Technological Change: An International Comparison, University of Michigan Press; Ann Arbor, 1991.

Fletcher, Max E., "The Suez Canal and World Shipping," Journal of Economic History, Vol. 18, no. 4 (December 1958), pp. 556-573.

Frankel, Ernest G., "Promoting Efficiency in Shipping," Marine Policy, Vol. 14, no. 5 (September 1990), 438-448.

Freeman, Christopher, The Economics of Industrial Innovation, 2nd ed. MIT Press; Cambridge, 1982.

Frenkel, Amman, and David Shefer, "Modeling Regional Innovativeness and Innovation," Annals of Regional Science, Vol. 30, no. 1 (1996), pp. 31-54.

Fusi, Deborah S., "States/Provinces Offer Broad Spectrum of High Tech Incentives to Spur Global Competitiveness," Site Selection, Vol. 33, no. 3 (1990), pg. 662.

Gilfillan, S.C, Inventing the Ship, Follet Publishing Co.; Chicago, 1935.

Gilriches, Z., "Research Costs and Social Returns: Hybrid Corn and Related Innovations," Journal of Political Economy, Vol. 76, no. 5 (October 1958), pp. 419-432.

Green, Alison, Christopher Harris, and David Maes, "Estimation of Technical Inefficiency in Manufacturing Industry," Applied Economics, Vol. 23, no. 10 (October 1991), pp. 1637-1647.

Hamilton, F.E.I. and G.J.R. Linge, "Regional Economies and Industrial Systems," in F.E.I. Hamilton and G.J.R. Linge, Spatial Analysis, Industry and the Industrial Environment, Vol. 3, Regional Economies and Industrial Systems, John Wiley and Sons; Chichester, 1983.

Hanink, Dean M., The International Economy: A Geographical Perspective, John Wiley and Sons, Inc.; New York, 1993.

Harley, C.K., "Skilled Labour and the Choice of Technique in Edwardian Industry," Explorations in Economic History, Vol. 11, No. 4 (1974), pg. 391-414.

----- "On the Persistence of Old Techniques: The Case of North American Wooden Shipbuilding," Journal of Economic History, Vol. 33, No. 2 (June, 1973), pg. 372-398.

----- "Ocean Freight Rates and Productivity, 1740-1913: The Primacy of Mechanical Invention Reaffirmed," Journal of Economic History, Vol. 68, no. 4 (December 1988), pp. 851-876.

Harrison, Richard, "Consequences of Technological Change: The Case of the Shipbuilding Industry," in Dereck L. Bosworth, ed, The Employment Consequences of Technological Change, MacMillan Press, Ltd.; London, 1983.

Hausman, William J., "The English Coastal Trade, 1691-1910: How Rapid Was It," Economic History Review, 2nd series, Vol. 40, no. 4 (1987), pp. 588-596.

Hettmansperger, Thomas P., Statistical Inference Based on Rank, John Wiley and Sons, Inc.; New York, 1984.

Hillings, David, "Technology and the Changing Port System of England and Wales," Geography, Vol. 74, no. 2 (April 1989), pp. 117-127.

hUallacháin, B. O', "The Location of US Manufacturing: Some Empirical Evidence on Recent Geographical Shifts," Environment and Planning A, Vol. 22, no. 9 (September 1990), pp. 1205-1222.

Hughes, J.R.T. and Stanley Reiter, "The First 1,945 British Steamships," Journal of the American Statistical Association, Vol. 53, no. 283 (September 1958). pp. 360-381.

Hume, J.R., 'Shipbuilding Machine Tools," in Butt, John and J.T. Ward, Scottish Themes, Scottish Academic Press; Edinburugh, 1976.

Jia, Liqun, "A Quantitative Analysis of Chinese Industrial Structure and Technological Change: Production Functions for Aggregate Industry, Sectorial Industries and Small Scale Industry," Applied Economics, Vol. 23, no. 11 (November 1991), pp. 1733-1740.

Johnson, Merrill L., "An Empirical Update on the Product-Cycle Explanation for Branch Plant Location in the Non-metropolitan US South," Environment and Planning A, Vol. 23, no. 3 (March 1991), pp. 397-409.

----- "Industrial Transition and the Location of High Technology Branch Plants in the Nonmetropolitan Southeast," Economic Geography, Vol. 65, no. 1 January 1989), pp. 33-47.

