Dynamic Comparative Advantage in International Shipbuilding: From Wood to Steel

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Abstract

Can temporary initial input cost advantages have a long-run impact on the spatial distribution of production and trade? I study this question in the context of the international shipbuilding industry during the transition from wood to metal ship production (1850-1912). Input price advantages gave Britain an early lead in metal shipbuilding, while the U.S. and Canada specialized in wood ship production. However, after 1890, Britain's initial price advantages disappeared. By comparing production patterns on the Atlantic Coast of North America, which faced British competition, to the Great Lakes, which were isolated from competition, I show that British competition substantially reduced the ability of North American producers to transition to metal ship production. I also exploit additional sources of variation to show how government protection and support moderated these effects for some Atlantic Coast producers, allowing them to survive the demise of wood shipbuilding. Finally, I provide evidence that the mechanism driving the persistence of Britain's lead was the development of large pools of skilled craft workers. These results shed light on the role of past conditions in influencing current production and trade patterns and with implications for the use of industrial policy and tariff protection.

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1 Introduction

Can initial input cost advantages have a persistent influence on the pattern of trade, even after those advantages disappear? Can government intervention effectively offset these persistent initial advantages? What are the channels through which persistent effects occur? These are classic questions in international trade, with implications for our understanding of the origins of current trade patterns as well as the impact of tariff protection and other forms of industrial policy. The answers to these questions are particularly relevant today, given ongoing debates over the use of tariff policy and other forms of government intervention to protect domestic industries.

The role of temporary initial advantages in influencing long-run trade patterns and welfare outcomes is the subject of a substantial theoretical literature (e.g., Krugman (1987), (Lucas, 1988, 1993), Grossman & Helpman (1991), Young (1991) and Matsuyama (1992)). However, generating empirical evidence in this area has proven to be challenging because it is difficult to find exogenous variation in input prices, trade costs, and decisions about industrial protection in settings where sufficient long-run data are available. Recent studies, such as Juhasz (2014), provide evidence that temporary protection from more advanced foreign competitors can have persistent effects on domestic industries, but questions remain about how general these findings are, as well as about the mechanisms through which this persistence occurs.[1]

To make progress in addressing the questions posed above, this paper studies the experience of the international shipbuilding industry from 1850 until just before the First World War. I focus on this period because it was during this time that the shipbuilding industry experienced a transition from wood to metal shipbuilding. In the mid-19th century, the vast majority of ships were built of wood, while metal (iron and steel) shipbuilding was in its infancy. By the end of the study period, the industry was completely dominated by metal shipbuilding. Importantly, there were large differences in the initial cost of wood and iron across the three major shipbuilding locations that I study – the U.S., U.K., and Canada – at the beginning of the study period. In particular, wood was much less expensive in the U.S. and Canada, while iron and steel were less expensive in the U.K. As a result, the U.S. and Canada specialized in the (much larger) wood shipbuilding sector, while U.K.

[1] Other papers studying the long-run effects of temporary protection or industrial policy include Irwin (2000) and Lane (2016).

producers began production in the smaller metal shipbuilding segment. However, these initial input costs differences had largely disappeared by the 1890s due to the discovery of new iron reserves in the U.S. and the exhaustion of timber supplies in the Eastern U.S. and Canada. This feature makes it possible to look at whether temporary initial input cost advantages had persistent effects.

The first question posed by this study is, how did competition from British shipbuilders with an initial lead in metal ship construction affect the development of the North American shipbuilding industry? In order to answer this question, I take advantage of a unique feature of the shipbuilding market. While North American producers on the Atlantic seaboard faced international competition, shipbuilders in the Great Lakes operated in a market that was effectively isolated due to geographic factors. In particular, before the opening of the St. Lawrence Seaway in the 1950s, it was not possible for large ocean going vessels to transit between the lakes and the Atlantic. Thus, within both the U.S. and Canada, it is possible to compare the experience of shipbuilders on the Atlantic Coast, which faced foreign competition, to those in the protected Great Lakes market.

By comparing shipbuilders on the Atlantic Coast of North America to those in the protected Great Lakes market, I show that competition from more advanced British producers had a strong negative effect on the North American shipbuilding industry. Specifically, I find that foreign competition substantially slowed the transition of Atlantic Coast producers to metal ship construction. In contrast, shipbuilders in the protected Great Lakes market rapidly switch to producing metal ships. In terms of magnitude, my estimates suggest that a location that was active in wood shipbuilding in the 1870s was 60-75% more likely to be active in metal shipbuilding in 1901-1910 if it was located in the Great Lakes rather than on the coast. Furthermore, conditional on being active in metal shipbuilding in 1901-10, being located on the Great Lakes was associated with a roughly 150% increase in metal ship tonnage relative to coastal locations.

A second question posed by this study is, what impact did government protection and support play in the development of the North American shipbuilding industry? Typically, understanding the impact of government protection is difficult because these policies are chosen endogenously. However, the setting I consider provides two sources of plausibly exogenous variation in access to government protection. The first dimension of variation comes from comparing producers in the U.S. and Canada. The U.S. government actively supported shipbuilders through protection from foreign competition in coastal trade and naval spending. In contrast, Canada was unable to offer its shipbuilders similar protection from British producers because it was part of the British Empire during this period and did not operate an independent navy. This provides an opportunity for studying how access to government protection can modify the impact of foreign competition. I also exploit a second source of variation in government support within the U.S. related to a shipyard's proximity to U.S. Navy Shipyards. The U.S. Navy operated several shipyards during the study period which could benefit nearby private yards through channels such as generating a trained local workforce, technology transfers, or improving access to Navy contracts. Because the location of these Navy shipyards were determined around the beginning of the 19th century, long before the introduction of metal shipbuilding, their placement is plausibly exogenous to a location's potential for metal, relative to wood, shipbuilding.

Using these sources of variation, I provide evidence that U.S. government protection had a substantial impact on the ability of U.S. shipbuilders to survive and transition to metal ship production. Specifically, U.S. producers on the Atlantic Coast did much better than Canadian shipbuilders. While the Canadian shipbuilding industry on the Atlantic Coast almost completely disappeared, in several locations U.S. shipyards were able to transition successfully to metal ship production. In terms of magnitude, I find that being located in the U.S. was as beneficial as being located on the Great Lakes. Moreover, of the U.S. locations that successfully transitioned to metal shipbuilding, the most important were located within 25km of an established U.S. Navy Shipyard. Overall, these results suggest that government support successfully protected the U.S. shipbuilding industry, allowing at least some private Atlantic Coast shipyards to transition to metal ship production.

The third question posed by this study is, what mechanisms generated the persistent impact of initial input price advantages on later production patterns? To shed light on this question, I undertake a careful review of the key features of the shipbuilding industry during this period. This review suggests that the development of pools of skilled craft workers played a central role in generating persistent local advantages. These workers possessed skills specific to the shipbuilding industry which had to be developed through experience. Moreover, unlike technology, machinery, or very high-skilled workers (e.g., naval architects and marine engineers), which were relatively mobile across locations, the large pool of craft workers actually engaged in ship construction were difficult to relocate, creating a fixed source of locational advantage. Interestingly, U.S. metal shipbuilders often used more advanced machinery and had new and better designed shipyards than their British competitors. However, evidence suggests that this more advanced technology reflected a weakness – the need to substitute for worker skills – rather than a strength.

In order to produce the evidence described above, this study draws on a unique and extraordinarily detailed source of data provided by ship registers. The register data that I use, which come from Lloyd's and the American Bureau of Shipping, were digitized from thousands of pages of raw documents and contain tens of thousands of individual ships. These registers exist because, in order to obtain insurance for vessels and their cargo, ships needed to be inspected and meet minimum quality criteria. Obtaining insurance was vital in the shipping industry, so the vast majority of major ships produced during the study period appear on at least one of these registers. The registers that I have digitized provide details on where and when a ship was constructed as well as ship characteristics including tonnage and construction material, allowing me to undertake an analysis at the level of individual shipbuilding locations.

This study is closely related to a recent paper by Juhasz (2014), which studies the impact of protection resulting from the Napoleonic blockade on the French cotton textile industry.[2] Juhasz shows that the stronger protection provided to textile producers in the north of France relative to those in the south had a long-run impact on the location of production in the country. Like Juhasz, I find evidence that temporary advantages can have long-run impacts on the pattern of production and trade, though the advantages I consider are generated by initial input prices rather than output protection. Where this study attempts to go further than previous work is in looking at the mechanisms behind these effects, as well as the impact of government intervention in offsetting these initial advantages.

This paper builds on a long line of research on the shipbuilding industry, which can be divided into two streams. One line of inquiry takes an aggregate approach to understanding the transition from wood to iron shipbuilding (Harley (1970), Harley (1973)). A more recent stream takes advantage of very rich data on Liberty Ship con-

[2]Two other similar studies are Irwin (2000) and Lane (2016).

struction during WWII to study learning-by-doing at the firm level (Searle (1945), Rapping (1965), Argote *et al.* (1990), Thompson (2001)). Thornton & Thompson (2001) extend this analysis beyond Liberty Ships to cover a variety of ship types during the WWII period.[3] My paper offers a bridge between these two strands of research. In particular, this study provides evidence that the types of learning forces identified in Liberty Ship studies such as Thompson (2001) and Thornton & Thompson (2001) can have broad impacts on long-run patterns of trade and the spatial distribution of production. At the same time, the use of more detailed data and a cleaner identification strategy allows me to improve upon the aggregate time-series analysis offered by Harley (1973).

This study emphasizes the role played by initial input price levels in influencing the long-run pattern of trade. As a result, there is a natural connection to papers examining the impact of falling trade costs on firms through imported intermediate inputs (Amiti & Konings (2007),Halpern *et al.* (2015), Goldberg *et al.* (2010)). In the context I study, the inability to cheaply import intermediate inputs is one cause of the initial input price differences, while falling trade costs contributed to the elimination of these differences by 1900. Thus, my findings imply that the time at which firms gain access to intermediate inputs can be important.

