Technical Change and the Wage Structure During the Second Industrial Revolution: Evidence from the Merchant Marine*

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Abstract

Using a large, individual-level wage data set, we examine the impact of a major technological innovation—the development of powerful and economical steam engines—on skill demand and the wage structure among the merchant marine during the turn of the century, 1892-1912. The new technology created demand for highly skilled workers, the engineers, in charge of maintaining the engines. On the other hand, technological innovation may have been deskilling for production work since experienced able-bodied seamen were replaced by laborers in the engine room. We find a substantial wage premium on steam vessels, even controlling for rank and occupation. The steam premium reflected a compensating differential in some occupations but it may have also reflected the sorting of better workers to steam. We also document the wage structure over a longer time period, 1865-1905, using wage observations in sailing vessels. Similar to previous studies which have examined other industries, we find that the skill premium (measured as the ratio of wages at the 90th and the 10th percentiles) did not change dramatically over this period. We do find, however, that wages fell in occupations, such as sail makers and able-bodied seamen, which utilized skills that were not readily portable across technologies.

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I. Introduction

Between 1939 and 1960, the returns to high school education exhibited a rising trend despite an enormous increase in relative supply (Welch, 1970). Since World War II, the returns to college education have similarly risen despite an increase in supply (Acemoglu, 2002, Figure 1). The only sustained deviation from this latter trend, during the 1970s, is associated with a period of moribund technological advance and an unusually rapid increase in the supply of college graduates. Residual inequality, after controlling for observable characteristics including education, has also shown a notable rise during much of the postwar period (Juhn, Murphy and Pierce, 1993). As a consequence, wage and income inequality in the United States is today greater than it has been at any time since 1939 (Goldin and Katz, 1999).

It is widely accepted that skill-biased technical change underlies this evolution of the wage structure. Skilled and educated workers may be better at using (Griliches, 1969; Jovanovic, 1998; Caselli, 1999) or learning (Nelson and Phelps, 1966; Greenwood and Yorukoglu, 1997; Rubenstein and Tsiddon, 1999; Galor and Moav, 2000) new technologies, so in periods of rapid technological change the demand for skill can outstrip even a rising supply. At the same time, a rising supply of skilled workers may induce technical change biased to such an extent that the skill premium rises (Acemoglu 1998, 2002).

Although wage inequality declined in the decades preceding World War II, technological change still appears to have been skill-biased. Goldin and Katz (1998) associate inter-industry variations in wages and employment of educated workers between 1909 and 1929 with the use of continuous-process and batch methods of manufacturing, and the adoption of electric motors. They conclude that wage inequality was prevented from rising only by the massive increase in education brought about by the high-school movement after 1910.

In contrast, there is now something of a consensus that technological change in the 19th century was deskilling (e.g., Braverman, 1974; Marglin, 1974). However, our understanding of this period is marred by inadequate data and ambiguous evidence. James and Skinner's (1985) evidence on the substitution of capital for skilled and unskilled labor at mid-century suggests that technological change was deskilling. On the other hand, Meyer's (2002) evidence on earnings inequality from 1865–1880 is consistent with skill-biased technological change. It is consequently no surprise that we are also not yet in a position to assess whether changes in the wage structure can be explained by a microeconomic Kuznets effect, whereby transitory increases in wage inequality arise because at any point in time only a fraction of firms have adopted the new technology (Rogers, 1995). Similarly, we do not know the extent to which new demand for skills in scarce supply or declining demand for skills in abundant supply may have shaped the wage structure.[1]

In this study we attempt to shed new light on how technological innovation affects skill demand and subsequently the wage structure. The specific technological innovation we examine is the development of powerful, economical steam engines. Steam power fundamentally changed the economy, especially in transportation and manufacturing, and we focus on its adoption in the maritime industry. Using a unique dataset on merchant mariners, we examine how the composition of jobs and skills differs across sail and steam-powered vessels. Our data consist of individual wage data for a large sample of workers serving on vessels registered in the Atlantic provinces of Canada from 1865 to 1912, a period spanning the wholesale substitution of steam for sail. The wage data are not only numerous, but also high quality – they are derived from crew lists which served contemporaneously as binding employment contracts.[3] In addition to providing precise wage data, the crew lists also record each individual's age, nationality, literacy, and job classification, as well as descriptions of the voyage undertaken. Furthermore, the individuals' data are linked to vessel registry records containing key technological details of the ships, including its age, size, and form of propulsion. In sum, our data is the earliest example of

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[1] The reorganization of the factory associated with the development of interchangeable parts in numerous industries during the latter half of the nineteenth century facilitated the substitution of unskilled factory workers for skilled artisans (Hounshell, 1984; Mokyr, 1990), but at the same time it created a new demand for, *inter alia*, engineers, managers and clerks (Goldin and Katz, 1998).

[3] Most notably, a failure on the part of the employee to fulfill the terms of his contract was a *criminal* offense. The crew list also protected the employee by laying out the responsibilities of the employer. However, most failures by the employer to meet his obligations constituted a civil offense.

matched employer-employee data that we are aware of, containing detailed characteristics of both the worker and the firm.

The data here have several clear advantages over those previously used to examine the effect of technological innovation on skill demand. First, most of the recent studies linking computer-related technology to skill demand have utilized inter-industry variation and have used investment in computers to proxy for technical change (Berman, Bound and Griliches, 1994; Autor, Katz, and Krueger, 1998). Even studies that have used more detailed plant-level data rely on indirect measures of technical change such as the adoption of various factory automation technologies (Doms, Dunne, and Troske, 1997). In contrast, our data allows a precise and unambiguous link between the worker, the firm, and the old and new technology—steam vs. sail. What constitutes a “firm” in our data also leaves less concern about endogenous adoption—the idea that the better firms hire more skilled workers and are also the first to adopt more advanced technologies. The “firm” in our data is not an on-going concern but is the vessel on a particular voyage. The “firm” changes with the hiring of the crew and it is clear that the technology dictates the skill composition of the crew rather than the reverse.[4]

To preview the results, we find that the wage bill share of able-bodied seamen and ordinary seamen (production workers) was 65% on sail-powered ships while it was less than 20% on steam-powered ships. On the other hand, steam power created new occupations—the skilled engineers and other engine room workers-- who accounted for over 50% of the wage bill share. Was new technology skill-biased or deskilling? Our results show that the answer lies close to Goldin and Katz’s (1998) description of the movement from skilled artisans to the factory during the earlier part of the 19th century. While technology replaced skilled production workers with less skilled production workers on the one hand, it also created the need for a new class of skilled workers who were responsible for the maintenance of the machines. We find that differences in skill and job compositions explain most of the substantially higher wage inequality found on steam-powered vessels. However, we also find substantial within-occupation steam premium.

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[4] This still leaves open the question of endogenous adoption of steam technology at a more aggregate level which may be related to the available skill supply (Acemoglu, 1998). We describe the slow adoption of the new technology in the next section.

Most strikingly, able-bodied seamen serving on steam ships earn 17 percent more than their counterparts on sailing ships, even after controlling for a variety of individual, voyage, and ship-level characteristics. While fewer able-bodied seamen are hired, those that are hired were paid more. The fact that ordinary seamen – less experienced crew members who nevertheless shared essentially the same responsibilities and working conditions as able-bodied seamen – did not earn a premium on steam provides some evidence that the premium was not a compensating differential related to vessel or voyage characteristics. It may be true, however, that since fewer able-bodied seamen were hired on steam, each individual had a larger set of tasks and those that were hired had to be higher average ability.

The second half of our paper attempts to shed light on the evolution of the skill premium during the latter half of the 19th century and the turn of the 20th century-- between 1865 and 1905. Of course, our findings are for one particularly industry but we think the unusual detail and quality of our wage data make exploration worthwhile. To study the skill premium over this longer period, we restrict our analysis to sail since the number of steam observations is sparse in the earlier part of our data. We find that skilled workers earned about twice as much as unskilled workers. Wage inequality among workers on sailing vessels shows no particular trend over the sample period, suggesting that the crude wage structure there was largely unaffected by the gradual switch to a new technology. However, we find distinct wage patterns across occupations which were differentially impacted by the diffusion of steam. Sail makers, whose skill was clearly being made obsolete by the new technology, experienced the sharpest declines in average wages. Wages of able-bodied seamen also declined. However, wages of cooks and stewards whose skills were readily portable to the new technology were relatively unaffected.

II. Background

Thomas Newcomen invented the first steam engine to see commercial success in 1712, but its mass and inefficiency restricted its use to pumping water out of mines. Thomas Watt's improved design, first patented in 1769 and soon after made commercially available through Watt's enormously successful partnership with Matthew Boulton, made the steam engine sufficiently compact and fuel efficient to open the door to steam transportation. A boat employing many features of the Watt and Boulton design operated the world's first steam passenger service, between Philadelphia and Trenton, in the summer of 1790 (Thurston, 1878, ch.5). Robert Fulton's well-known *Clermont*, which plied the Hudson from 1807, in fact used an engine manufactured in Watt and Boulton's Soho factory. The first steam-powered vessel to operate in Canadian waters was launched in 1809 (Lewis, 1997). Steam transportation on inland waterways in North America became commonplace by 1830, and dominated the rivers by the time our sample data begins in the 1860s (Hunter, 1949). By 1890, more steam than sailing merchant vessels were registered on the US Great Lakes (Smith and Brown, 1948).

Steam was adopted more slowly on the oceans. Early engines consumed too much fuel for long voyages and could not compete with sail. The first steam-powered vessel to cross the Atlantic, the SS *Savannah*, did so in 1818, but steam was just an auxiliary source of power and the vessel spent 26 of its 29 days at sea under sail (see Figure 1). Three British companies had vessels cross the Atlantic entirely under the power of steam in 1838. But fuel consumption remained a problem. One vessel arrived in port only after burning its cabin furniture, a spare mast and half its decking; none of the three companies were successful financially.[5] Nonetheless, Britain led the way in developing a transoceanic steam fleet, aided by the early adoption of steam by the Royal Navy (in 1820), government subsidies granted under the guise of mail contracts (from 1830), and the establishment of an extensive network of military coal depots throughout the empire (from 1840).