Jones, Leslie, Shipbuilding in Britain: Mainly Between the Two World Wars, University of Wales Press; Cardiff, UK, 1957.

Kendleberger, C.P., "The Panic of 1873," in Eugene N. White, ed., Crashes and Panics: the Lessons from History, Dow Jones-Irwin; Homewood, IL, 1990.

Kuznets, Simon, Secular Movements in Production and Prices: Their Nature and Their Bearing Upon Cyclical Fluctuations, Haughton Mifflin; Boston, 1930.

----- "Schumpeter's Business Cycles," American Economic Review, Vol 30, no. 2 (June 1940), pp. 257-271.

----- "Innovation Activity: Problems of Definitions and Measurement," in The Rate and Direction of Innovative Activity, National Bureau of Economic Research, 1962.

Lester, Richard I., "The Procurement of Confederate Blockade Runners and Other Vessels In Great Britain During the American Civil War", The Mariner's Mirror, Vol. 61, no. 3 (August 1975), pp. 255-270.

Link, Albert N., Technological Change and Productivity Growth, Harwood Academic Publishers; New York, 1987.

Lloyd's Registry, Lloyd's Register of British and Foreign Shipping, J. L. Cox and Sons; London, 1840.

Lloyd's Registry, Lloyd's Register of British and Foreign Shipping, J. and H. Cox, Brothers (late Cox and Sons); London, 1845.

Lloyd's Registry, Lloyd's Register of British and Foreign Shipping, J. and H. Cox, Brothers; London, 1850.

Lloyd's Registry, Lloyd's Register of British and Foreign Shipping, J. and H. Cox, Brothers, and Wyman; London, 1855.

Lloyd's Registry, Lloyd's Register of British and Foreign Shipping, Cox and Wyman; London, 1860.

Lloyd's Registry, Lloyd's Register of British and Foreign Shipping, Cox and Wyman; London, 1865.

Lloyd's Registry, Lloyd's Register of British and Foreign Shipping, Wyman and Sons; London, 1870.

Lloyd's Registry, Lloyd's Register of British and Foreign Shipping, Wyman and Sons; London, 1875.

Lloyd's Registry, Lloyd's Register of British and Foreign Shipping, Wyman and Sons; London, 1880.

MacGreggor, David, R., Merchant Sailing Ships, 1775-1815: Their Design and Construction, Argus Books (Model and Allied Publications); Werks, UK, 1980.

----- Merchant Sailing Ships, 1850-1875: Heyday of Sail, Naval Institute Press, Anapolis, 1984.

Mansfield, E, The Economics of Technological Change, W.W. Norton and Co.; New York, 1968.

Markusen, Ann Roell, Profit Cycles, Oligopoly, and Regional Development, MIT Press; Cambridge, 1985.

----- Peter Hall, and Amy Glasmeier, High Tech America: the What, How, Where, and Why of the Sunrise Industries, Allen and Unwin; Boston, 1986.

Massey, D.B. and R.A. Meegan, "The Geography of Industrial Planning: the Spatial Effects of the Restructuring of the Electrical Engineering Sector under the Industrial Reorganization Corporation," Progress in Planning, Vol 10 (1979), pp. 155-237.

Maywald, Karel, "The Construction Costs and Value of the British Merchant Fleet, 1850-1938," Scottish Journal of Political Economy, Vol. 3 (1956), pp. 44-66.

McNeil, Ian, ed., An Encyclopedia of the History of Technology, Routledge; London, 1990.

Mensch, Gerhard, Stalemate in Technology: Innovations Overcome the Depression, Ballinger Publishing Company; Cambridge, 1978.

Mitchell, B. R., British Historical Statistics, Cambridge University Press, Cambridge, 1988.

Mitchell, B. R., International Historical Statistics, 1750-1988, Macmillan Academic and Professional; London, 1991.

Muckle, W. and D.A. Taylor, Muckle's Naval Architecture, 2nd ed., Butterworth's; London, 1975.

Moyse-Bartlett, ""From Sail to Steam; the Final Development and Passing of the Sailing Ship," The Historical Association (Series No. 4); London, 1946 (reprinted 1968).

North, Douglas, "Ocean Freight Rates and Economic Development," Journal of Economic History, Vol. 18, no. 4 (December 1958), pp. 537-555.