The next section of the paper describes the empirical setting, followed by a description of the data, in Section 3. Section 4 analyzes the persistent effects of the initial input price advantages, as well as the impact of government protection. Section 5 then provides evidence on the mechanisms lying behind these effects. Section 6 concludes.

2 Empirical setting

The shipbuilding industry was an important industrial sector in both the British and North American economies through the 19th and well into the 20th century. In Britain, Pollard & Robertson (1979) estimate that aggregate wages in shipbuilding made up roughly 1-2 percent of total British wages from employment in the period from 1871-1911 (p. 36). The importance of the industry in the U.S. is harder to

[3] Another related paper in this literature is Thompson (2005), which uses data on U.S. iron and steel shipbuilding from 1825-1914 to study the relationship between firm age and firm survival. Thompson (2007) studies organizational forgetting among Liberty Ship builders.

estimate, but likely to be similar.

During the period covered by this study, the shipbuilding industry underwent dramatic changes, the most important of which was the shift from wood ships to ships made of iron or, later, of steel. In the 1850s, iron shipbuilding was still in its infancy. By 1912, the vast majority of ships were made of iron. This transition was driven by several other changes. One important factor was the shift from sail to steam power. This advantaged iron ships, which were better able to handle the increased vibration and hull stress associated with steam power.[4] The quality and availability of iron and steel inputs also increased during this period. At the same time, timber became increasingly scarce in many shipbuilding areas in the late 19th century.

The evolution of input prices will play an important role in this paper. At the beginning of the study period, there was a distinct pattern of comparative advantage in the shipbuilding industry driven by local input prices. In particular, the forests of the Eastern U.S. and Canada gave North American shipbuilders cheap access to wood. As a result, the U.S. was the world's leading shipbuilder, while Canada was also an important ship producer.[5] In contrast, shipbuilders in Britain had access to cheaper iron inputs thanks to their large domestic iron industry. Not surprisingly, this give British producers an early lead in iron shipbuilding.

By the late 19th century, however, these initial input price differences had almost completely disappeared, as shown in Figure 1. For wood prices, shown in the top panel of Figure 1, the rise in (eastern) U.S. prices was due to the increasing scarcity of forests near the shipbuilding areas.[6] As a result, by the late 19th century, shipbuilders on the Atlantic coast of North American often had to import wood from the Great Lakes region.[7] For iron prices, shown in the bottom panel of Figure 1, the convergence between North American and British prices was driven by the discovery of new iron ore reserves in the U.S., such as the rich reserves in the Mesabi iron ore range in

[4]Harley (1973).

[5]Pollard & Robertson (1979) write (p. 12), "The extraordinarily rapid growth of American shipbuilding in the first half of the nineteenth century had been based on the abundance of timber on the North American continent...Canadian shipbuilding, like the American, was based on cheap supplies of softwood timber."

[6]See, e.g., Hutchins (1948), which describes (p. 17) that, "After 1880 there was a general shortage on the Atlantic Coast..."

[7]Hutchins (1948) writes (p. 35) that, "The most important change compared with the prewar period was the state of the timber supply, which unfortunately after 1860 was far from satisfactory, even in Maine...Much of the timber used now came from afar...the major quantity had to come from the Great Lakes and Ohio Valley regions – an expensive process."

Minnesota. These discoveries led to an expansion in U.S. iron and steel production and drove a surge in manufacturing exports starting in the 1890s (Irwin (2003)). While Figure 1 describes iron prices, similar patterns appear for steel.[8] U.S. iron and steel exports surged from $25.5 million (3% of exports) in 1890 to $121.9 million (9% of exports) in 1900 and reached $304.6 million (12.5% of exports) in 1913 (Irwin (2003)). By 1900, U.S. manufacturers were even exporting substantial amounts of iron and steel to Britain. The dramatic reduction in transport costs that occurred in the second half of the 19th century also contributed to input price convergence.[9] Changes in tariff policy also played a role.[10] As a result of this combination of factors, the strong initial patterns of comparative advantage driven by input prices which defined the shipbuilding industry in the mid-19th century had essentially disappeared by 1900.

Ships are naturally easily transportable between navigable locations. As a result, during the study period shipbuilding was effectively global, with one major exception. Prior to the opening of the St. Lawrence Seaway in the 1950s, it was virtually impossible for large vessels to transit between the Great Lakes and the Atlantic Ocean.[11] This created an isolated Great Lakes market, naturally protected from international competition. This market provides us with a benchmark for tracking the development of North American shipbuilding in the absence of foreign competition. Thus,

[8] Allen (1981) reports that, "Before the 1890s American [steel] prices substantially exceeded British prices, and the American industry achieved a large size only because of high tariffs. During the 1890s American prices dropped to British levels or below, and America emerged as a major exporter of iron and steel." Focusing on steel rails in particular, Allen found that, "Between 1881 and 1890 the average price of steel rails at Pennsylvania mills was $37.01 while the average British price was $23.62. During the period 1906-13 the American price had fallen to $28.00 while the British price had risen to $29.46."

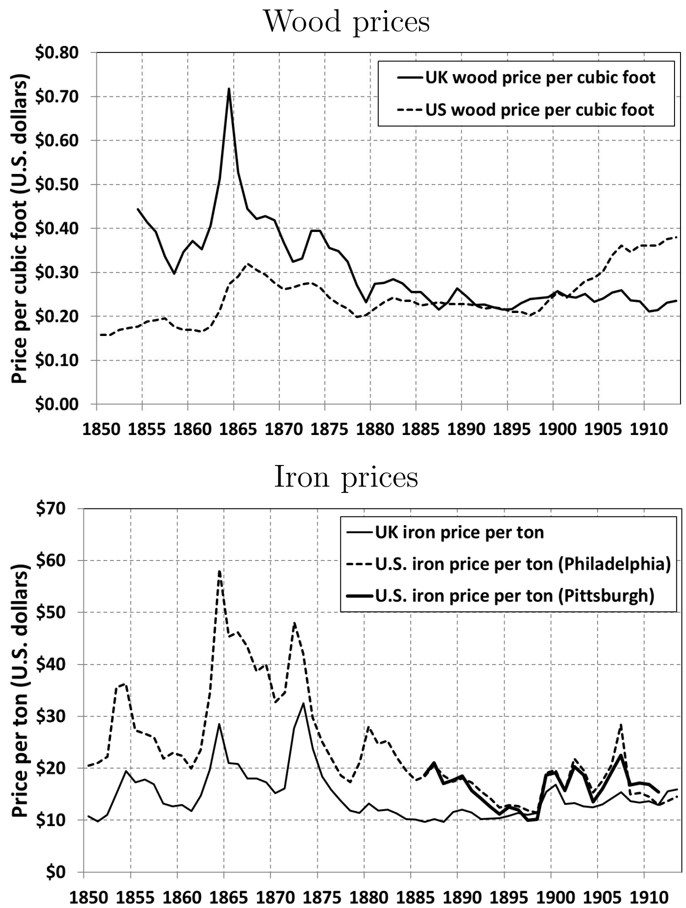
[9] Jacks *et al.* (2008) provide evidence that international trade costs fell by 23 percent relative to domestic trade costs between 1870-1913, a decline that was even larger than the fall that occurred after 1950.

[10] In particular, the Dingley Tariff of 1897 specifically exempted from duty steel used in the construction of vessels for the foreign trade (Dunmore (1907)), which increased the foreign competition faced by U.S. steel producers.

[11] The *Annual Report to the Commissioners of the Navy* for 1901 (p. 15) describes how, "The experiment of building large vessels, cutting them in two to pass the locks, and then reuniting the parts has been made successfully in a few instances, but at the present time it does not appear that this method of construction on the lakes for the seaboard will become general." Smaller vessels were able to pass through the canals available, but as that report states, "Through this lock, accordingly, a vessel of over 2,300 or 2,400 tons can not pass, even were the delays and dangers of the St. Lawrence route much less than experience has shown. Vessels of such small dimensions are not adapted to modern trans-Atlantic trade requirements."

a comparison of the North American Atlantic Coast and Great Lakes shipbuilding industries provides an opportunity for assessing the impact of foreign competition on industry development.

Figure 1: Input prices in the U.S. and U.K., 1850-1913



Notes: U.K. iron prices are from the Abstract of British Historical Statistics. U.K. wood prices are from the Statistical Abstract of the United Kingdom. U.S. prices are from Historical Statistics of the United States, Colonial Times to 1870, Vol. 1. U.K. prices are converted into dollars using the exchange rates reported by `http://www.measuringworth.com/exchangeglobal/`.

Importantly, the bottom panel of Figure 1 also shows that there was little difference in the price available on the Atlantic Coast (Philadelphia price) and the price available on the Great Lakes (Pittsburgh price). This suggests that differences between the patterns observed in these two regions are unlikely to be due to regional differences in iron or steel prices. Moreover, the fact that Atlantic Coast producers were importing timber from the Great Lakes and the Ohio Valley suggest that, if anything, Great Lakes producers had a comparative advantage in wood ship production relative to Atlantic Coast producers.[12]

Industrial policy and protection from foreign competition played an important role in the shipbuilding industry. Major shipbuilding nations used a variety of tools to help protect and nurture domestic shipbuilders. The U.S. was particularly active in this regard. One tool used by the U.S. was a ban on the use of foreign-built ships for direct trade between American ports (coastal trade). This policy, which existed throughout the study period, created a protected market for U.S. shipbuilders, though the size of this market was limited. A second type of industrial policy, which was applied by nearly all of the major shipbuilding nations, was the subsidization of mail-carrying routes, which had to be served with domestically-built ships. However, these policies only affected a small fraction of shipping tonnage. A third important channel of government influence on shipbuilding was through the Navy. Both the U.S. and Britain operated government shipyards and purchased warships exclusively from domestic shipbuilders. Warship construction could play an important role in the development of the domestic shipbuilding industry because the demand for naval vessels could give yards experience and generate pools of skilled workers. The U.S. began a substantial expansion of the Navy in the 1880s, often described as the "New Navy" because the new ships were metal rather than wood. Thus, we should expect to see benefits for U.S. shipbuilders, relative to Canadian builders, starting in this period.[13]

This study takes advantage of an exogenous source of variation in access to government protection provided by the empirical setting. Specifically, while the U.S. had access to the full range of protective policies, Canada, as part of the British Empire, did not have the ability to enact similar policies. Specifically, Canada could not close coastal trade to British-built ships, nor did it have an independent navy during this period to provide orders to domestic yards or to operate government shipyards.[14] Thus, comparing the experience of the U.S. and Canada allows us to observe the

[12]See Hutchins (1948) p. 35.