The switch to steam power for international trade was slower yet in North America, particularly so in the fleets of the Atlantic provinces of Canada. By 1890, for example, 63 percent of Britain's registered merchant tonnage was steam-powered, and 42 percent of the United States fleet was steam (Smith and Brown, 1948); in Atlantic Canada, the corresponding figure was only 25 percent.[6] Despite the later start, steam inevitably came to dominate the Canadian fleet. The

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[5] Two companies abandoned the Atlantic in 1840. The third company, the owner of the famous *Great Western*, closed down in 1846.

[6] Why the Canadian fleet was so late to convert to steam is not well understood. The fact that in 1890 two-thirds of the tonnage clearing Canadian ports was steam suggests that the delay was not a product of the business opportunities available to it. Sager and Panting (1990) conclude that investment in steam vessels

following Figure 2 shows the spread of steam-powered vessels in Atlantic Canada in the late nineteenth century and beginning of the twentieth century.[7] As elsewhere, the adoption of steam technology in ocean-going vessels began later than in the coastal service, but it then took place at an accelerated pace. Within a twenty year span, steam-powered vessels had taken over transoceanic transport: they accounted for only 10% of all ocean-going vessels in 1890, but 70% by 1910. Sail technology had become obsolete for transoceanic transport, and existing sailing vessels were being phased out.

Potential Impacts on the Wage Structure

Although both sail and steam vessels provided international shipping services, the technology of production was different and it is an open question whether this difference impacted skill demand and the wage structure. Technical change destroyed some occupations and created others. Even for occupations common to both old and new technologies, technical change altered the job content.

One occupation made obsolete by steam was the sail maker. A sail vessel typically had an extra set of sails that had been made ashore in case the installed sails got worn by normal wear or inclement weather. For added insurance that there would be working sails, a sail maker might be hired for voyages. This worker was usually an older seaman with sufficient skills to mend sails and perhaps make sails in an emergency. With the advent of steam, harnessing wind energy was no longer critical in the timely completion of a voyage. Although some steam vessels still had sails to take advantage of wind energy, they did not hire sail makers since they could get repairs and replacements when they reached a port. Switching from sail to steam involved the destruction of this occupation.

A variety of jobs were created by steam, and they revolved around the engine. The skilled workers were the engineers, who “were required to tend the machinery, ensure that it was operating properly, undertake repairs, start, stop and reverse the engines when arriving or leaving

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in Atlantic Canada was profitable, and that cultural factors induced many shipowners to direct new investment to land-based opportunities.

[7] The data on which the graph is based are described in the next section.

port, and supervise the firing of the boilers" (Griffiths, 1997, p.132). Pursuant to an 1862 amendment to the Merchant Shipping Act, seagoing engineers were required to obtain a certificate of competency (an examination and sufficient training were required), and all steam-powered vessels had to have certified engineers aboard. The production workers in the engine room were firemen, trimmers, donkey men, and oilers and greasers, who provided mostly manual labor under the management of the engineers. Both the skilled (engineers) and unskilled (engine room operatives) spent their work time in the engine room, isolated from the rest of the crew; "[k]eeping a steamer's boiler fired was hard, hot and dirty work and keeping the boilers and engines in an efficient operating state was equally demanding. Work was hot and often dangerous, many engineers suffering injury through coming into contact with operating machinery or being scalded while repairing some part of the steam plant" (Griffiths, 1997, p. 133).

Many of the occupations on sailing vessels carried over to steam as well. The master was the person in charge of the voyage, assisted by one or more mates. The mates transmitted the master's orders to the seamen, commanded a share of the seven round-the-clock watches each day, had responsibility for the cargo, kept the log-book detailing the journey, and made navigational measurements. The mates were capable of performing the physical tasks any able-bodied seamen was, although they rarely had to do them. The majority of the masters and mates had attained their high status only after passing examinations administered by the government. The mariners – in order of experience, they were the able-bodied seamen, ordinary seamen and boys/apprentices – were the most numerous production workers on vessels. They were expected to undertake a wide variety of tasks under the direction of the mates. [8]

Even among ranks that survived the transition from sail to steam, the nature of the skills involved changed markedly. On sailing vessels, as one mariner recalled, "three quarters of [one's] waking time is devoted to fondling rope"[9] and there were many ropes to learn (see Figure 3). Locating and handling the rigging was a skill arduously learned before promotion from ordinary

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[8] The sample records over 60 distinct job titles that are not discussed here. Most of them were absent from a typical voyage.

[9] Quoted in Sager (1989, p. 133).

to able-bodied seaman, and made mostly obsolescent by steam. Steam demanded a different set of skills. The mariner on a steam ship "had become a tender of new types of machinery, and ship-owners were prepared to pay a premium to hire experienced and reliable men" (Sager, 1989, p. 261). Yet a further challenge to the production workers on steamships was a change in workplace composition. Not counting the engine room, the number of mariners on a steamship was typically less than half the number on a sailing vessel of similar size, possibly increasing the range of responsibilities and tasks performed above deck..

Technical change can be expected to change the wage structure in the maritime industry, as it changed the skill mix demanded of workers. The creation and destruction of jobs alone would alter it, since engineers were extremely well-paid, reflecting their scarcity and excellent job opportunities ashore. But in addition, changes in crew composition, and an apparent shift in demand away from narrow job-specific skills to a broader need for quality, may be expected to alter the wage structure in occupations that survived the transition from sail to steam. The extent to which these changes altered the wage structure is an empirical question, and we will pursue them after describing the data.

III. Data

We use data on vessels and crew members compiled by the Atlantic Canada Shipping Project at Memorial University at Newfoundland in the late 1970's and published in electronic form by the Maritime History Archive in 1998. These data have been studied extensively by maritime historians (e.g. Sager, 1989, 1993; Sager and Panting, 1990), but they have yet to be brought to the attention of labor economists and analysis has so far been restricted to tabulations of sample means.[10]

Information on vessels, including their type, dimensions and age, are in the vessel registry database. This database covers the universe of vessels listed in the shipping registries of ten major Atlantic Canadian ports from 1787 to 1936.[11] For a subset of the vessels, researchers also

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[10] One exception is Thompson (2003), who used the data to test theories of technology diffusion.

[11] Ship owners of the British Empire were required by law to register their vessels with the customs officer in their home port, and so the database should accurately reflect ships with home ports in Atlantic Canada.

compiled information from crew agreements. A crew agreement contains information on each crew member's name, date of birth,[12] place of birth, wages, rank, place of joining and leaving the vessel and so forth. Researchers recorded individual-level data from the crew agreements for about 30% of the vessels registered in four ports (Saint John, New Brunswick, Yarmouth and Halifax). For all the vessels registered in these four ports, they recorded data on the voyages taken, including intended destination, intended duration and start date.

We define a vessel's technology based on the "type of vessel" variable. Researchers placed each vessel into one of seventeen categories: steamer; steam/sail; steam/paddle; schooner; brig; brigantine; barque; barquentine; ship; sloop; ketch; cutter; shallop; snow; other; fuel only (oil, gas or kerosene without sails); and fuel with sails. We classify members of the first three categories as steam-powered vessels. The steam/sail category reflects vessels that have steam propulsion, but also use wind as an auxiliary power source. We classify the following five categories as ocean-going vessels: steam/sail; barquentine; barque; brig; and ship.

We matched the individual-level data from the crew agreements to the vessel-level data (using the official vessel number available in both databases); this enables us to identify the technology on which each worker worked. A vessel makes multiple voyages over its lifetime, and we matched the individual-level data to voyage-level data as well in order to control for certain voyage characteristics; the voyage is probably the unit most comparable to a firm. We restrict the sample to international voyages; the domestic coastal trade may have faced different labor market constraints.[13] We have therefore eliminated individuals on voyages with Canada as both the country of embarkation and country of intended destination, or on voyages less than six months in intended duration, or on small vessels not intended for ocean-going trade. Furthermore, to make

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[12] Although no data are available to confirm it, we think that age serves as a good proxy for marine experience. Sager (1993, p. 37) points out that "Most went to sea when they were young. This was true of workers in Canadian sailing ships in the nineteenth century, and it was true in the twentieth century as well. It was rare for an older person, with a good job on land, to join the company of seafarers, unless wartime service required it."

[13] Some of the domestic voyages pertained to the fishing and whaling industries, not the shipping one. Also, employer-employee relationships on domestic voyages were generally more personal than on international voyages (Sager, 1989).

the measured wages more comparable, we only include workers paid on a monthly basis in British sterling, U.S. dollars or Canadian dollars. In practice, few workers were paid at a different frequency or in a different currency. Using exchange rates from Officer (2001), we have converted all monthly wages to British sterling. These wages are then converted to 1900 prices using the British consumer price index from McCusker (2002). We are left with approximately 149,000 individual-level observations for the time period spanning 1861 to 1912. However, because there are numerous individual observations with missing wage data in the first few years, we restrict our analysis to the period 1865-1912.

Of the 149,000 observations, only 4,000 are for individuals working on steam vessels. Although steam was spreading over the entire period, it did not become dominant until the twentieth century, and by this time the Atlantic Canadian fleet was rather smaller than it had been earlier. But this explains only part of the relatively small sample size for steam: researchers also compiled more individual-level data for the earlier period than the later period. Given this, our empirical analysis on technical change and the skill premium will be based on sail and steam observations from 1891 to 1912. During these last two decades of the sample period, we have observations on both technologies. Thus, sample moments for both technologies would reflect the common macroeconomic conditions. Our empirical analysis concerning the evolution of the skill premium will be based on sail observations only since we want consistent data spanning as long a period as possible.

Figure 4 shows that in most years steam-powered ships are under-represented in the individual wage data, which raises concerns about whether this sample is representative of all workers serving on ocean-going vessels. Only beginning in 1907 does the fraction of vessels that are steam-powered in the sample approximate the fraction in the population. This means that for the years before 1907, the sample moments will be too heavily weighted by sail. But even though we cannot get the correct sample moments for transoceanic transportation as a whole, the data still provide insights about steam and sail separately. In particular, we argue that the steam observations in the sample are representative of all workers serving on steam-powered vessels, and similarly that the sail observations are representative of all workers serving on sailing vessels. To advance this argument, we first compare the vessels for which we have individual-level crew information (“in sample”) to the vessels that are not in the sample. Recognizing that the “steam/sail” category of ocean-going vessels is rather heterogeneous, we focus on international voyages made by the vessels. We compare the voyages that are in our sample to voyages that are not in our sample.