----- "Sources of Productivity Change in Ocean Shipping," Journal of Political Economy, Vol. 76, no. 5 (September/October 1968), pp. 953-970.

Norton, R.D., and J. Rees, "The Product Life Cycle and the Spatial Decentralization of American Manufacturing," Regional Studies, Vol. 13, no. 2 (1979), pp. 141-151.

Oakey, R.A., and S.Y. Cooper, "High Technology Industry, Agglomeration and the Potential for Peripherally Sited Small Firms," Regional Studies, Vol. 23, no 4 (August 1989), pp. 347-360.

Parkinson, J.R., The Economics of Shipbuilding in the United Kingdom, University Press; Cambridge, 1960.

Pollard, Sidney, "The Decline of Shipbuilding on the Thames," Economic History Review, 2nd Series, Vol. 3, no. 1 (1950), pg. 72-89.

Pollard, Sidney, "British and World Shipbuilding, 1890-1914: A Study in Comparative Costs," Journal of Economic History, Vol. 17, no. 3 (1957), pp. 426-444.

Pollard, Sidney and Paul Robertson, The British Shipbuilding Industry, 1870-1914, Harvard University Press; Cambridge, MA, 1979.

Rees, John, "Technological Change and Regional Shifts in American Manufacturing," Professional Geographer, Vol. 31, no. 1 (February 1979), pp.45-74.

Rees, John, and Howard A. Stafford, "Regional Growth and Industrial Location," in Rees, John, ed. Technology, Regions, and Policy, Rowman and Littlefield; Totowa, NJ, 1986.

Robb, A. M., "Shipbuilding and Marine Engineering," in J. Cunnison and F.B.S. Gilfillan, The Third Statistical Account of Scotland: Glasgow, William Collins Sons & Co.; Glasgow, 1958.

Rosegger, G., The Economics of Production and Innovation, Pergamon Press; Elmsford, 1980.

Rosenberg, Nathan, Inside the Black Box: Technology and Economics, Cambridge University Press; Cambridge, 1982.

----- Exploring the Black Box, Cambridge University Press; Cambridge, 1994.

Rother, Detlef, The Restructured West European Shipbuilding Industry, Institute of Shipping Economics and Logistics, Book Series No. 11, Bremen, 1985.

Rothwell, Roy, and Walter Zegveld, Industrial Innovation and Public Policy: Preparing for the 1980s and 1990s, Greenwood Press; Westport, 1981.

Rowland, K.T., Steam at Sea: A History of Steam Navigation, Praeger Publishers; New York, 1970.

Salter, W.E.G., Productivity and Technical Change, Cambridge University Press; Cambridge, 1960.

Saul, S.B., Technological Change: the United States and Britain in the Nineteenth Century, Methuen and Co.; London, 1970.

Saul, S.B., The Myth of the Great Depression of 1873-1896, 2nd. ed., MacMillan Publishers; London, 1985.

Sayer, Andrew, "Theoretical Problems in the Analysis of Technological Change and Regional Development," in F.E.I. Hamilton and G.J.R. Linge, eds. Spatial Analysis, Industry, and the Industrial Environment, Vol. 3, Regional Economics and Industrial Systems, John Wiley and Sons; Chichester, 1983.

Schumpeter, Joseph A., Business Cycles: A Theoretical, Historical, and Statistical Analysis of the Capitalist Process, 2 vols., McGraw-Hill; New York, 1939.

----- Capitalism, Socialism, and Democracy, 3rd ed., Harper & Bros; New York, 1950.

Segarstrom, Paul A., T.C.A. Anant, and Elias Dinopoulos, "A Schumpeterian Model of the Product Life Cycle," American Economic Review, Vol. 80, no. 5 (December 1990), pp. 1077-1091.

Sherwood-Call, Carolyn, "Changing Geographical Patterns of Electronic Components Activity," Economic Review, Federal Reserve Bank of San Francisco, 1992, no. 2, pp. 25-35.

Slaven, Anthony, "Scottish Shipbuilders and Marine Engineers: The Evidence of Business Biography," in T.C. Smout, ed., Scotland and the Sea, John Donald Publishers, Ltd.; Edinburgh, 1992.

Smith, David M., Industrial Location: An Economic Geographical Analysis, 2nd ed., John Wiley and Sons; New York, 1981.