[13]Hutchins (1948) writes that (p. 35), "it is probable that a substantial modern shipbuilding industry would have been long in coming in the United States but for the naval expansion of the 'eighties, 'nineties, and early twentieth century."

[14]The Royal Canadian Navy was not founded until 1910 and initially it was equipped with vessels from the Royal Navy.

evolution of this industry with and without access to government protection.

This study also exploits spatial variation in government influence on the shipbuilding industry within the U.S. related to the location of U.S. Navy Shipyards. Navy shipyards could influence local shipbuilding by providing a pool of workers with skills in cutting-edge shipbuilding practices, through technology transfers, or by influencing the ability of local shipbuilders to obtain Navy contracts. Moreover, the location of the Navy shipyards active on the Atlantic Coast during this period had been established long before metal shipbuilding began. These early shipyards, with their year of establishment, were: Portsmouth, VA (Norfolk NSY, 1767), Boston, MA (1800), New York City (Brooklyn NSY, 1800), Philadelphia (1801), and Kittery, ME (1800).[15] These shipyard locations, which are plausibly exogenous to input supply conditions in the late 19th century, provide a useful additional source of spatial variation for studying the impact of government policy on the private shipbuilding industry.

3 Data

This study draws on a unique new data set derived from individual ship listings on two registers, one produced by Lloyd's and the other by the American Bureau of Shipping (ABS, sometimes called "American Lloyd's"). The primary purpose of these registers was to provide insurers and merchants with a rating of the quality of each ship that they might be asked to underwrite or to ship their products. This provided shipowners with a strong incentive to have their ship included on at least on and often more than one registry. As a result, the registration societies claimed that the vast majority of major ships (e.g., over 100 tons) were included on one of the lists. To be included on a register, a ship had to be inspected. This often occurred multiple times during the construction process and at periodic intervals after construction was complete. To complete these inspections, the registration societies employed a set of local inspectors in the majors shipbuilding areas of the world.

The registers were published annually and included, for each ship, information on

[15]The only other early Atlantic shipyard, in Washington, DC, was opened 1799 but this yard largely ceased ship construction after the War of 1812 because the Anacostia River was too shallow to accommodate larger vessels. A Coast Guard shipyard was opened in Baltimore in 1899, but I do not include that in my analysis because it is likely that the location of that yard was influenced by Baltimore's potential as an iron and steel shipbuilding center.

the location and year of construction, often the shipbuilder, the tonnage, construction material, and other characteristics of the ship.[16] Figure 2 provides an example of the data from the first page of the Lloyd's Register for 1871-72. We can see that the first ship on this list, the A.D. Gilbert, was a schooner (Sr) of 177 tons built in Truro (UK) by the Hodge shipyard in 1865. The details below the name indicate that this was a wood ship. The third entry, the A. Lopez, was a screw steamer (ScwStr) and below the name we can see that this ship was made of iron.[17] For cost reasons, I have digitized only a subset of the information shown in the register in Figure 2: the ship name, type and construction details (shown in the "Ships" column), the tonnage, and information on the location of construction, shipyard, and year of launch (shown in the "Build" column).

Figure 2: Example of raw data from Lloyd's Register for 1871-72

1871–72. **A**

No.	Ships.	Masters.	Tons.	Dimensions. Length.	Breadth.	Depth.	Build. Where.	When.	Owners.	Port belonging to.	Port of Survey and Destined Voyage.	Years Assigned.	Character for Hull and Stores, also Date of Last Survey.
1	A. D. Gilbert Sr YM.69overpt I.B.	WHodgejr	177	108·0	23·5	12·5	Truro *Hodge*	1865 10mo.	W.F.Hodge	Truro	Lon.W.Inds. (A.&C.P.)	12	A 1 2,69
2	A. Hastings Sr I.B.	W.Donald *Salted*	81	86·2	21·4	8·8	N.Brns *M'Lelin*	1856	R.Jackson	Belfast	Bel.Coaster Rest.Bel.71–	— 6	A 1 3,71
✠3	A. Lopez ScwStm (Iron) MC.65	Villevarde 400HP.	1969 1371	282·0	38·5	26·1	Dmbtn *Denny B.*	1865 11mo.	Lopez&Co.	Alicante *4 Blk Hds*	Cly.Alicante (A.&C.P.)	—	A 1 1,66

This study uses data from registers for three years, 1871, 1889 and 1912. Because the registers include all active ships in these years, and because ships generally last many years after construction, these snapshots provide coverage for ships built from roughly 1850 through the First World War.[18] Specifically, I use the 1871 register to track ships built between 1850 and 1870, the 1889 register to track ships built between 1871 and 1887, and the 1912 register to track ships from 1888-1911.[19]

For 1871 and 1889, I digitized both the Lloyd's Register and the ABS Register, as

[16] The register also included additional information about the current owner, home port and master of each ship. These data were not entered for cost reasons.

[17] I am grateful to Hathi Trust and the Mystic Seaport Library for providing these scans.

[18] I focus on only three "snapshots" rather than digitizing all registers during this period because digitizing each register is extremely costly as well as time consuming.

[19] The registers often did not have complete coverage for ships in the year in which they were published.

Table 1: Number of vessels in each Register used in this project

Year	Register	Total number of ships	No. vessels by location of build: U.S.	Canada	U.K.	Others
1871	Lloyd's	8,521	100	1,086	6,879	456
	ABS	12,186	5,594	2,547	1,503	2,542
1889	Lloyd's	8,626	11	282	7,431	902
	ABS	8,474	3,326	2,050	547	2,551
1912	Lloyd's	23,002	2,453	580	12,714	7,255

The counts from the 1871 registers include entries for ships built from 1850-1870. The 1889 register entries include ships built from 1871-1887. The 1912 entries include ships built from 1888-1911.

neither provides complete coverage of both British and North American vessels. For 1912, the Lloyd's Register claimed to have comprehensive coverage (ships over 100 tons), so only the Lloyd's Register was digitized for that year. Table 1 describes the number of vessels included in the data from each of the registers used in this study.

These data required extensive processing to clean and standardize location names, eliminate duplicate entries that appeared in both registers, identify the construction material for each ship, etc.[20] The analysis in this paper uses only data from the U.K. as well as the East Coast and Great Lakes regions of the U.S. and Canada.[21] Within these analysis areas, it is possible to identify the exact location of construction for the vast majority of ships built in the U.S., Canada and the U.K.[22]

[20] In the 1889 data, I have identified 2,663 U.S., British or Canadian ships that were listed in both registers. In the 1871 data, I find 602 ships that were listed in both.

[21] There was very little ship construction in the Gulf of Mexico. Construction on the Pacific Coast was also relatively small during most of the study period.

[22] For ships built in the U.S., Canada and the U.K., I am able to identify the construction location for over 99% of ship tonnage in data from the 1912 register, over 95% of tonnage in the 1889 registers, and . In data from the 1871 registers, the share of tonnage linked to a location within the U.K, the U.S. and Canada, respectively, is 99.5%, 98.4% and 88.2%. The larger share of tonnage with missing locations in the Canadian data is due to the fact that only the province of construction was provided for many Canadian ships registered in Lloyd's.

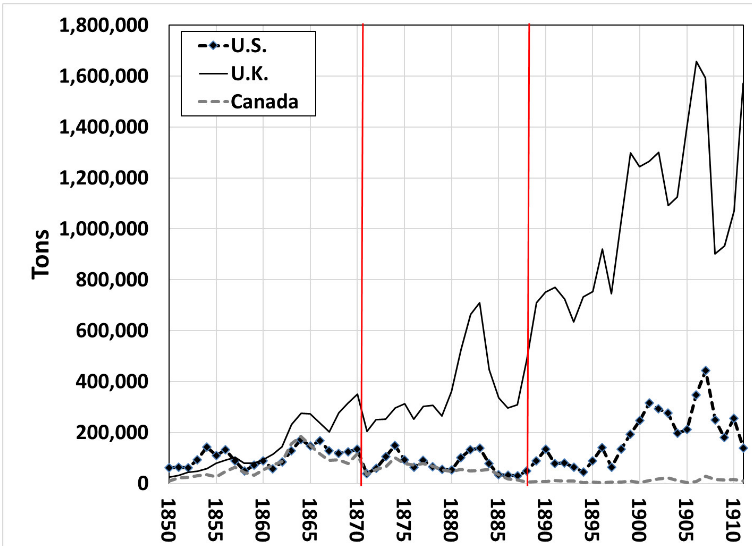
4 Analysis

This section begins with a review of the key patterns in the data, followed by the econometric analysis. A useful starting point is Figure 3, which describes the evolution of ship production in the U.S., U.K., and Canada across the study period using data from the ship registers. The top panel of Figure 3 shows that the U.S. was the leading shipbuilder in 1850, with Canada and the U.K. not far behind. However, by 1911 the U.K. was by far the dominant producer. While the U.K. gained a small lead in the late 1850s and 1860s (likely due in part to the U.S. Civil War), the main divergence occurred in the 1880s. We can also see that the U.S. experienced some recovery in the late 1890s, which corresponded to the reduction in Britain's advantage in iron prices. However, despite this reversal the U.S. remained far behind Britain in overall ship production in 1911. In Canada, where output was comparable to U.S. production from the 1860s to the 1880s, no similar recovery took place, so that it had ceased to be a major shipbuilding nation by 1911.