Table 1 shows that from 1891 to 1912, approximately 27% of all registered ocean-going vessels in the four ports are in our sample. The center two columns show that the age and dimensions of the sailing vessels that are in the sample do not differ much from those that are not, which bolsters the case that our sail observations may be representative. The right-most two columns show that the steam vessels in the sample are physically much larger than those not in the sample. This appears to be an artifact of how vessels are categorized. As noted before, all vessels were placed in one of seventeen categories, only three of which were steam. The more detailed categorization of sailing vessels enabled us to eliminate types of sailing vessels not intended for crossing oceans. We are not able to do this equally well for steam vessels. We have eliminated steamers and steamboats with paddles from the sample, as these were typically used for short-distance transport. But the remaining steam category, “steam/sail” is broad. Judging from the low average tonnage of the 148 steam vessels that are not in the sample, it seems like many short-distance vessels have been placed into the steam/sail category. Although our steam observations cannot be considered representative of all workers in steam vessels, nonetheless they might be considered representative of all workers in steam vessels capable of making international voyages. In Table 2, we present the characteristics of international voyages taken by ships in the sample to those not in the sample. The right-most two columns show that our steam observations reflect all the international voyages taken by steam vessels between 1891 and 1912. The sail observations capture 42% of all the international voyages taken by sailing vessels, and since the characteristics of the ships and voyages do not differ much, we shall assume them to be them representative of all workers in sailing vessels capable of making international voyages.

IV. Results

Technical Change and Skill Demand

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[16] It also produced unusually unhappy workers. Sager (1993, p. 44) reports that in the British merchant

In this section, we examine to what extent the skill composition of workers differs across the new and old technologies, steam and sail. Since we are interested in making comparisons between steam and sail, we will restrict our analysis to 1891 to 1912, the time period for which we have both sail and steam observations (earlier years have only sail observations). By focusing on a period in which the two technologies co-existed, we can control for general macroeconomic conditions facing all workers and compare the remaining variation in wages by technology.

Table 3 contains our main results. The table shows the occupational composition of the crew in steam and sailing vessels in terms of raw number, employment share, and wage bill share. Table 3 shows that while total crew size was similar between steam (35) and sail (32), there were striking differences in the composition of the crew. The shift to steam made some jobs, such as the sail maker, obsolete while creating others, such as the engineer and other engine room occupations. It also changed the mix of workers across occupations common to both technologies. The sail crew typically had 23 able-bodied seamen, a steam crew had only nine. The employment share of able-bodied seamen and ordinary seamen fell from 77 percent on sailing ships to 27 percent on steam ships. In terms of wage bill share, the share of these production workers fell from 65% on sail to less than 20% on steam. However, the steam crew had an average of 16 workers working in the engine room, four engineers and twelve engine room operatives. These new occupations accounted for over 52% of the total wage bill on steam vessels.

Was the new technology skill-biased? While the engine room operatives were paid more on average than able-bodied seamen, it cannot be said that their tasks required more skill. Most likely the higher wages for engine room operatives reflected not a skill premium, but a compensating differential for the unpleasant work environment in the engine room. Manual labor in the engine room was hot, unpleasant, and unusually dangerous.[16] In contrast, engineers were highly skilled employees with required special training and, in the case of the first engineer, certification. They were in high demand both on land and at sea, and knowledge and experience

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marine 100 firemen and trimmers committed suicide in 1893 and 1894: "Driven mad by the heat, they would throw themselves overboard."

were prized because steam engines were expensive and temperamental machines. As a consequence, engineers were usually the highest paid members of the crew.[17] Similar to Goldin and Katz's (1998) description of the movement of production from skilled artisans to the factory, the introduction of the steam engine may have lead to deskilling of production workers. At the same time, it created the need for highly trained specialists who knew how to maintain the machines.

Table 3 also documents a substantial wage premium associated with steam, even within an occupation such as able-bodied seamen. In the next section we investigate possible sources of this steam premium.

What Explains the Higher Wages on Steam Ships?

In Figure 5, we plot wages by year and technology. Mean wages were higher in steam than in sail, as shown in Panel A. On average, workers in steam vessels were paid 43 percent more than workers in sailing vessels. In Panel B, the 90th percentile wage is higher in steam, but the 10th percentile wage is similar between steam and sail. Consequently, wage inequality as indicated by the ratio of the 90th and 10th percentile wages was greater in steam vessels. The average 90/10 ratio was 2.1 in sailing vessels while it was 2.9 in steam vessels. As the results in the last section suggested, a substantial portion of both the higher mean wage and higher inequality on steam ships can be explained by the creation of a new high-paying occupation on board, the engineer.

In Figure 6, we reproduce the graphs of Figure 5 after excluding engineers from the sample. Steam workers still have higher mean wages, but the difference is smaller (the steam premium is 26 percent instead of 43 percent). Naturally, the 10th percentile wage continues to be similar between steam and sail, but the elimination of engineers reduces the average 90/10 ratio from 2.94 to 2.35. Thus, creation of the engineer occupation accounts for almost half the average steam-premium, and much of the greater wage inequality in steam.

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[17] Probably except the master, but the wages of the master are not in the data set.

More formally, we look at the steam premium in a regression framework, which enables us to control for worker and firm characteristics that affect wages.[18] In Table 4, Column 3, we show the difference in log wage for steam workers after controlling for worker's age (which roughly corresponds to work experience) and year dummies (to control for macroeconomic variations). The next-to-last row shows that steam workers are paid 28% more than sail workers. Dropping engineers, steam workers are still paid 19% more than sail workers. Thus, about one-third of the regression-adjusted wage increase associated with the shift from sail to steam arises from the creation of the engineer occupation.

Interestingly, steam workers are paid more even in occupations common to both technologies. The two largest occupations forming the crew earn significantly more on steam: able-bodied seamen earn 17% more and mates earn 12% more, and both differences are significant at the 95% level of confidence. Carpenters also earn significantly more on steam vessels, but although the coefficient is large it is less precise that the estimates for able-bodied seamen and mates since there are many fewer observations.[19]

What could account for the within-occupation steam premium suggested in Table 4? One hypothesis is that, given an occupation, workers in steam were more skilled than the workers in sail. One direct measure of skill that we have is whether the worker can sign his own name. An individual is coded as literate if he signs his name on the crew agreement, and illiterate if he put

[18] Engineers were older than the average mariner.

[19] Each vessel typically has only one carpenter. The category "Other" contains occupations not elsewhere classified. This category has a large steam premium, but it is almost entirely due to uninteresting within-category occupation changes. Boys, who are inexperienced seamen, are the dominant components of the "other" category in sail. Assistant stewards and mess hall stewards comprise the greater part of this category on steam, and, perhaps because they needed to interact well with passengers, earned more than the green hands on deck.

[24] Also, nearly three quarters of the engineers are British.

down an "X". In our sample, one quarter of the seamen were illiterate, although literacy was rising rapidly over the entire period. But it turns out that controlling for literacy does not affect our estimates of the skill premium, as can be seen in the first column of Table 5. Perhaps by 1891 to 1912, literacy is virtually universal, and it was not difficult to hire a literate worker. The illiterate workers that are hired might be exceptional in a skill dimension that is valued by the employer, but not correlated with literacy.

Another potential proxy for skill is country of birth. Depending on where the worker grew up, his quantity and quality of schooling, training and work experience could be quite different. Wages could therefore be expected to differ. In Table 5, Column 2, we control for a full set of country of birth dummies. The steam premium for mates is cut in half, but that for able-bodied seamen and carpenters remains the same magnitude as in the basic specification. This appears to arise from the fact that steam vessels are more likely to hire British mates. In our sample, 40% of mates on steam vessels are British, compared to only 23% in sailing vessels. All the individuals in our sample are working in vessels registered in Canada, and so even though there are twenty-six different nationalities among the mates, the mates are predominantly from Britain and her former empire.[24] The top four countries of birth for mates are Canada, Britain, Ireland and the U.S. The proportion of mates who are Canadian and Irish are not different between sail and steam, but the proportion of mates who are American and other nationalities is lower. As an interesting contrast, the proportion of able-bodied seamen who are British are similar between the two technologies (21.1% for sail and 21.6% for steam). The greater tendency to hire British mates for steam vessels can likely be interpreted as a rise in the skill premium: the British merchant marine was both the earliest adopter of the steam engine technology, the most widespread user of formal apprenticeships, and the pioneer in professionalizing the service (Burton, 1990).

A second hypothesis is that the work environment could be quite different on sail and steam vessels, and the wage premium is merely a compensating differential. On its face this seems unlikely, at least for able-bodied seamen. There is no corresponding premium for ordinary seamen, yet they worked and lived side by side with the able-bodied seamen. But to assess the hypothesis more formally, we control for some voyage and vessel-level characteristics: crew size, whether embarking from home country, whether discharging at home country, gross tonnage of ship, year ship was constructed and intended duration of the voyage. The results are displayed in

Table 5, Column 3. When voyage controls are added, the steam premium in a sample of all workers *increases* to 30% from 28% in the basic specification in Table 4, Column 3. In retrospect this is not too surprising. There is a premium for longer voyages, most plausibly a compensating differential, and steam voyages were on average much shorter than sailing voyages.

However, the impact of the voyage controls is different across the occupations. For able-bodied seamen and carpenters, the steam premium is even larger than before; voyage characteristics at least as measured here do not account for the steam premium. In contrast, for mates, the steam premium is cut in half. The regression results suggest that part of the premium for mates in steam vessels was from having responsibility over a larger cargo (as proxied by gross tonnage). While at sea, the mates have to ensure the security of the cargo. When the vessel stops at a port, the mate must stay behind at the vessel to watch the cargo; the rest of the crew can go pursue the diversions on the land. In our sample, the steam vessels have much higher gross tonnage than sailing vessels, and since mates are paid more when gross tonnage is higher (the coefficient for gross tonnage is positive and significant), when we omit gross tonnage from the regression we get a higher steam premium. In the final column of Table 5, we control simultaneously for literacy, country of birth and voyage characteristics. Although the point estimate for mates is still positive, it is no longer significant. The compensating differential required to watch more cargo, and the reward for having greater familiarity with steam technology, appear to account for the steam premium for mates.