Smith, J.W.. and T.S. Holden, Where Ships are Born, Sunderland 1346-1946: A History of Shipbuilding on the River Wear, Thomas Reed and Co., Ltd.; Sunderland, 1953.

Sorenson, David J., "An Empirical Examination of Profit Cycle Theory," Journal of Regional Science, Vol. 37, no. 2 (May 1997), pp. 275-305.

Souza, Anthony R. and Frederick P. Stutz, The World Economy, MacMillan College Publishing Company; New York, 1994.

Spencer, Warren F., The Confederate Navy in Europe, University of Alabama Press; University, Alabama, 1983.

Storper, Michael and Richard Walker, The Capitalist Imperative: Territory, Technology, and Industrial Growth, Basil Blackwell, Inc.; New York, 1989.

Sweeeney, G.P., Innovation, Entrepreneurs, and Regional Planning, Frances Pinter; London, 1987.

Taggart, Robert, Marine Propulsion: Principles and Evolution, Gulf Publishing Company; Houston, 1969.

Teitz, Michael, "Changes in Economic Development Theory and Practice," International Regional Science Review, Vol. 16, no 1 and 2 (1994), pp. 101-106.

Thomas, Brinley, Migration and Economic Growth: A Study of Great Britain and the Atlantic Economy, University Press; Cambridge, 1954.

Thornton, R.H., British Shipping, Cambridge University Press; Cambridge, 1959.

Todd, Daniel, The World Shipbuilding Industry, St. Martin's Press; New York, 1985.

Tsongas, Paul, The Road From Here: Liberalism and Realities in the 1980s, Knopf; New York, 1981.

Turnock, David, the Historical Geography of Scotland: Geographical Aspects of Modernization, Cambridge University Press; London, 1982.

Usher, A.P., A History of Mechanical Inventions, Harvard University Press; Boston, 1954.

Vernon, Raymond, "International Investment and International Trade in the Product Cycle," Quarterly Journal of Economics, Vol. 80, no. 2 (May, 1966).

Ville, Simon, "Total Factor Productivity in the English Shipping Industry: The North-east Coal Trade 1700-1850," Economic History Review, 2nd. series, Vol. 39, no. 3 (August 1986), pp. 355-370.

----- "Shipping in the Port of Sunderland 1815-1845: A Counter-Cyclical Trend," Business History, Vol. 32, no. 1 (January 1990), pp. 32-51.

Walton, Gary M., and James F. Shepherd, The Economic Rise of Early America, Cambridge University Press; Cambridge, 1979.

Walker, Fred M., Song of the Clyde: A History of Clyde Shipbuilding, Patrick Stephens; Cambridge, 1984.

Warren, Kenneth, Consett Iron, 1840 to 1980: A Study in Industrial Location, Clarendon Press; Oxford, 1990.

Weinstein, Bernard, Harold T. Gross, and John Rees, Regional Growth and Decline in the United States, 2nd. ed., Praeger; New York, 1985.

----- and Harold T. Gross, "Spatial and Structural Consequences of Industrial Change: The American Gulf Coast Petrocrescent," in F.E.I. Hamilton, Industrial Change in Advanced Economies, Croom Helm; London, 1987.

Wijers, G.J., "The Economic, Industrial, and Institutional Setting," in G.P. Sweeney, Innovation Policies, an International Perspective, St. Martin's Press; New York, 1985.

VITA

Daniel Stephen Allen was born in Atlanta, Georgia, on May 29, 1952. He graduated from high school in 1970 and entered the University of Georgia in 1971. Dr. Allen left the University in 1973 to become a professional beekeeper, an occupation he pursued for thirteen years. He completed his undergraduate degree at the University of Georgia, graduating cum laude with a bachelor of arts degree in history in 1979.

Dr. Allen received a master's degree from the University of Georgia in Geography in 1990 and, in 1997, his doctor of philosophy degree in geography from Louisiana State University. His awards include Best Student Paper, Georgia Academy of Sciences; Best Student Paper, Masters, Southeastern Division of the Association of American Geographers; and Best Student Paper, Historical Geography Specialty Group, Association of American Geographers. Dr. Allen also served an internship with the National Geographic Society in Washington, D.C., and served as the coordinator for the Minority Student Program, conducted at Louisiana State University under the auspices of the Association of American Geographers.