The two red lines in this figure mark the points at which the registers providing the data switch, which may generate discontinuities. However, we can see that these are not large. In addition, the patterns over time described in Figure 3 are very similar to those in the aggregate data, shown in Appendix Figure 8, though the tonnage levels are not strictly comparable.[23] This provides some confidence that the values derived from the registers are reasonable.

[23]There are two issues in comparing tonnage across different data sets. One issue is in determining the set of ships included. Aggregate statistics often cut off ships below a certain tonnage level, but they are often not explicit about exactly what the cutoff is. Some types of ships, such as barges, may also be excluded. Also, many of the available aggregate statistics include only vessels that were both produced in a country and then subsequently registered in that country. The second issue in comparing to aggregate statistics has to do with they type of tonnage measure. In general, the registers used a measure called net tonnage, while many aggregate statistics, particularly for the U.S., use gross tonnage. Unfortunately the relationship between gross and net tonnage is different for each vessel, so there is no way to easily translate between them. For a further discussion of tonnage measurement issues see Appendix A in Pollard & Robertson (1979).

Figure 3: Merchant ship production in the U.S., U.K., and Canada 1850-1913

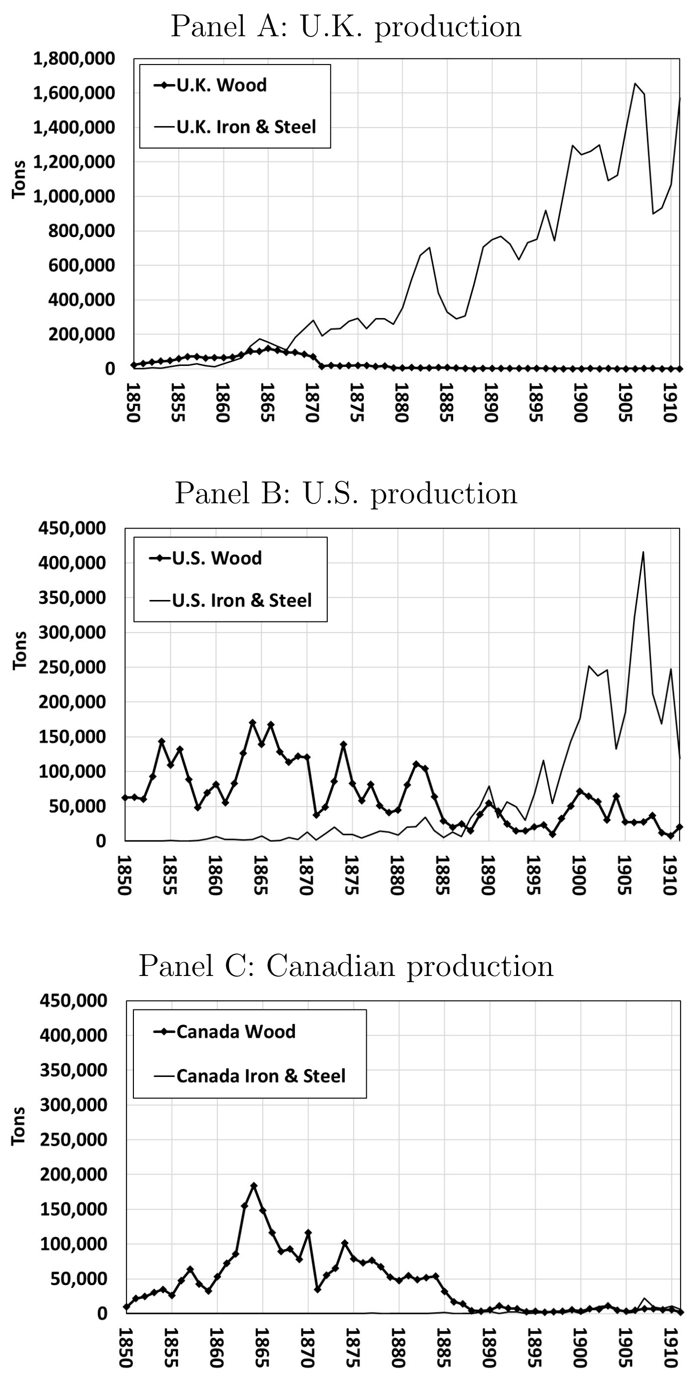


Data based on both the Lloyd's and ABS Registers. The U.K. includes all of Ireland. The two red lines show the points at which the registers providing the data change, where we might expect discontinuities.

The next set of charts, in Figure 4, can help us start to make sense of the overall production patterns. These graphs present output for each country divided into wood or metal ships. Here we can see that the U.K. transitioned to metal ship production early, in the 1860s and 1870s, with wood ship production in the U.K. almost completely disappearing by the 1870s. In the U.S., the transition to metal ship production happened much later. It is worth noting the substantial increases in iron ship production in the late 1880s, just after the beginning of the New Navy program, and again in the late 1890s, when U.S. iron prices fell to U.K. levels. A third pattern is offered by Canada, where we see no evidence of a substantial move into iron ship production. Instead, most Canadian producers remained tied to the declining wood shipbuilding industry.

Figures 3-4 describe the patterns that this study aims to understand. The next set of results will provide evidence that can help us begin to explain these patterns. Specifically, the next set of results look at how production patterns within North America differed between Atlantic producers, which were exposed to international (mainly British) competition, and those in the protected Great Lakes market.

Figure 4: Shipbuilding tonnage by construction material

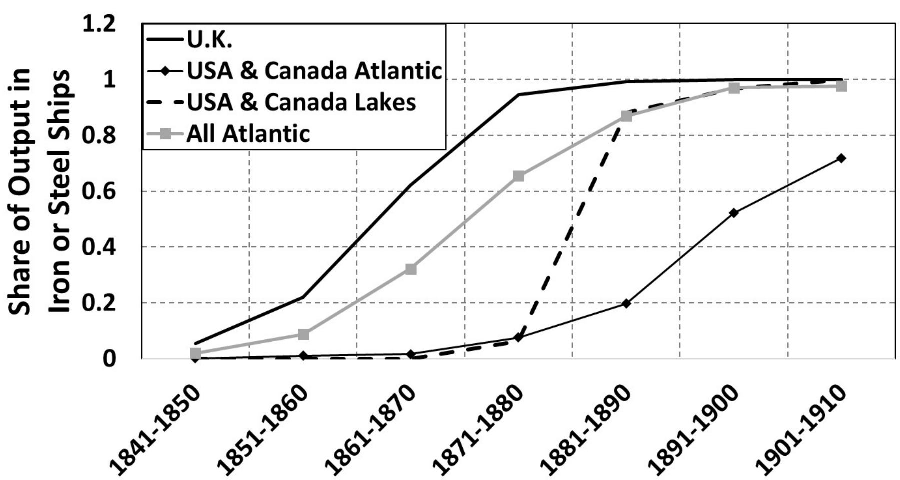


Data based on both the Lloyd's and ABS Registers. The U.K. includes Ireland.

Figure 5 looks at the share of output (by tonnage) in metal or wood ships in the

U.K., on the Atlantic coast of the U.S. and Canada, and in the Great Lakes. The key feature to note in this graph is the production pattern observed on the Atlantic Coast of North American and the pattern observed in the Great Lakes. While the share of metal ship production was similar in these two regions until 1880, after 1880 we can see that there was a dramatic shift. Shipbuilders in the Great Lakes rapidly converged to the pattern of production observed in the overall Atlantic market (U.K., U.S. and Canada), while this convergence process was much slower among Atlantic coast producers. Thus, this graph reveals the impact of exposure to foreign competition on Atlantic coast producers.

Figure 5: Evolution of production patterns by region



Data based on both the Lloyd's and ABS Registers. The U.K. includes Ireland. The "All Atlantic" category includes production in the U.K., U.S. and Canada.

Figure 6 maps the distribution of production of wood and metal ships in the decades 1871-1880 and 1901-1910. I consider these two periods because the first falls after the U.S. Civil war but before the elimination of the differences in input prices between the U.S. and Britain, while the second period falls after the input price differences had disappeared. These maps illustrate the strong shift in North American ship production from the Atlantic Coast to the Great Lakes, and the shift from wood to metal ships. It is clear that the shift from wood to metal was more extensive in the Great Lakes than on the Atlantic Coast, despite the preferential access of Great Lakes shipbuilders to timber resources. These maps bring us closer to the approach used in the econometric analysis, which studies patterns at the level of individual shipbuilding locations.