Finally, we investigate the existence of the wage premium on steam for the same individual. Our data allows us to create a limited panel, matching observations with the same surname, first name, birth year, country and city of birth.[26] The process allows us to identify a substantial panel consisting of 21,948 observations and 9,263 individuals with two or more observations. However, we identify few individuals who actually switch technologies between sail and steam. We observe 24 individuals, accounting for 69 observations, who switch

[26] To increase sample sizes, we include all years 1861-1922 in this exercise. We start with 168,177 observations which are from 155,492 distinct individuals.

technologies. In Table 6, we report estimates from wage equations which include individual fixed effects. Not surprisingly, given the small number of switchers, the coefficient on steam is still positive (.141 in the specification which includes voyage characteristics) but no longer significant.

In Table 7, we investigate further the extent to which the wage premium on steam is due to unobserved quality differences, particularly among able-bodied seamen and carpenters. We found in Table 5 that the steam premium persisted for these occupations even when a variety of voyage, year and individuals controls were added to the regression. We estimated wage equations on sailing vessels, controlling for year and the full set of individual and voyage characteristics. In the table we report the average percentile position in the residual distribution of those individuals who switched technologies. We find little evidence of higher unobserved quality among mates. On average, they were at the 46th percentile of the residual distribution in sail. We find some evidence that the able-bodied seamen who switched to steam were slightly better quality. They were approximately at the 56th percentile of the residual distribution in sail. Similar to the findings related to industry wage premiums (Krueger and Summers, 1988; Murphy and Topel ,1990) the above suggests that the steam premium may reflect a combination of workplace and worker characteristics. The caveat, of course, is that we have only a handful of observations so the evidence presented here is suggestive rather than conclusive.

To conclude, the introduction of steam technology increased skill demand in the sense that it created the need for highly trained individuals, the engineers, who were responsible for maintaining the new machines. On the other hand, production work may have required less skill in the sense that experienced seamen such as the able-bodied seamen were replaced by machine operatives and laborers in the engine room. While these engine room occupations paid substantially higher wages, existing descriptions of the unpleasant working conditions suggest that this was most likely a compensating differential. We also find a substantial steam premium for able-bodied seamen. The premium cannot be explained by differences in measurable worker characteristics and the absence of a premium for ordinary seaman indicates that it cannot be a compensating differential for voyage characteristics. One possibility is that the steam premium reflects a combination of the two-- compensating differential related to the job and also unobserved quality of the worker. Since fewer seamen are hired, each seaman is responsible for a larger set of tasks; at the same time, he also has to be above-average ability to handle these tasks.

Wage Inequality and Skill Premium: 1865-1905

In this subsection, we document the wage structure among mariners on sailing vessels. We restrict attention to the period 1865 to 1905 because relatively few observations for sail are available after 1905. Relatively little is known about skill premiums and wage structure during the latter half of the nineteenth century. Atack, Bateman and Margo (2000) report that wage dispersion across manufacturing establishments rose in the U.S. during this period. Meyer (2002) shows that within-industry wage inequality increased, particularly in industries experiencing rapid technical change. However, skill premiums measured as occupational pay ratios exhibit relatively little movement over this period (Lindert and Williamson, 1980). In Britain, evidence suggests that skill premiums fell at the very end of the nineteenth century (Williamson, 1980; Lindert and Williamson, 1983).

Our purpose in this section is two-fold. First, we bring more data to the continuing debate regarding the evolution of the skill premium. While our study covers one industry-- the transatlantic maritime industry—the quality and the detail available on our data is quite unique. With our data, we can examine overall inequality such as the 90-10 wage ratio as well as skill premiums measured as occupational pay ratios or the literacy premium. Our second purpose is to understand how the introduction and diffusion of new technology affected wage structure in the industry over time.[27] The previous section suggested that steam had differential impact on demand across job categories. It created the demand for engineers and engine room occupations. It diminished the need for able-bodied seamen. It made some occupations, such as sail makers, completely obsolete. On the opposite end of the spectrum, other occupations, such as mates and cooks were relatively unaffected. We examine whether there were different changes in wages across occupations depending on the portability of skills across technologies.

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[27]Due to the absence of consistent numbers of steam wage observations, we restrict our analysis to wages in sailing vessels although ideally we should include both.

In Figure 7, Panel A, we plot the 90th, 50th and 10th percentile wages and mean wages by year for men aged 16 to 65 working in sailing vessels. During the four decade span, the relative wages of the higher-paid to lower-paid did not change dramatically. The 90th percentile wage is on average 2.2 times the 10th percentile wage and 1.7 times the median wage. The median wage is 1.3 times the 10th percentile wage. The mean is higher than the median, and the median is much closer to the 10th percentile wage than the 90th percentile wage, indicating that most of the workers are concentrated at the bottom of the wage distribution. This makes sense, since the bulk of the crew are ordinary seamen and able-bodied seamen; these account for both the 10th and 50th percentile workers, and their wages are more similar to each other than to the mates who are the likely 90th percentile workers.

The ratio of the 90th percentile wage to the 10th percentile wage, a standard measure of wage inequality, ranges from 1.8 to 2.7 over the four-decade period, as shown in Figure 7, Panel B. The 90/10 ratio for this period is lower than what has been observed for much of the twentieth century. Goldin and Margo (1992) calculate the ratio at each decennial year since 1940, the first U.S. Census for which income micro data are available, and find that the lowest value was 2.9 in 1950. They term the mid-century period with unusually low inequality the Great Compression. We suspect that the 90/10 ratio we have calculated for the turn of the century is lower because we are examining only one industry, whereas studies using more recent micro data use all industries. The maritime industry, and likely other industries impacted by the steam engine such as manufacturing and land transportation, was neither the highest-paying nor the lowest-paying industry.

In Figure 8, we plot wages by literacy and year. Panel A shows that mean wages were higher for the literate; literate seamen were paid an average ten percent more than illiterate seamen. Panel B shows that the 10th percentile wage is the same for both the literate and illiterate, but the 90th percentile is higher for the literate. In other words, wage inequality is higher for the literate. The ratio of the 90th percentile wage to the 10th percentile wage is 2.4 for the literate, 1.9 for the illiterate.

We might also measure skill using occupation. The wage inequality literature often looks at the wage differential between non-production and production workers, or white-collar and blue-collar workers, to describe the skill premium. We take mates to be the skilled/non-production/white-collar workers and the able-bodied seamen to be the less skilled/ production/blue-collar workers. The mates are able-bodied seamen who have passed the necessary examination to be certified and subsequently managed to find a job as mate. Mates spend most of their time engaged in managerial and supervisory activities, and record-keeping. The second mate and third mate might still perform physical tasks alongside the able-bodied seamen, but the first mate would not. We plot the wages for mates and able-bodied seamen in Figure 9. Panel A shows that, as expected, mean wages are higher for mates than for able-bodied seamen. Mates' wages are 1.9 times able-bodied seamen's wages, ranging from 1.6 to 2.3. Unlike the stability of the 90-10 wage ratios we reported earlier, the ratio of wages of mates and able-bodied seamen shows a slight upward trend (Panel B). This is not surprising given the sharp reduction in demand for able-bodied seamen in steam-powered vessels (Table 3) and given the rapid adoption of steam technology even among ocean-going vessels at the end of the nineteenth century.

While we have little information about supply, occupational wage bill shares in sail and steam vessels indicate that demand for certain occupations and skills declined with the introduction of steam technology. Figure 10 shows the evolution of wages in three occupations distinguished by the portability of skills across technologies. We indexed wages to the average value over 1865-1867, the beginning period of our sample. Average wages of cooks, an occupation that was relatively unaffected by the switch in technology, was about the same in 1905 as it was in 1865. In sharp contrast, the average wage of sail makers, an occupation that had become all but obsolete with the introduction of new technology, fell approximately 20 percent. We have not graphed years with fewer than 25 observations, but if we included these years, the decline in sail maker observations would be even larger. Average wage of able-bodied seamen also fell, although the precise amount depends on how much weight we place on the last few observations where the number of wage observations in sail becomes relatively sparse.

To put our findings in context we compare these ratios of wages of mates to able-bodied seamen to other skill premiums reported in various sources in Figure 11. In Panel A we juxtapose the mates/able-bodied seamen wage ratio from our data (line marked by squares) to skill ratios in British printing and building trades as reported in Williamson (1980). The figure also includes skill ratios from the U.S. over the same time period reported in Lindert and Williamson (1980).

Panel B compares our occupational premium to other white-collar/blue-collar wage ratios, such as the wage ratio of clerks to unskilled labor in Britain, as well as the wage ratios of ministers to unskilled labor in Britain and U.S. The figure illustrates that the mate/seamen premium we report is more in line with skill ratios measured within manufacturing or other blue collar occupations. The white-collar premium was orders of magnitude larger. The other point is that consistent with what we find in our data, skill premiums did not change remarkably during 1865-1905, particularly in the U.S. There is some evidence that the white-collar premium fell at the turn of the century in Britain.[28]

This subsection has provided new empirical evidence on the wage structure for the period 1865 to 1905. The skilled worker on sailing vessels (defined either as the 90th percentile wage earner or the non-production worker) made approximately twice as much as the unskilled worker (defined as the 10th percentile wage earner or the production workers). The skill premium was fairly stable over the four decade period, despite the steady substitution of steam for sail. We find that wages in occupations which became obsolete with the diffusion of steam technology steadily declined over the period.

V. Conclusions

Not much is known about the evolution of the wage distribution at the end of the nineteenth century and beginning of the twentieth century because individual-level wage data that are collected consistently over time are not available until the second half of the twentieth century. Yet, this is a critical juncture in our economic history. Many of today's modern economies began industrialization then; the modern wage structure has its roots at the turn of the century. We have taken advantage of a data set on merchant mariners to detail the skill premium at turn of the century, and to estimate the impact of technical change on the wage structure.

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[28] The ratios we report are also similar to wage ratios of skilled to unskilled workers calculated for the early twentieth century (see Goldin and Margo, 1992, Table VII).One series from Goldin and Margo seems especially comparable to ours – the ratio of monthly wages of clerks to laborers in class-I steam railroads. This series begins in 1922 at 1.57, is stable through the 1920s, rises to as much as 2 in the 1930s, and declines to 1.73 in 1940, and then declines further in the 1940s marking the Great Compression.