Dr. Allen is currently employed at the U.S. Army Corps of Engineers Waterways Experiment Station, in Vicksburg, Mississippi, working in the Natural Resources Division of the Environmental Laboratory. His research focuses on the economic aspects of natural and cultural resource management programs on lands maintained by the Corps and Department of Defense.

DOCTORAL EXAMINATION AND DISSERTATION REPORT

Candidate: Daniel Stephen Allen

Major Field: Geography

Title of Dissertation: The Impact of Technological Change on the Economic Viability of Individual Production Centers: The Case of the 1840-1880 British Ocean-Going Iron and Steam Shipbuilding Industry

Approved:

Gregory Veeck
Major Professor and Chairman

[signature]
Dean of the Graduate School

EXAMINING COMMITTEE:

Richard H. Kesel

James P. Geaghan

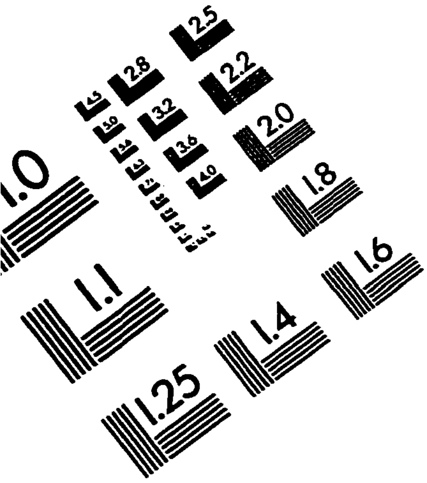
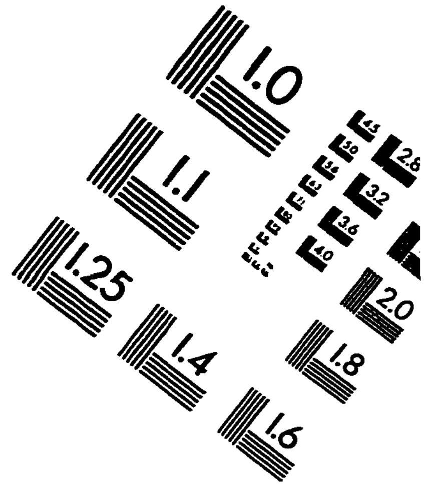
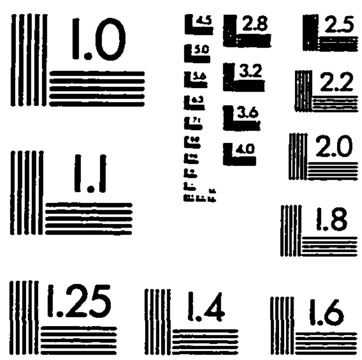
[signature]

Paul F. Paskoff

Date of Examination:

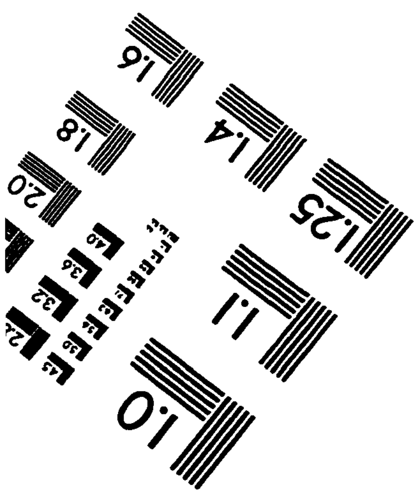
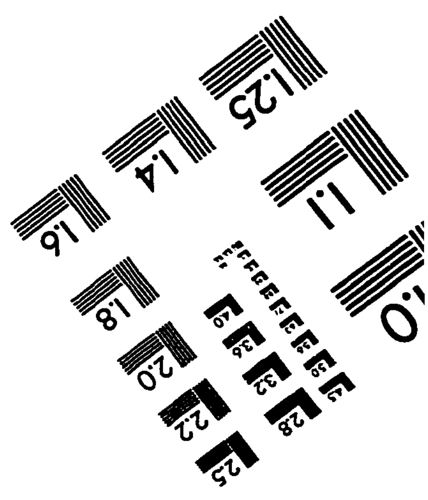
October 24, 1997

IMAGE EVALUATION TEST TARGET (QA-3)

150mm

6″

APPLIED IMAGE . Inc
1653 East Main Street
Rochester, NY 14609 USA
Phone: 716/482-0300
Fax: 716/288-5989