Figure 6: Ship production in the U.S. and Canada, 1871-80 and 1901-10

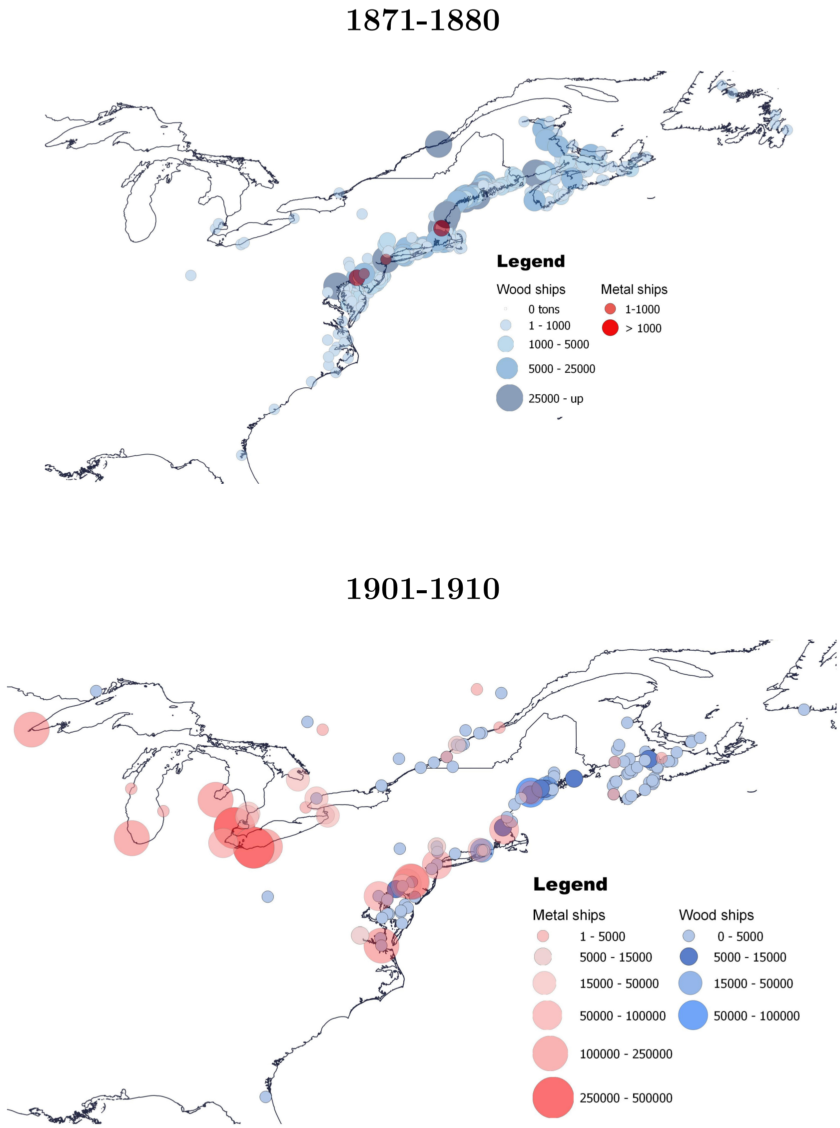


Figure 6 also shows that on the Atlantic Coast metal ship production was mainly concentrated in a few locations: Boston, New York, along the Delaware River (Philadelphia, Camden, Wilmington, and Chester), Baltimore, and Portsmouth/Norfolk, Virginia. Notably, each of these locations was also home to one of the Navy shipyards established in the early 19th century, with the exception of Baltimore (where a Coast Guard shipyard was established in 1899). The case of Portsmouth/Norfolk, Virginia is particularly interesting because this was not a major shipbuilding location in the 1870s. However, it emerged as an important producer of iron ships by 1900.

Next, I analyze these patterns econometrically. I begin with a set of cross-sectional regressions looking at outcomes in the last decade before the First World War. The first set of results look at whether there are active shipbuilders in a particular sector and location, using Probit regressions. The specification is,

$$\begin{aligned} A_{ls} &= 1[a^*_{ls} > 0] \\ a^*_{ls} &= \alpha_0 METAL_s + \alpha_1 LAKES_l + \alpha_3 US_l \\ &+ \alpha_4 (METAL_s \times LAKES_l) + \alpha_5 (METAL_s \times US_l) + X_{js}\Gamma + e_{js} \end{aligned} \tag{1}$$

where A_{ls} is an indicator variable for whether location l is active in shipbuilding sector $s \in \{wood, metal\}$ in the 1900-1910 decade and a^*_{ls} is an unobserved latent variable which depends on the set of explanatory variables. $METAL_s$ is an indicator variable that takes a value of 1 when $s = metal$ and 0 otherwise. $LAKES_l$ is an indicator variable for whether the location is in the Great Lakes region. US_l is an indicator for whether the location is in the U.S. The coefficients of interest in this regression are α_4 and α_5, which tell us, respectively, how being in the protected Great Lakes market and how being in the more protected U.S. market affects the probability that a location is active in metal shipbuilding.

Among the control variables that I consider is whether a location has been active in shipbuilding in some past decade (usually either 1851-60 or 1871-80 to avoid the decade of the U.S. Civil War) at all, or in sector s specifically, and if so, the tonnage produced in that past decade in the location overall or in sector s specifically, the location's latitude and longitude, and in some cases production patterns in other nearby locations. These controls are meant to help capture both the location's physical assets for ship production, such as a deep harbor, as well as geographic factors that affect access to inputs in 1901-1910.

Table 2 presents Probit regression results based on Eq. 1. These regressions are run on the full set of U.S. and Canadian shipbuilding locations on the East Coast or Great Lakes which were active at some point in the 1850-1910 period. The first column presents results looking only at how being in the Great Lakes area and in the U.S. affected the likelihood that a location remained active in either the metal or wood shipbuilding sectors in 1901-1910. The estimates in Column 1 suggest that locations were much more likely to be active in metal shipbuilding if they were in on the Great Lakes or if they were in the U.S. In Columns 2, I add in additional information about production in each location in the 1851-1860 decade. These additional variables help control for factors such as fixed locational advantages. These results suggest that whether a location was active in earlier decades is not a strong predictor of activity in 1901-1910, but location that produced more tonnage in the past were more likely it was to remain active in at least one shipbuilding sector. Column 3 adds controls for latitude and longitude. These suggest that locations further East were more likely to be active. In Column 4, I substitute in controls based on shipbuilding activity in 1871-1880. This reduces the estimated effect only slightly relative to using 1851-60 as the comparison year. Finally, in Column 5, I add in additional controls reflecting production patterns in all locations within 100km. The coefficients on these controls suggest that locations are more likely to be active if they are near other locations that are active in the same sector and less likely to be active if they are near other locations active in the other sector.

To interpret the magnitude of the results shown in Table 2, I apply the estimates shown in Column 5 assuming a location that was active in 1870 producing wood ships with tonnage equal to the average observed in the data.[24] If the location was in Canada, then the estimates in Table 2 suggests that the probability that it was active in metal shipbuilding in 1900-10 if it were on the Atlantic Coast would be 0.113, while if the location were in the Great Lakes the probability would be substantially higher, at 0.185. The same exercise applied to a U.S. location implies probabilities of 0.070 and 0.123 for the Atlantic Coast and Great Lakes, respectively. Thus, in these examples being in the protected Great Lakes market increases the probability that a location is active in metal ship production by 60-75%.

[24]For simplicity, I also assume that it is at the mean latitude and longitude.

Table 2: Probit regression results

	DV: Location is active in producing ships of type s in 1901-1910				
	(1)	(2)	(3)	(4)	(5)
Great Lakes x Metal	1.329***	1.796***	2.368***	1.296***	0.936**
	(0.383)	(0.440)	(0.483)	(0.419)	(0.436)
U.S. x Metal	0.797***	0.906***	1.129***	1.038***	1.219***
	(0.247)	(0.309)	(0.325)	(0.286)	(0.310)
Metal ind.	-1.397***	-2.083***	-2.830***	-1.507***	-1.259***
	(0.207)	(0.297)	(0.359)	(0.296)	(0.321)
U.S. ind.	-0.698***	-0.284*	-0.809***	-1.480***	-1.482***
	(0.137)	(0.161)	(0.235)	(0.211)	(0.237)
Great Lakes ind.	0.514*	-0.352	-1.399***	-0.734*	-0.622
	(0.286)	(0.334)	(0.496)	(0.414)	(0.416)
Active in the same sector-loc in 1851-60		-0.526* (0.314)	-1.062*** (0.352)		
Active shipbuilding location in 1851-60		-1.296*** (0.262)	-1.259*** (0.276)		
Tons in same sector -location in 1851-60		-0.0284 (0.0955)	-0.0680 (0.0968)		
Total tons in the location in 1851-60		0.323*** (0.0591)	0.354*** (0.0617)		
Active in same sector-loc in 1871-80				0.378 (0.266)	0.269 (0.283)
Active shipbuilding location in 1871-80				-0.0245 (0.234)	0.0636 (0.251)
Tons in same sector-loc in 1871-80				0.0573 (0.131)	-0.155 (0.160)
Total tons in location in 1871-80				0.276*** (0.0857)	0.465*** (0.127)
Tons in same sector within 100km in 1871-80					0.0890** (0.0358)
Total tons within 100km in 1871-80					-0.0768** (0.0355)
Latitude			-0.00970	0.0546	0.0553
			(0.0361)	(0.0338)	(0.0354)
Longitude			-0.0462*	-0.130***	-0.128***
			(0.0279)	(0.0251)	(0.0259)
Constant	-0.334***	0.820***	-1.118	-11.54***	-11.50***
	(0.106)	(0.185)	(3.183)	(2.859)	(2.867)
Observations	890	890	881	881	881

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Consider a second example comparing U.S. and Canadian producers on the Atlantic Coast.[25] In this example, the probability that a U.S. location is active in metal ship production in 1900-10 (0.703) is very similar to the probability it is active in wood ship production (0.701). In contrast, the probability that a Canadian location is active in metal ship production in 1900-10 (0.126) is much lower than the chance that the location remains active in wood ship production (0.503).

Next, I consider an alternative regression approach which looks at the shipbuilding tonnage produced in a location in 1900-1910 conditional on it being active in a particular sector in that decade. The regression specification is,

$$\begin{aligned} Y_{ls} &= \beta_0 METAL_s + \beta_1 LAKES_l + \beta_3 US_{ls} \\ &+ \beta_4 (METAL_s \times LAKES_l) + \beta_5 (METAL_s \times US_l) + X_{js}\Gamma + \epsilon_{js} \end{aligned} \quad (2)$$

where Y_{ls} is ship tonnage of type s produced in location l and the remaining variables are defined as before. In some specifications I also consider log tons as the dependent variable. The main coefficients of interest in this regression are β_4 and β_5 which reflect the impact of being in the Great Lakes market or in the U.S., respectively, on ship output.

Table 3 presents the results of regressions based on Eq. 2. Columns 1-3 present results using tonnage as the outcome variable, while in Columns 4-6 the outcome variable is log tons.[26] In both cases, the set of observations is limited to those sector-locations that were active in 1901-10.