We first examine the period when both sail and steam vessels provided transoceanic shipping services, 1892-1912. We find that both wage levels and wage inequality was considerably higher in the new technology. The higher wage inequality is largely accounted for by changes in the composition of jobs. The steam technology reduced the demand for able-bodied seamen (production workers) and created the need for highly trained engineers. While the production workers on steam (engine room operative) were paid well relative to able-bodied seamen, it was most likely a compensating differential for working in a hot and dangerous environment, the engine room. This suggests that pure production work may have become less skill-oriented with the introduction of new technology. We also find that able-bodied seamen working on steam received a substantial wage premium. Steam ships in the early phases of oceanic travel utilized a hybrid technology of steam and sail. This hybrid system still necessitated the hiring of able-bodied seamen, although many fewer were hired. Due to the limited number of mariners, each mariner was responsible for a larger set of tasks which may have required both a compensating wage differential as well as greater general ability of the mariners. In other words, among the able-bodied seamen demand for narrowly-defined, job-specific skills may have been usurped by a demand for general ability. Meyer (2002) reaches this conclusion for US industry in the latter half of the 19th century.

Using wage observations from sail that span a longer time period, 1865-1905, we found that the skill premium, as measured by the ratio of skilled (mates') to less skilled (able-bodied seamen's) wages or as the ratio of the 90th to 10th percentile wages among mariners, did not undergo dramatic changes. Skilled labor earned roughly twice as much as less skilled labor, which is similar to the skilled/unskilled wage ratios measured by several different studies for the pre-1940 part of the twentieth century. Thus, in the eighty years preceding 1940, there appears to have been no major compression or dispersion. We do find however evidence of steam's impact. Wages of sail makers, an occupation that was made obsolete by the diffusion of steam, steadily declined over this period. Wages of able-bodied seamen also fell while wages in occupations such as cooks and stewards where skills were largely portable across technologies remained unaffected.

The dramatic way that the steam technology impacted the international shipping industry also happened in many other industries. The empirical findings here are likely applicable to other industries, with a few caveats. First, the industry we have considered crosses country borders; the crew came from all over the world. If we were interested in the impact of steam on a particular country's wage structure, we would need to see what type of worker that country tends to supply. Great Britain, which supplied a disproportionate share of the engineers and mates in steam vessels, gained more skilled jobs than any other country, and steam would appear to have benefited workers at more points in the wage distribution. Second, land-based firms could have gotten away with hiring fewer engineers, since they can pay for an engineer when a machinery problem arises. Ships have to staff in anticipation of their problems; once at sea, they will be unable to get additional help. This might mean that the number of new skilled jobs might be fewer than predicted from the example of the shipping industry. Finally, part of steam premium that we observed could have been temporary, owing to the shortage of qualified engineers. More individuals will enter the field, and supply grows faster than demand, then wages will be driven down. The steam premium measured here may have been too high because the steam technology is relatively new.

Our findings might also have implications for the contemporary debate over the cause of rising wage inequality since the 1970s. Wage inequality is higher on steam vessels than sailing vessels, and as a steam technology spreads while sail technology is phased out, wage inequality will rise (all else constant). In sailing vessels, the 90/10 ratio averaged 2.1, in steam vessels, 2.9. There is a 40% increase in the 90/10 ratio switching completely from the old technology to the new one. This is similar to the wage inequality increase between the early 1970s and late 1980s (see, for example, Katz and Murphy (1992) and Juhn, Murphy and Pierce (1993)). Moreover, the modern rise in wage inequality appears to be due both to an increase in wages for new types of formal skills, as well as to increased demand for general ability. The experience with steam during the second industrial revolution may share much in common with the computer revolution.

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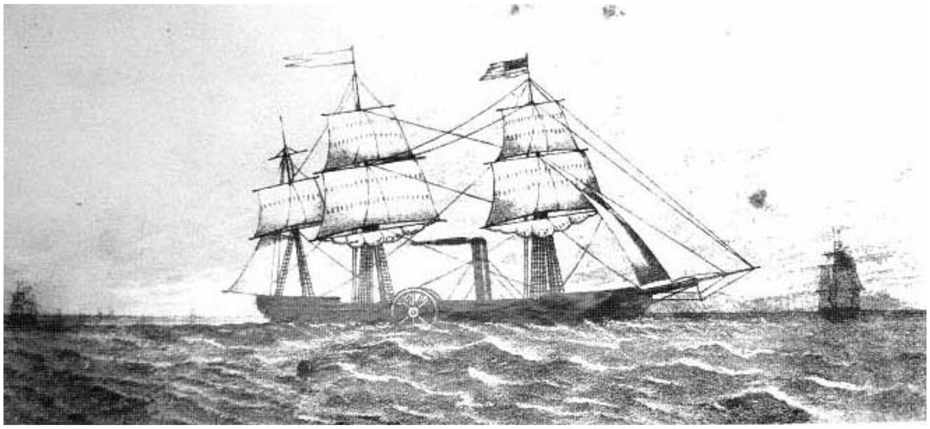


FIGURE 1. The SS *Savannah*. Source: Georgia Historical Society, Photographic Collection #1361 PH, Box 29, Folder 20.

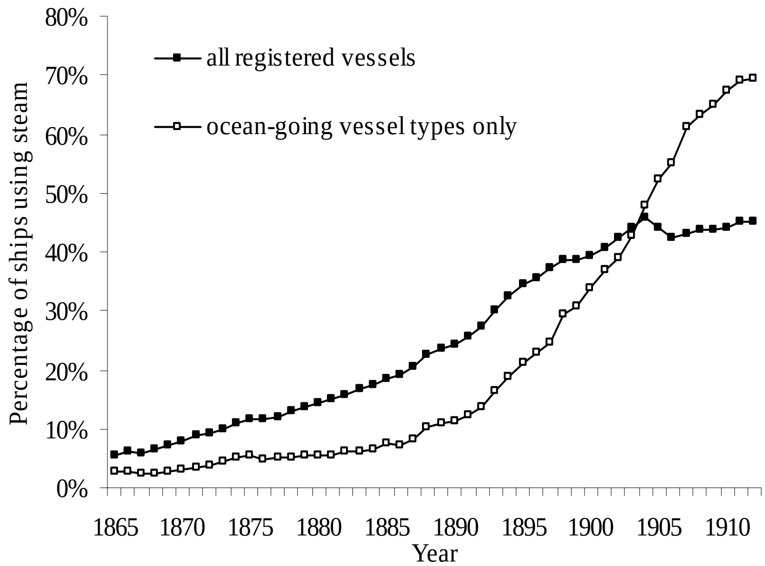


Figure 2. Spread of steam-powered ships in Atlantic Canada. Notes: Based on the vessel registry database, which contains data on the universe of ships registered in ten major Canadian ports. Each point gives the stock of steam-powered ships as a fraction of either the stock of all vessels or ocean-going vessels. Ocean-going vessels are defined as barquentines, barques, brigs, ships, and steam/sail. The latter type of vessel uses steam technology whereas the others use only sail technology.

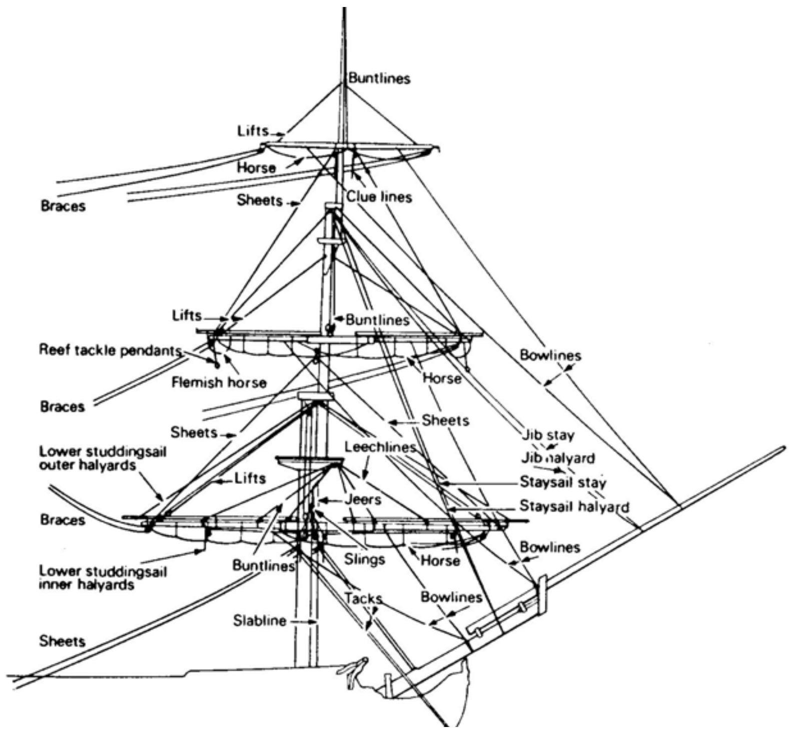


FIGURE 3. Main rigging on a ship's foremast. Source: Kemp (1976).