The results in Table 3 suggest that, conditional on a location being active in a particular sector, tonnage of metal ship production was higher in locations in the Great Lakes region and those in the U.S. The magnitudes of these effects are large; either being in the Great Lakes or in the U.S. is associated with an increase in metal ship production of 1.5-2 times,[27]

[25] Here I also assume a location that was active in wood shipbuilding in 1870 producing the average tonnage observed for locations in the data and, for simplicity, located at the mean latitude and longitude.

[26] Note that, regardless of whether I use tons or log tons as the outcome variable, the controls for tonnage in previous decades use tons rather than log tons to avoid dropping many observations where tonnage was zero.

[27] Mean production in active metal shipbuilding locations in the data in 1901-10 was 66,000 tons.

Table 3: Tonnage regression results

Dep. var.:	Tons produced in 1901-1910			Log of tons in 1901-1910		
	(1)	(2)	(3)	(4)	(5)	(6)
Great Lakes x Metal	54,501*	63,030*	41,698	1.623**	1.580**	1.555**
	(29,311)	(37,785)	(28,156)	(0.621)	(0.676)	(0.657)
U.S. x Metal	79,131***	75,625***	79,140***	2.143***	2.261***	2.014***
	(20,444)	(19,398)	(20,687)	(0.613)	(0.627)	(0.607)
Metal ind.	-16,249	-23,291	1,681	0.695	0.940	1.174*
	(13,443)	(24,996)	(15,631)	(0.505)	(0.631)	(0.599)
U.S. ind.	4,603**	-583.2	5,294	1.121***	1.025**	1.061***
	(2,207)	(7,183)	(6,886)	(0.282)	(0.401)	(0.396)
Great Lakes ind.	-1,023	3,509	6,866	-0.632*	0.122	0.236
	(639.4)	(11,070)	(9,836)	(0.347)	(0.522)	(0.460)
Active in same sector-loc. in 1851-60		-19,838			0.525	
		(39,578)			(0.515)	
Active location in 1851-60		24,172			0.132	
		(43,258)			(0.515)	
Tons in same sector-loc. in 1851-60		1,581			0.0795	
		(2,397)			(0.0860)	
Total tons in location in 1851-60		-418.2			0.0301	
		(1,987)			(0.0534)	
Active in same sector-loc. in 1871-80			28,752			0.829
			(19,937)			(0.620)
Active location in 1871-80			-36,557*			-0.0812
			(21,376)			(0.656)
Tons in same sector-loc in 1871-80			3,754			0.180*
			(3,044)			(0.0915)
Total tons in location in 1871-80			-30.52			0.0120
			(2,045)			(0.0480)
Latitude		-1,073	-979.0		-0.0238	-0.0434
		(1,432)	(1,111)		(0.0590)	(0.0595)
Longitude		261.5	868.7		0.0452	0.0382
		(1,062)	(1,000)		(0.0320)	(0.0314)
Constant	1,064***	65,041	106,253	6.259***	10.04**	10.17***
	(192.0)	(123,484)	(103,018)	(0.172)	(3.880)	(3.756)
Observations	141	141	141	141	141	141
R-squared	0.422	0.434	0.452	0.585	0.623	0.644

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

The next set of results, in Table 4, present regressions run separately for the U.S. and Canada (top panel) as well as results from regressions run separately for the Atlantic and Great Lakes regions. In the top panel, we can see that the protection offered by the Great Lakes generally appears in both the U.S. and Canada. The bottom panel shows that U.S. producers enjoyed an advantage in both regions, consistent with the impact of active U.S. protection for the shipping industry.

Table 4: Regression results by region or country

Results for the U.S. and Canada separately						
	Probit regs.		Tonnage regs.		Log tons regs.	
	Canada	U.S.	Canada	U.S.	Canada	U.S.
	(1)	(2)	(3)	(4)	(5)	(6)
Great Lakes x Metal	0.217	2.526***	1.910**	2.267**	13,214*	102,501
	(0.657)	(0.675)	(0.913)	(0.870)	(7,821)	(63,486)
Metal ind.	-1.474***	-0.571**	0.695	3.530***	579.1	79,218***
	(0.374)	(0.276)	(0.449)	(0.559)	(828.4)	(21,388)
Great Lakes ind.	-0.568	-2.035**	-0.690	-0.443	-1,341	27,402
	(0.623)	(0.867)	(0.508)	(0.746)	(1,149)	(33,175)
Observations	287	594	70	71	70	71
R-squared			0.405	0.628	0.417	0.457
Results for the Atlantic Coast and Great Lakes separately						
	Probit regs.		Tonnage regs.		Log tons regs.	
	Atlantic	Lakes	Atlantic	Lakes	Atlantic	Lakes
	(1)	(2)	(3)	(4)	(5)	(6)
U.S. x Metal	0.741**	3.002***	2.676***	3.347*	49,340***	235,095**
	(0.311)	(0.854)	(0.628)	(1.691)	(12,266)	(107,848)
Metal ind.	-1.321***	-1.101*	0.432	2.982***	12,847	-18,305
	(0.308)	(0.594)	(0.538)	(0.995)	(10,780)	(34,333)
U.S. ind.	-1.495***	-2.648***	1.170***	-1.217	1,454	-144,352
	(0.226)	(0.927)	(0.408)	(1.825)	(3,974)	(104,520)
Observations	828	53	114	27	114	27
R-squared			0.564	0.813	0.577	0.431

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. All regressions include controls for whether a location was active in 1871-1880, whether it was active in the same sector in 1871-1880, total tonnage produced in the location in 1871-1880, tonnage produced in the same location and sector in 1871-1880, latitude and longitude.

Next, I look at the timing of the effects using the full panel of data. The specification is,

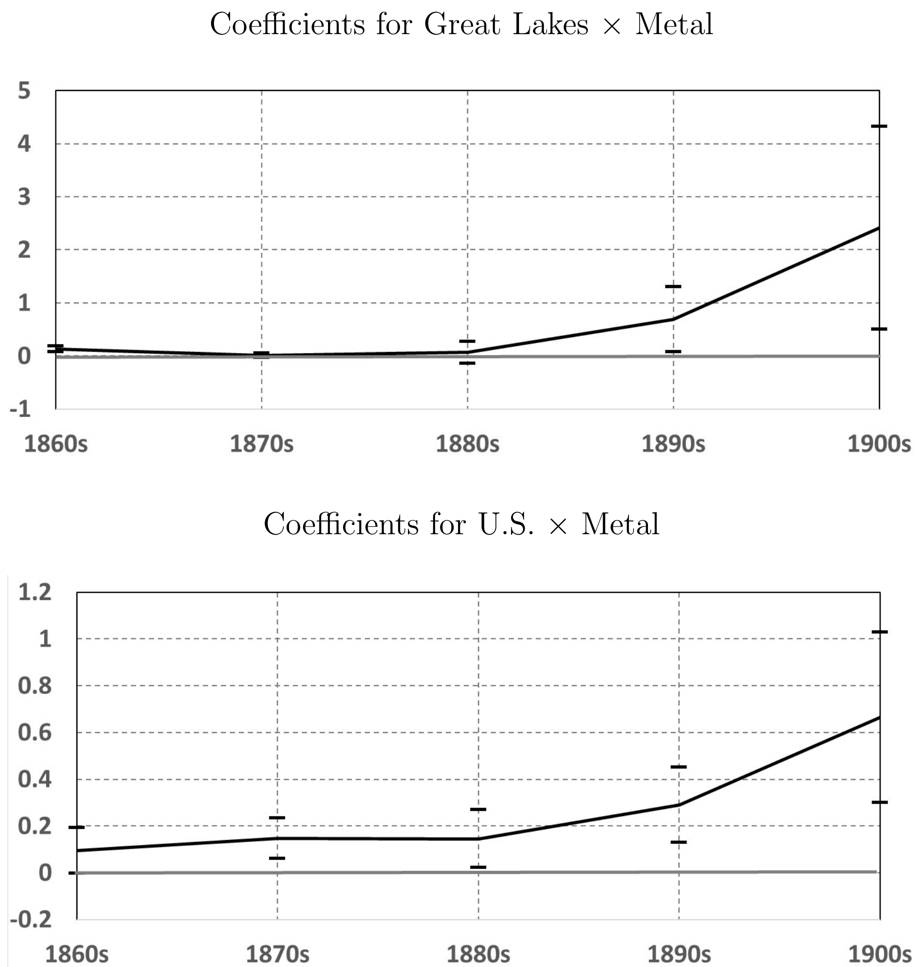
$$
\begin{aligned}
Y_{lst} &= \sum_t \beta_{0t}(METAL_s \times D_t) + \sum_t \beta_{1t}(LAKES_l \times D_t) + \sum_t \beta_{2t}(US_l \times D_t) \\
&+ \sum_t \beta_{3t}(METAL_s \times LAKES_l \times D_t) + \sum_t \beta_{4t}(METAL_s \times US_l \times D_t) \\
&+ X_{jst}\Gamma + D_t + \phi_{ls} + \epsilon_{js}
\end{aligned} \tag{3}
$$

where D_t is a set of indicator variables for each decade t and ϕ_{ls} is a set of fixed effects for each sector-location. These regressions allow me to look at the impact of being in the Great Lake or in the U.S. on iron ship output while controlling for changes in output over time as well as differences in regional production patterns over time. Because we may be concerned about serial correlation in these regressions, standard errors are clustered by sector-location.