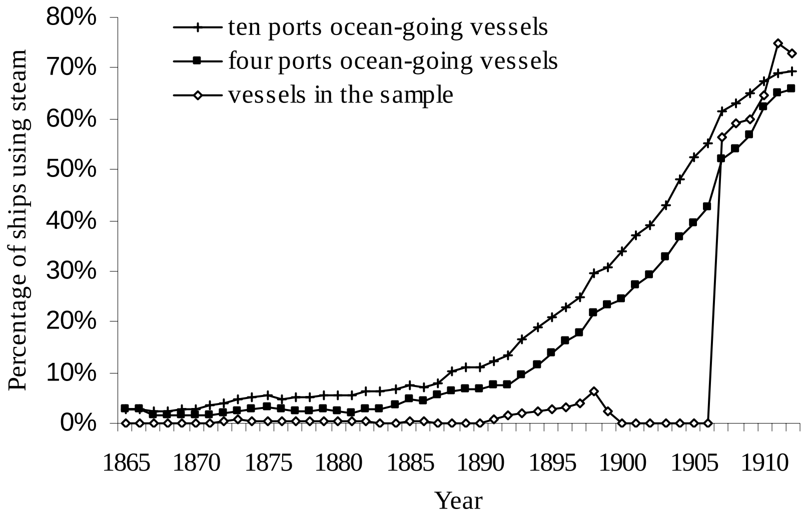
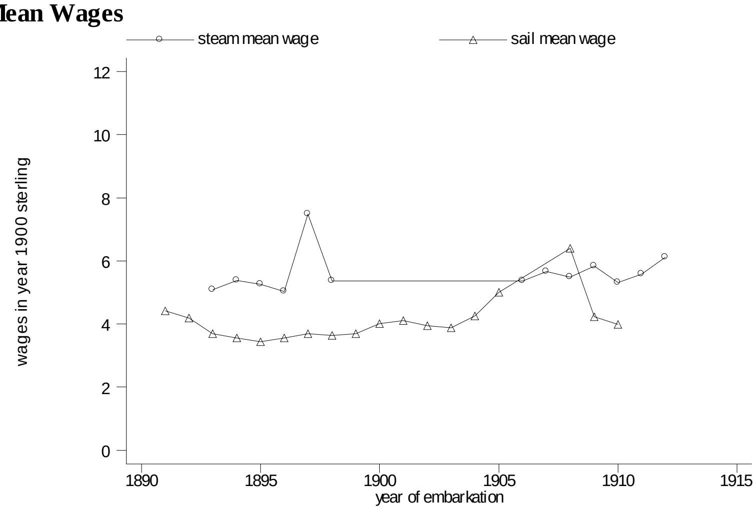


Figure 4. Coverage of steam-powered vessels in sample. Only ocean-going vessels included in this graph. The vessel registry database contains data on the universe of ships registered in ten major Canadian ports. For ships registered in four of these ports (Halifax, St. John, Windsor and Yarmouth), data from crew agreements (on voyages, masters and ports) were collected. For a sample of ships registered in these four ports, individual-level crew information was collected.

Panel A. Mean Wages



Panel B. Wages at the 10th and 90th percentiles

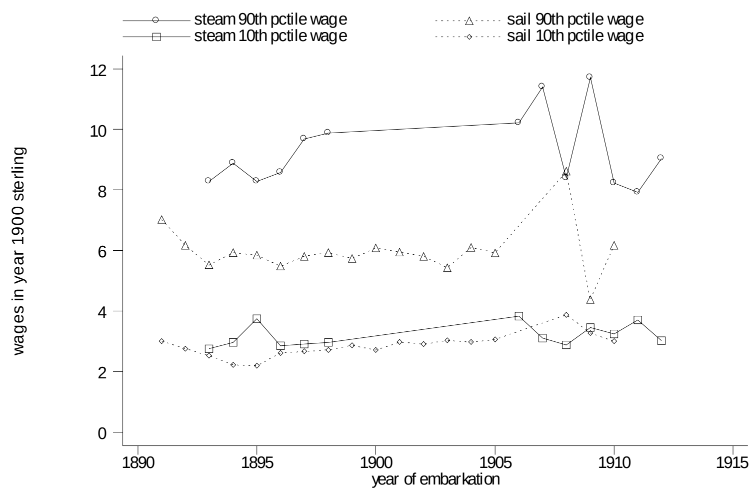
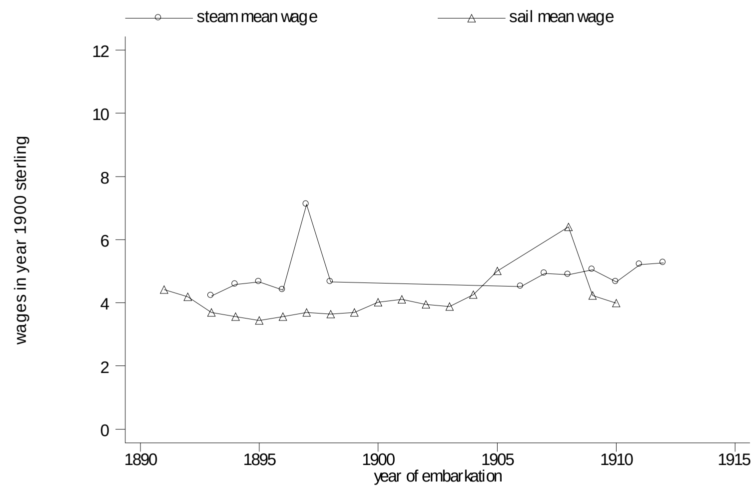


FIGURE 5. Wages by Technology, All Male Seamen Aged 16 to 60. Raw statistics computed from sample of 19,773 individuals (16,218 from sailing vessels and 3,555 from steam vessels. Rank-year cells with fewer than 25 observations have not been graphed.

Panel A. Mean Wages



Panel B. Wages at the 10th and 90th percentiles

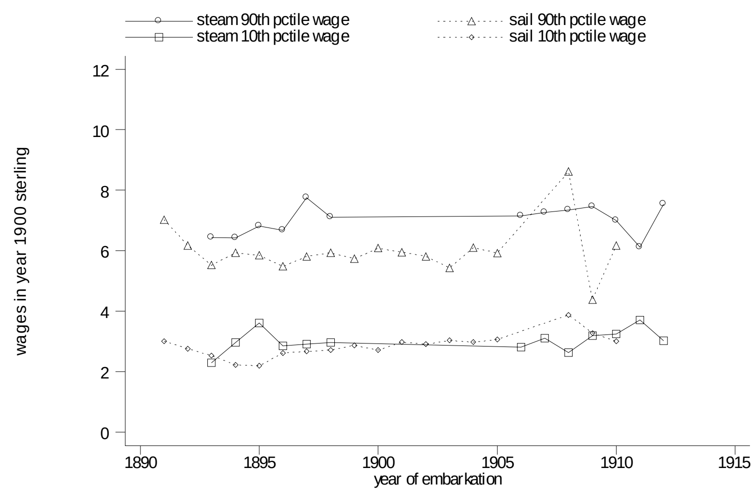
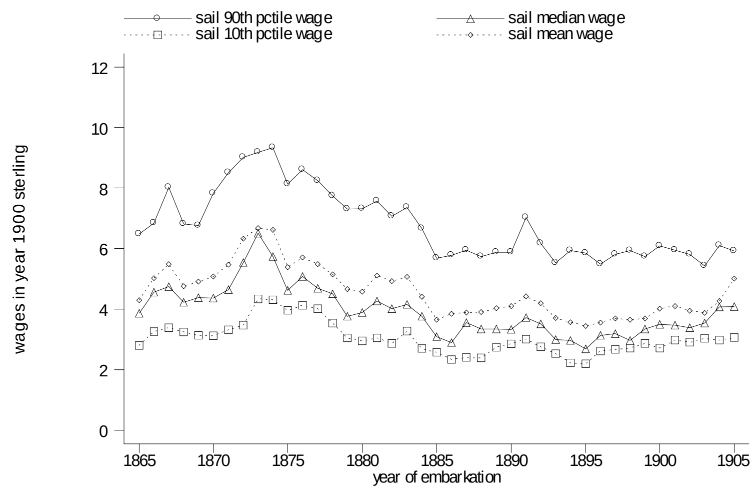


FIGURE 6. Wages by Technology, Excluding Engineers. Raw statistics computed from sample of 19,346 individuals (16,217 from sailing vessels and 3,129 from steam vessels. Rank-year cells with fewer than 25 observations have not been graphed.

Panel A. Mean Wages



Panel B. 90th percentile wage / 10th percentile wage

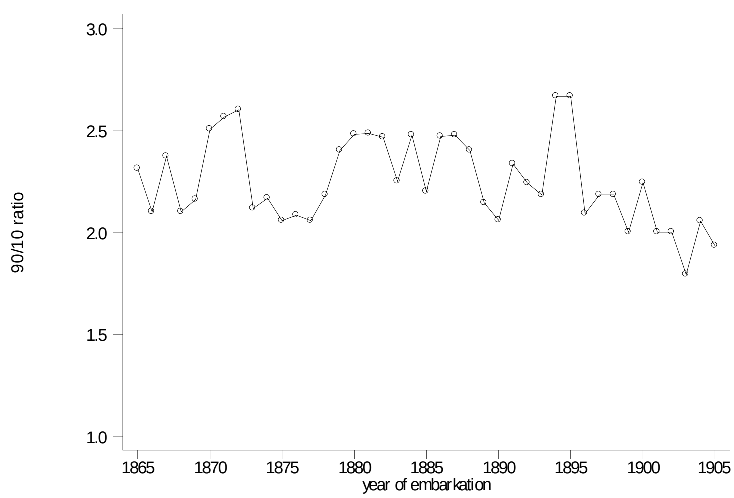
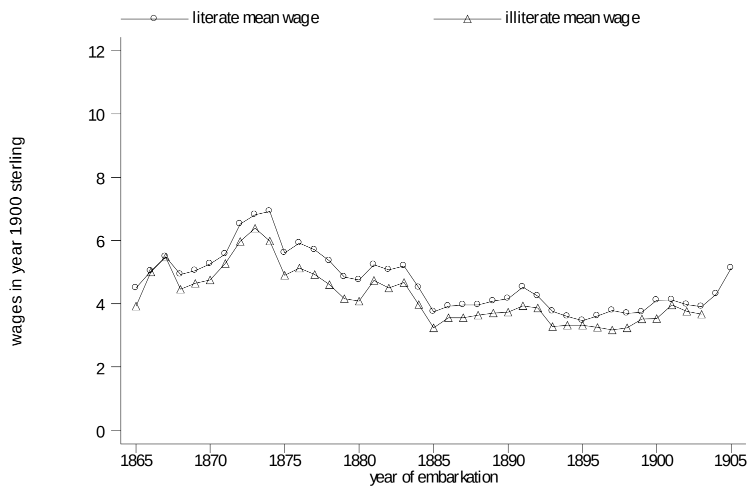


FIGURE 7. Wages for Male Seamen Aged 16-60 (Sail). Raw statistics computed from sample of 144,924 individuals working in sailing vessels. Year cells with fewer than 25 observations have not been graphed.