The coefficients of interest in Eq. 3 are the vectors β_{3t} and β_{4t}, which reflect the impact of being in the Great Lakes or being in the U.S. in each decade. These parameter estimates, together with their 95% confidence intervals, are described in Figure 7. The top panel shows the coefficients estimated for each decade on the interaction between the metal shipbuilding sector and the Great Lakes. These results suggest that being located in the great lakes had little impact on metal shipbuilding output until the 1890s. This timing corresponds with the fall in U.S. iron prices. In the bottom panel, we see that the U.S. always had an advantage in metal ship production relative to Canada. This makes sense given that U.S. producers enjoyed a protected market throughout the study period. The advantage of U.S. locations increased in the 1890s, corresponding with the fall in U.S. iron prices and the expansion of the U.S. Navy.

The results presented so far suggest that shipbuilding locations that were protected from foreign competition, either because of geographic factors or the availability of government support, were more likely to successfully transition to producing metal ships. Next, I did deeper into the role of government support by looking at the influence of proximity to U.S. Navy Shipyards on the success of private producers. Importantly, the location of the U.S government shipyards was determined by the early 19th century, long before the introduction of iron ships. We would not expect these locations to have been affected by a location's later potential for metal ship production relative to wood shipbuilding. Thus, the location of these government yards provides a plausibly exogenous source of spatial variation in U.S. government support for private shipbuilders.

Figure 7: Panel data regression results



Results looking at the impact of proximity to U.S. Navy shipyards are presented in Table 5. These regressions are run only on U.S. Atlantic Coast shipbuilders. Columns 1-2 present results from Probit regressions. The results in Column 1 show that a location was much more likely to be active in metal ship production if it had a Navy shipyard within 25km. There is also some evidence that locations near Navy shipyards were less likely to be active in wood ship production. Column 2 looks for additional effects for locations within 100km. There appears to be little additional effect of Navy

Table 5: Results looking at the impact of proximity to U.S. Navy Shipyards

	(1)	(2)	(3)	(4)	(5)	(6)
Navy yard within 25km x Metal	2.115***	2.053***	0.967	-0.306	44,684*	27,151
	(0.726)	(0.778)	(0.736)	(1.110)	(26,304)	(43,360)
Navy yard within 25km	-0.968*	-0.711	0.0207	0.584	-6,562	-3,014
	(0.579)	(0.596)	(0.352)	(0.486)	(6,848)	(5,716)
Navy yard within 100km x Metal		0.153		2.148*		30,683
		(0.444)		(1.144)		(41,547)
Navy yard within 100km		-0.450**		-0.893*		-6,211**
		(0.225)		(0.478)		(2,886)
Additional controls	Yes	Yes	Yes	Yes	Yes	Yes
Observations	565	565	58	58	58	58
R-squared			0.577	0.618	0.633	0.648

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. All regressions include controls for whether a location was active in 1871-1880, whether it was active in the same sector in 1871-1880, total tonnage produced in the location in 1871-1880, tonnage produced in the same location and sector in 1871-1880, latitude and longitude.

shipyards at this distance, suggesting that their influence falls off rapidly.[28] Columns 3-4 present results looking at log tonnage, while Columns 5-6 present results looking at tonnage as the outcome. These regressions, which are based on just 58 observations, do not offer strong results, though there is some evidence that metal ship tonnage was higher near Navy shipyards while wood ship tonnage was lower.

Overall, the results above show that protection from foreign competition had an important influence on whether shipbuilding locations made the transition from wood to iron production. Whether this transition was made determined the ultimate success of the industry in each location as wood shipbuilding disappeared in the early 20th century. In terms of magnitudes, the regressions above suggest that the advantages of being in the U.S. were nearly as large as the benefits of being in the isolated Great Lakes market in terms of shipbuilder's ability to transition to metal ship production. The effects of U.S. industrial policy also influenced the distribution of iron ship production within the country, which concentrated near U.S. Navy Shipyards.

[28]Similar results appear when I look at proximity with a 50km cutoff.

5 Channels

What forces caused Britain's early advantage in iron ship construction relative to North American producers to persist well after the initial cost advantages disappeared, and ultimately to retard the ability of North American producers to shift to iron ship production? The existing literature suggests a number of potential answers to this question. These include productivity advantages gained through learning-by-doing, as in Krugman (1987) and Young (1991) or through R&D, as Grossman & Helpman (1991).[29] Initial advantages could also generate persistence through achieving internal economies of scale. Another potential mechanism emphasizes the importance of workers, and in particular, the development of workers skills ((Lucas, 1988, 1993), Stokey (1991)). In this section, I conduct a careful review of available evidence describing the operation of the shipbuilding industry during this period with the aim of differentiating between these alternative explanations.

One of the most notable features of the international shipbuilding industry was the high level of competition that existed throughout the study period, particularly outside of the small number of firms that produced the largest luxury ocean liners or warships.[30] Hutchins (1948), for example, describes shipbuilding as "naturally one of the most highly competitive of all markets..."[31] Consistent with these reports, the HHI calculated from the data used in this study, for the U.K. only (where I have better data on individual firms), ranges from 173-348 for the years from 1880-1912, indicating a very low level of industry concentration. Since most of the largest firms in the world were in the U.K., concentration levels across all world producers are likely to have been even lower. One reason for this diffuse market structure was the fact that geographic features placed limitations on the size of individual shipyards. This feature suggest that internal economies of scale was not an important mechanism in generating persistence in this setting.

One consequence of the highly competitive nature of the industry was that shipbuilders had few resources to put into research and development efforts. As a conse-

[29]Directed technical change models, such as the one described in Acemoglu *et al.* (2012) could also generate this type of persistence.

[30]It is important to distinguish shipbuilding from the shipping industry, where combinations between the major lines substantially reduced competition.

[31]Pollard & Robertson (1979) states that, "the industry was highly competitive in this tramp cargo class, which constituted the majority of its output..."

quence, Pollard & Robertson (1979) write that (p. 148),

> *Many improvements, if not most, however, were developed outside of the industry, in the steel-making, electrical products, or engineering industries...it was only necessary for the shipbuilders to adopt innovations after the basic research had been done elsewhere. Few laboratories were established in the yards, and as the reluctance to use experimental tanks [to test ship designs] demonstrates, builders were not even very interested in investing funds to solve problems peculiar to their industry.*

This statement was made with regard to British shipbuilders, but is likely to have been even more true for more marginal U.S. and Canadian producers. Thus, it does not seem likely that advantages related to R&D were behind the persistent effects that I observe.

Another feature of the industry was that output was largely driven by demand factors, which were highly volatile over time.[32] As a result, shipbuilders largely took prices as given and sought to produce ships at the lowest possible cost. The primary strategy that shipyards used to cope with volatile demand was to limit, as much as possible, capital expenditures. As Pollard & Robertson (1979) (p. 28-29) describe,

> *The principal task of the shipbuilders was to minimize total overhead expenses while maintaining the ability to build large and complex ships at prices that were competitive on the world market...The experience of German and especially American shipbuilders had demonstrated the dangers of heavy capital expenditures...In the United States, vast overheads crippled builders in all but the best years. British yard owners were able to take advantage of their more highly skilled workforces by investing only in equipment that was absolutely necessary to manipulate the large, heavy, and hard components of modern ships, and by refusing to purchase as many labor-saving machines as German and American builders did.*

[32] Pollard & Robertson (1979) explain that, "freight rates were based on the demand for shipping services relative to the existing pool of tonnage. As new tonnage was only a small portion of the total amount available, freight rates affected shipbuilding output much more strongly than the converse, although new tonnage did help to drive down rates at the peak of the cycle of freights."

This quote emphasizes the central role played by skilled workers in the shipbuilding industry during this period. It also highlights an important fact; evidence suggests that American producers were actually equipped with more advanced technology than their British competitors. For example, American yards were more likely to adopt more efficient electric and hydraulic riveters, while British yards continued to use cumbersome pneumatic tools. The fact that American yards were using more advanced construction technologies provides further evidence that innovation was not behind the persistence of British dominance. Despite using more advanced technology, evidence suggests that the cost of producing most merchant ship types in U.S. yards was much higher than in Britain.[33] In the end, "expensive equipment could not compensate for the lower level of skills..."[34]

Additional evidence also suggests that the dearth of skilled shipbuilders in the U.S., and the consequent higher wages, was the primary factor in generating the higher cost in U.S. yards. For example, the *Report of the Merchant Marine Commission*, ordered by Congress and published in 1905, argues that (p. X), in explaining the relative weakness of the U.S. shipbuilding industry, "The real dominant factor is thus not the price of materials, but the high wages of the skilled American workmen who fashion the plates and beams into the finished ship."[35] That report goes on to offer the following example:

[33]Hutchins (1948), for example, suggests that (p. 47), "British costs were from 30 to 40 percent less." The *Report of the Merchant Marine Commission* found that in 1905 the difference was 30 to 50 percent (p. viii).

[34]Pollard & Robertson (1979) p. 47.

[35]This report was requested by the President and prepared by a commission consisting of five Senators and five Representatives. Their findings were based on a large number of public hearings which took place in cities throughout the U.S.

> *Convincing proof on this point was offered in 1900, when steel plates and beams, because of labor troubles abroad, were selling at \$40.86 in England, and \$28 in the United States. Boston shipowners at that time invited bids from an American and a British builder for a cargo steamship of about 5,000 tons capacity. With both yards figuring for a small competitive profit, the American estimate was \$275,000 and the English \$214,000. The material of the American ship would have cost \$63,000; of the English ship, \$80,000. But this difference was more than offset by the higher wages paid to the American shipyard mechanics. However, the narrowing of the difference of shipyard labor cost that will come with increased experience, improved standardizing and constant production, as it has come already in the bridge and locomotive works, makes the reduced cost of materials a factor of undeniable importance.*

The last sentence in this quote is notable, because it suggests that the higher wage rates in iron and steel shipbuilding were not found in other similar engineering industries. Further evidence on this point comes from Hutchins (1948), which describes how wages in iron shipbuilding differed from those in wood shipbuilding:

> *The inability of the American yards to compete with those of Great Britain and the Continent during the late 'sixties and 'seventies was a cause of considerable surprise and disappointment...Probably the primary difficulty was the be found in the high cost of labor. While there was substantial variation in the wage rates among both American and British yards, British wages [in iron shipbuilding] were in general from 40 to 50 per cent under those in the United States. This difference was considerably more than that prevailing in wooden shipbuilding, which was, of course, nearly extinct in Britain.*

Later, writing about the decade after 1900, Hutchins writes, "in 1900 wage costs in American yards were from 50 to 100 per cent above those of Great Britain...In general, American shipyard work which could be effectively mechanized cost no more than that in Britain, but handicraft work, of which there was a large amount, was much more expensive." Importantly, as Pollard & Robertson (1979) note, the wage differential was due in large part to differences in worker productivity. They suggest (p. 47) that, "Piece rates [in the U.S.] were on a par with the British, but time rates were 50 percent higher, so the U.S. wage bill exceeded the British by 25-33 percent."