Panel A. Mean Wages



Panel B. 90th percentile wage / 10th percentile wage

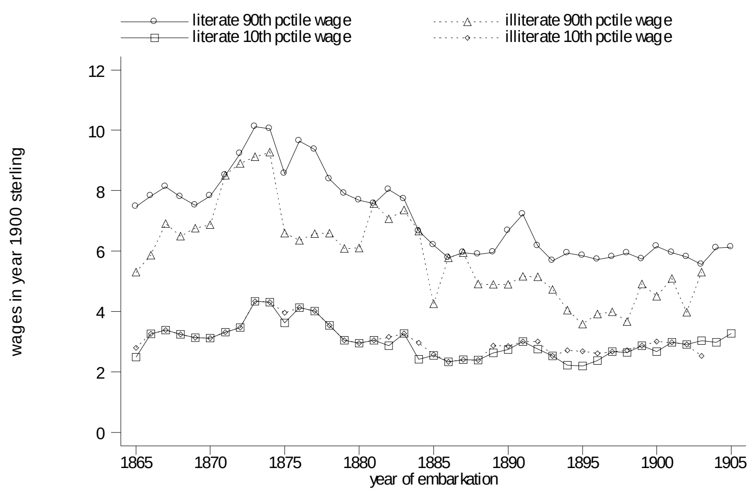
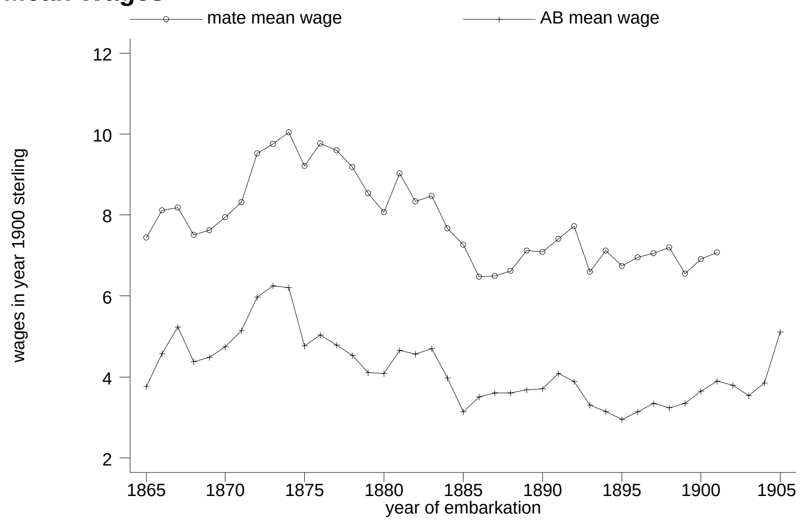


FIGURE 8. Wages by Literacy (Sail). Raw statistics computed from sample of 144,924 individuals working in sailing vessels. Year cells with fewer than 25 observations have not been graphed.

Panel A. Mean Wages



Panel B. Mate/AB Seamen Wage Ratio

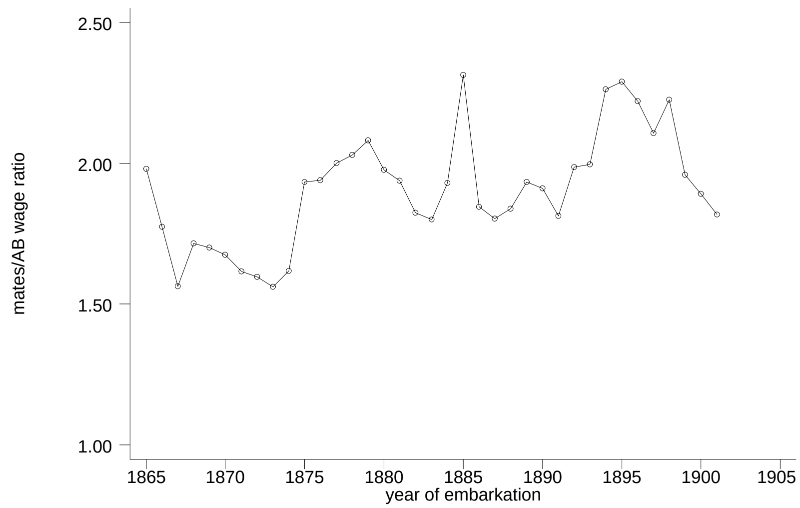


FIGURE 9. Wages by Rank (Sail). Raw statistics computed from sample of 144,924 individuals working in sailing vessels. Year cells with fewer than 25 observations have not been graphed.

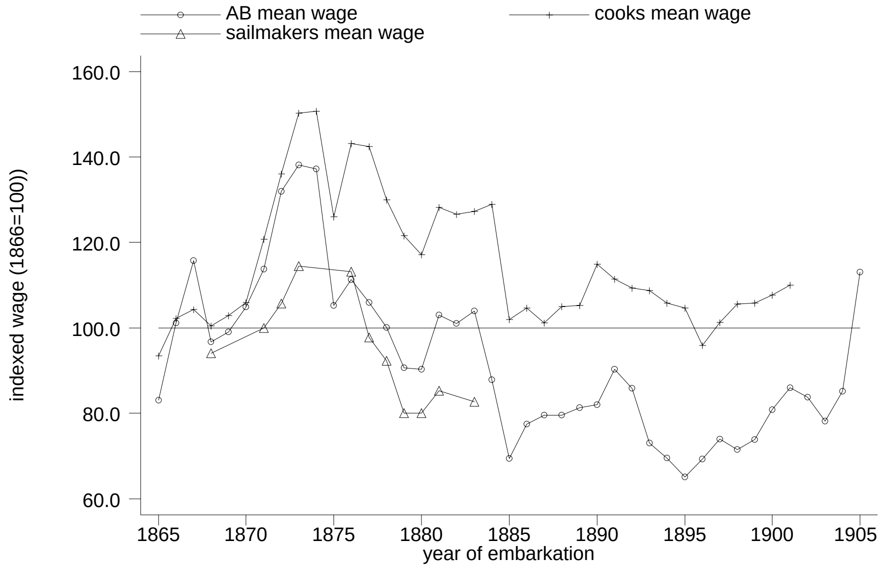
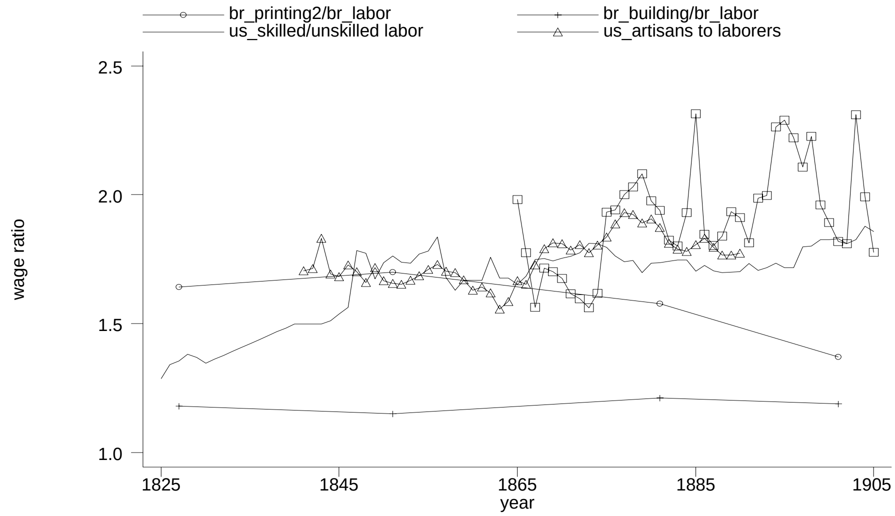


FIGURE 10. Indexed Wages in Different Occupations (1866=100)
Raw statistics computed from sample of 144,924 individuals working in sailing vessels. Year cells with fewer than 25 observations have not been graphed.

Panel A. Comparion of Mate/AB Wage Ratio to Other Skill Premiums in U.S. and Britain



Panel B. Comparison of Mate/AB Wage Ratio to Other White-Collar/Blue-Collar Premium

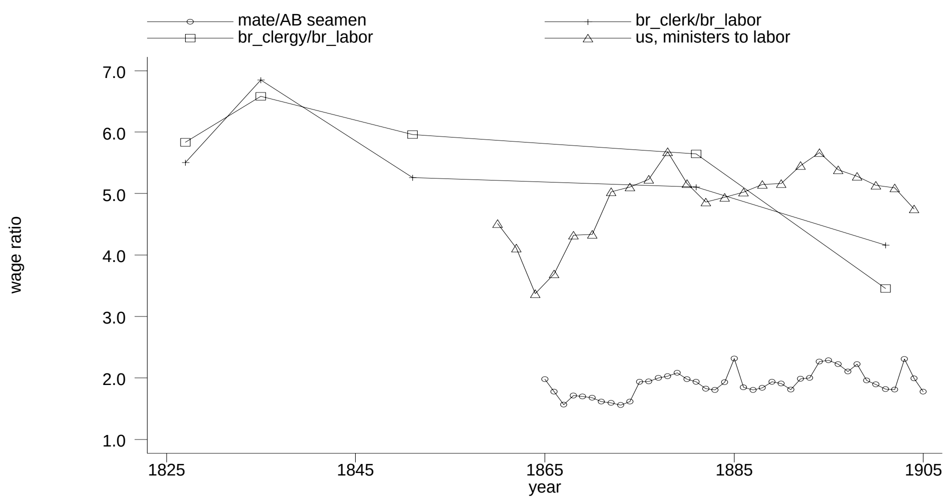


FIGURE 11. Comparison of Mate/AB Wage Ratio to Other Skill Premiums

Source: British data from Williamson (1980), appendix table 1.

U.S data from Lindert and Williamson (1980), appendix D.

TABLE 1. Comparison of in-sample and not-in-sample vessels

	All ocean-going vessels		Sail		Steam	
	In sample	Not in sample	In sample	Not in sample	In sample	Not in sample
Type of vessel						
Steam-powered	16	148	–	–	16	148
Barque	72	125	72	125	–	–
Barquentine	7	68	7	68	–	–
Brug	2	8	2	8	–	–
Ship	64	77	64	77	–	–
Total Number	**161**	**426**	**145**	**278**	**16**	**148**
Gross tonnage	1,354	688	1,185	1,354	2,884	253
Length	202	147	189	171	315	99
Width	38	30	37	35	44	20
Depth	22	16	22	19	23	9
Year constructed	1879	1884	1878	1879	1894	1895
Year registered	1881	1887	1879	1881	1905	1900
Year abandoned	1898	1905	1897	1899	1911	1917

Data the from vessel registry database. Ocean-going vessels with active registration anytime from 1891-1912 at one of the four ports with crew data (namely, Halifax, St. John, Windsor and Yarmouth) are used in above analysis. "In sample" means that individual-level crew information is available for this vessel.

TABLE 2. Comparison of in-sample and not-in-sample voyages

	All ocean-going vessels		**Sail**		**Steam**	
	In sample	Not in sample	In sample	Not in sample	In sample	Not in sample
Type of vessel						
Steam-powered	115	8	–	–	115	8
Barque	201	327	201	327	–	–
Barquentine	7	61	7	61	–	–
Brug	–	–	–	–	–	–
Ship	241	237	6241	237	–	–
Total Number	**564**	**633**	**449**	**625**	**115**	**8**
Gross tonnage	1,708	1,148	1,406	1,141	2,887	1,728
Length	229	189	206	187	317	276
Width	40	21	39	37	44	35
Depth	23	16	23	21	24	23
Year constructed	1885	1880	1882	1880	1896	1884
Year registered	1886	1881	1882	1881	1903	1891
Year abandoned	1903	1900	1901	1901	1910	1898
Year voyage commenced	1897	1894	1895	1894	1905	1892
Intended duration of voyage (months)	24	24	25	24	21	12
Intended destination						
Argentina	6.5%	6.3%	5.0%	6.4%	12.6%	0.0%
Brazil	14.8%	14.3%	15.6%	14.5%	11.7%	0.0%
Canada	25.6%	27.4%	24.6%	26.6%	29.7%	100.0%
Great Britain	9.6%	10.2%	10.2%	16.0%	7.2%	0.0%
USA	23.8%	26.0%	26.0%	17.4%	15.3%	0.0%
Other	19.7%	18.7%	18.7%	19.2%	23.4%	0.0%

Data the from vessel registry database. Ocean-going vessels with active registration anytime from 1891-1912 at one of the four ports with crew data (namely, Halifax, St. John, Windsor and Yarmouth) are used in above analysis. "In sample" means that individual-level crew information is available for this vessel.

Table 3. Wages, Employment, and Wagebill Share by Occupation: Steam vs. Sail

A. Steam occupation	**average wage** (£ 1900)	**Number**	**Employment** % of Total Crew	**Wage Bill** % of Total Crew
1-mate	9.15	2.5	7.3%	12.2%
2-bosun	5.13	0.5	1.4%	1.2%
3-able-bodied seamen	4.22	9.0	24.4%	18.1%
4-ordinary seamen	2.71	0.9	2.9%	1.5%
5-cook/steward	6.17	2.5	7.7%	8.9%
6-carpenter	5.43	0.6	1.9%	2.0%
7-sailmaker	--	0.0	0.0%	0.0%
8-engineer	10.64	3.9	12.3%	24.3%
9-engine room occupations	4.56	12.0	33.5%	27.9%
10-other	2.43	2.9	8.5%	3.8%
Total Crew	5.56	34.7		

B. Sail occupation	**average wage** (£ 1900)	**Number**	**Employment** % of Total Crew	**Wage Bill** % of Total Crew
1-mate	7.32	2.0	6.9%	13.9%
2-bosun	5.51	1.1	3.9%	5.6%
3-able-bodied seamen	3.50	22.6	70.0%	60.2%
4-ordinary seamen	2.35	2.4	7.0%	4.8%
5-cook/steward	6.51	1.6	5.6%	10.0%
6-carpenter	5.36	0.8	2.4%	3.5%
7-sailmaker	3.86	0.1	0.2%	0.3%
8-engineer	--	0.0	0.0%	0.0%
9-engine room occupations	--	0.0	0.0%	0.0%
10-other	1.48	1.2	3.9%	1.7%
Total Crew	3.93	31.8		

Notes: For voyages with years of embarkation from 1891-1912, number of workers by occupation is reported. There were 111 steam voyages and 564 sail voyages. Wages are averaged over all individuals with non-missing wages (20,160 individuals). The occupations have been aggregated as follows:

Aggregate occupation:	*Includes:*
1-mate	First Mate, Second Mate, Third Mate
2-bosun	Bosun, Bosun/Mate
3-able-bodied seamen	only one occupation
4-ordinary seamen	only one occupation
5-cook/steward	Cook, Steward, Cook/Steward
6-carpenter	Carpenter, Carpenter/Bosun, Carpenter/AB, Carpenter's Mate, Second Mate/Carpenter
7-engineer	Engineer, Second Engineer, Third Engineer, Fourth Engineer
8-sailmaker	Sailmaker, AB & Sailmaker, Bosun & Sailmaker
9-engine room occupations	Leading Fireman, Fireman, Bosun & Lamp Trimmer, Fireman & Trimmer,
	Donkey Man, Trimmer (Steamer), AB & Lamp Trimmer, AB & Trimmer,
	Oiler & Greaser
99-other	All other occupations, predominantly Boy, Stewardess, Apprentice,

TABLE 4. Wages by occupation for males aged 16-60

Occupation	**Sail** mean wage (pounds) (standard deviation) No. of observations	**Steam** mean wage (pounds) (standard deviation) No. of observations	Difference in *log wage* for steam, regression-adjusted for age quadratic and year dummies (standard error)
Mate	7.17	9.14	0.1221 **
	(2.35)	(2.08)	(0.029)
	1,078	259	1,337
Bosun	5.35	5.31	–0.0022
	(5.70)	(0.96)	(0.059)
	609	50	659
Able-bodied seaman	3.58	4.29	0.1674 ***
	(2.21)	(2.61)	(0.026)
	11,532	916	12,448
Ordinary seaman	2.43	2.95	–0.0781
	(0.88)	(3.19)	(0.109)
	1,222	93	1,315
Cook/steward	6.31	6.25	0.0002
	(2.65)	(1.23)	(0.032)
	839	255	1,094
Carpenter	5.30	5.45	0.1743 ***
	(4.97)	(0.97)	(0.032)
	422	63	485
Sailmaker	3.85		Occupation in Sail only
	(0.70)		
	48		
Engineer		10.52	Occupation in Steam only
		(6.43)	
		426	
Engine room operatives		4.74	Occupation in Steam only
		(1.51)	
		1,242	
Other	1.63	2.56	0.6335 ***
	(1.33)	(1.21)	(0.108)
	464	250	714
ALL occupations	3.93	5.56	0.2809 ***
	(2.77)	(3.70)	(0.019)
	16,217	3,555	19,773
ALL occupation except engineers	3.93	4.89	0.1879 ***
	(2.77)	(2.48)	(0.018)
	16,217	3,129	19,346

Data from 1891-1912. Columns 1 and 2 are raw statistics. Each cell in column 3 comes from a separate regression. Robust standard errors in parentheses. Single, double, and triple asterisks denote 90%, 95% and 99% level of confidence, respectively.

TABLE 5. Difference in wages by technology, additional controls

Occupation	*Difference in log wage for steam, basic specification in Table 4, Column 3 plus:* dummy for able to sign own name	dummies for country of birth	voyage characteristics	All previous columns' controls
Mate	0.1232 ***	0.0634 **	0.0558	0.0352
	(0.029)	(0.029)	(0.034)	(0.034)
	1,337	1,327	1,258	1,249
Bosun	–0.0140	–0.0143	–0.0522	–0.0560
	(0.060)	(0.059)	(0.071)	(0.067)
	659	651	637	629
Able-bodied seaman	0.1677 ***	0.1676 ***	0.2157 ***	0.2203 ***
	(0.026)	(0.026)	(0.028)	(0.028)
	12,448	12,232	12,062	11,852
Ordinary seaman	–0.0723	–0.0300	–0.0151	–0.0318
	(0.105)	(0.103)	(0.100)	(0.092)
	1,315	1,281	1,290	1,256
Cook/steward	–0.0044	–0.0254	–0.0006	–0.0361
	(0.032)	(0.035)	(0.047)	(0.052)
	1,094	1,083	1,033	1,024
Carpenter	0.1690 ***	0.1585 ***	0.2309 ***	0.2190 ***
	(0.033)	(0.039)	(0.065)	(0.061)
	485	478	463	456
Other	0.6305 ***	0.6743 ***	0.7669 ***	0.7530 ***
	(0.110)	(0.117)	(0.162)	(0.167)
	714	692	670	649
ALL occupations	0.2786 ***	0.2715 ***	0.3006 ***	0.2827 ***
	(0.019)	(0.019)	(0.023)	(0.023)
	19,773	19,443	19,042	18,723
ALL occupation except engineers	0.1875 ***	0.1829 ***	0.2205 ***	0.2022 ***
	(0.018)	(0.018)	(0.022)	(0.022)
	19,346	19,020	18,641	18,325

Data from 1891-1912 for men aged 16-60. Each cell comes from a separate regression. Robust standard errors in parentheses. Single, double, and triple asterisks denote 90%, 95% and 99% level of confidence, respectively. See notes to Table 3 for definition of "Other" category. Voyage characteristics are crew size (quadratic), whether embarking form home country, whether discharging at home country, gross tonnage, year ship was constructed, and intended duration (quadratic).

Table 6. Estimation of the Steam Premium using Panel Data

Regression of log wage

	(1)		(2)		(3)	
steam	0.1887	***	0.1316		0.1418	
	(0.0316)		(0.0958)		(0.0965)	
age	0.0277	***	0.1167	***	0.1203	***
	(0.0021)		(0.0076)		(0.0586)	
age squared	-0.0003	***	-0.0015	***	-0.0015	***
	(0.0000)		(0.0001)		(0.0001)	
N	18586		19726		18586	
year controls	yes		yes		yes	
occupation dummies	yes		no		no	
individual fixed effects	no		yes		yes	
voyage controls	yes		no		yes	

Notes: Estimates based on panel data created by matching surname, first name, birth year, country and city of birth. The panel data contains 21,948 observations and 9,263 individuals. Data from all years 1861-1922 are used. Steam effect is identified from 69 observations 24 individuals observed in both technologies.

Table 7. Percentile Position of Switchers to Steam

occupation	Percentile Position in Wage Distribution in Sail	Number of Observations
1-mate	46.4	12
2-bosun	49.1	5
3-able-bodied seamen	55.8	9
4-ordinary seamen	38.5	5
5-cook/steward	52.0	1
6-carpenter	49.0	2

Notes: Estimates based on panel data created by matching surname, first name, birth year, country and city of birth. The panel contains 21,948 observations and 9,263 individuals. Data from all years 1861-1922 are used. The table reports average percentile position of switchers in the residual wage distribution in sail. The regressions control for age, age squared, year, literacy, country of birth and voyage characteristics.