One factor that contributed to the importance of skilled workers in this industry was that most ships were bespoke products.[36] This lack of standardization limited the ability of most builders to improve productivity through focusing on standardized products.[37] One consequence of the constant variation in the types of ships produced at most yards was the increased importance of skilled workers who could flexibly adapt to each new ship type.[38]

In summary, the evidence suggests that the availability of pools of high skilled labor, generated through decades of shipbuilding experience, played the critical role in the persistence of British dominance in the industry. This conclusion is summed up by Pollard & Robertson (1979), who write (p. 129),

> *Clearly shipbuilding before 1914 is an example of an instance of an industry in which, on balance, the nation with a head start had an advantage. While foreign [non-U.K.] builders were able to choose better sites and design more efficient yards and shops, they were unable to overcome completely the greater efficiency of British labor, an efficiency that in part derived from Britain's longer tradition as a producer of iron and steel steamships.*

Finally, in focusing on the role of skilled workers, it is worth highlighting the distinction between the large number of skilled or semi-skilled craftsmen who did most of the work in shipyards from the small number of elite workers, such as naval architects, marine engineers, or shipyard designers, who often had more formal training. Evidence suggests that it was the large pool of craft workers, rather than the small set of elite workers, that was critical for the persistence of locational advantages.

[36] Pollard & Robertson (1979) write that (p. 106), "...most shipowners wanted their vessels to be designed to custom specification and approach builders directly to obtain exactly what was needed."

[37] Standardization would play an important role in the industry later, during the World Wars and beyond. One example of the importance of specialization in the later period is the Liberty Ship program.

[38] Pollard & Robertson (1979) write (p. 152) that, "...the fact that [the shipbuilding industry] produced for the most part a large, custom-made commodity that was not susceptible to many of the techniques of mass production, ensured that a premium continued to be placed upon skilled labor."

This difference in numbers matters; while firms could hire small numbers of very high-skilled workers from other locations, or send a few workers for training abroad, inducing large numbers of craft workers to move was prohibitively expensive.[39] In addition, because skills were gained through experience, skilled workers were older and often had families, which made moving them even more difficult. Thus, skilled labor pools amounted to a largely immobile production input. In contrast, other production inputs, including capital, technology, and very high-skilled workers, were much more mobile.

In addition to explaining Britain's persistent advantage in metal shipbuilding, a mechanism based on the importance of skilled craft workers can also help explain the survival of wood shipbuilding for many decades after the development of more advanced iron ships. One of the conclusions of Harley (1973) was that immobile skilled wood shipbuilders, particularly in Maine and the Maritime Provinces of Canada, played an important role in the persistence of wood shipbuilding.[40]

6 Conclusions

The experience of the international shipbuilding industry documented in this study offers a window into the evolution of comparative advantage over time. Taking advantage of uniquely detailed data and several dimensions of exogenous variation, this study produces three main results. First, initial input price advantages can have a long-run impact on the spatial distribution of production and trade patterns when firms are exposed to competition from more efficient foreign producers. Second, government protection or support can offset these initial advantages. Third, the development of pools of skilled workers through on-the-job experience appears to be an important mechanism through which initial advantages can persist, at least in some industries.

[39] For example, Pollard & Robertson (1979) describe how young naval architects from the U.S. were sent to study in Glasgow and Greenwich (p. 41) and how "most warship designs were still obtained from London," while "Encouraged by the needs of the navy, the Bethlehem Steel Company acquired forging equipment from Whitworth's [of Newcastle-upon-Tyne] and armor plate equipment from Schneider-Creuzot [of France]." However, "Because of the lack of skilled labor in an industry founded overnight...expensive equipment was the rule in the American shipyards of 1894-1901."

[40] Consistent with this view, Hall (1882) provides evidence that shipbuilding wages in Maine, where the vast majority of ships were made of wood, declined substantially between 1869 and 1880.

One implication of these results is that there may be opportunities for countries to gain long-term advantages through the use industrial policy or tariff protection. In particular, my results suggest that industrial policy may be effective when used in industries that are at an early stage of development and where large pools of skilled workers are important. Policies aimed a worker training may be particularly effective. Of course, any dynamic advantages generated through industrial policy or tariff protection must be assessed against the costs that these policies impose, which are not observed in this study. Generating further evidence on the relative costs and benefits of such intervention is likely to be a valuable direction for future research.

My results also have implications for how access to cheaper inputs due to trade liberalization will impact local economic activity. In the setting I consider, access to cheaper iron and steel inputs had a more substantial effect on North American producers in the protected Great Lakes market relative to Atlantic producers, who were exposed to competition from more established foreign competitors. This suggest that the impact of access to cheaper inputs is likely to depend on the level of competition in output markets, which in turn may be influenced by the level of development of the industry abroad.

Finally, my findings can inform our understanding of the relationship between resource abundance and economic growth. There is now an extensive literature suggesting that natural resource abundance may be harmful for economic growth (see, e.g., Sachs & Warner (2001)). Others, such as Irwin (2003), argue that the impact of resources depends on their tradeability, which influences whether resources will attract local manufacturing. This study offers a more nuanced view. In the case of international shipbuilding in the 19th century, it was important to have both the right resources – rich coal and iron deposits – and to exploit them first, in order to gain an initial competitive advantage.

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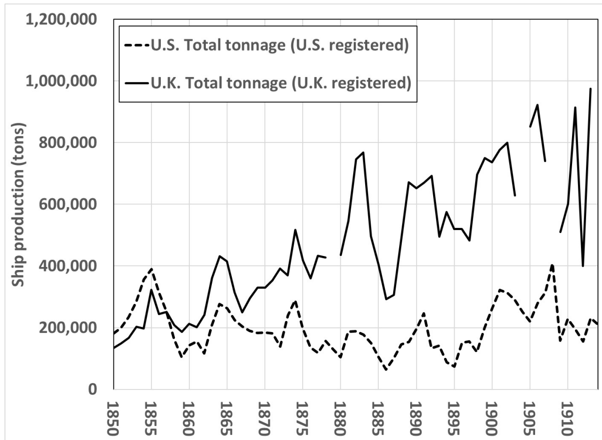
A Appendix

Figures 8 and 9 present aggregate data series on shipbuilding output in the U.S. and U.K. We can compare the patterns observed in these series to those in the main text, which come from the Registers, though its worth noting that the actual tonnage values are not strictly comparable. One reason for this is that the values shown in these figures are based on ships that were built and registered (with the government, not Lloyd's or ABS) in the same country, which will miss ships sold to foreign shipping firms. Also, the U.S. data have to be converted from gross to net tons.

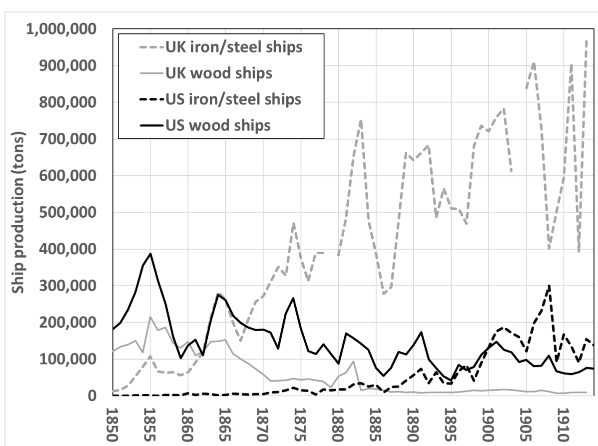
In general the patterns shown in Figure 8 look similar to those in Figure 3 in the main text. For example, both data series show total tonnage in the U.K. surpassing output in the U.S in 1857. Other patterns, such as the depression in 1886-87 and the spike in output in 1906-07 also look fairly similar. There are also many similarities between the patterns observed in Figure 4 in the main text and those shown in Figure 9. For example, both series show that U.K. metal ship output exceeded wood ship output around 1861-82. However, the series in Figure 9 do suggest that U.S. metal ship output grew more slowly relative to wood ship output than I observe in the data used in the main text in the 1890s. One explanation for this may be that some U.S. metal ships were being sold abroad. Another explanation is that wood ships may have been taken out of service relatively sooner, which would cause them to not appear in the 1912 Registers.

Figure 8: Merchant shipbuilding tonnage produced in the U.S. and U.K., 1850-1913



Notes: Data for U.K. shipbuilding registered in the U.K. are from Mitchell & Deane (1962). All U.K. data were reported in net tons. Data for the U.S. come from Hutchins (1948) and are reported in gross tons. These have been converted to net ton using a ratio of 1.5 gross tons to net ton which is derived by comparing U.K. output in gross tons and net tons using data from 1878-1911.

Figure 9: Merchant shipbuilding tonnage in the U.S. and U.K. by type, 1850-1913



Notes: Data for U.K. are from Mitchell & Deane (1962) and include only ships first registered in the U.K. These data are reported in net tons. Data for the U.S. come from Hutchins (1948) and are reported in gross tons. These have been converted to net ton using a ratio of 1.5 gross tons to net ton which is derived by comparing U.K. output in gross tons and net tons using data from 1878-1911. Composite ships are included with wood.