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TECHNOLOGICAL CHANGE, OCCUPATIONAL COMPOSITION, AND WAGE PREMIUMS: EVIDENCE FROM LINKED EMPLOYER-EMPLOYEE DATA

WORKING PAPER
N:O 364

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ISBN: 978-951-39-4038-6
ISSN: 1799-3040
Jyväskylä 2010

ABSTRACT

This study analyzes the impacts of the technological change on wage premiums and the occupational composition of the labor force using linked employer-employee panel data. We find that (i) technological change (steam engine) had both new-skill-demanding and skill-replacing aspects, showing up as an increase in the demand for highly skilled and unskilled labor and a decline in the demand for moderately skilled labor, and (ii) unobserved individual and workplace heterogeneity captures a significant part of the observed technology premiums in wages. The results provide support for the hypothesis of the polarizing effect of the technological change on the labor market.[1]

Keywords: wage premiums, skill composition, technological change, polarization

JEL: J31

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[1] We are indebted to Miikka Rokkanen, Sampo Pehkonen, and Janne Eskelinen for their excellent research assistance. We thank participants at the 21st EALE conference in Tallinn, the 5th IMEHA congress in Greenwich, and the VATT research seminar in Helsinki for useful comments and suggestions. The financial support of the Yrjö Jahnsson Foundation (grant number 5957) is gratefully acknowledged.

1. Introduction

Recent empirical research on changes in the wage inequality and skill composition of workers has certain common features. First, most of the studies have focused on the evolution of wages and skill composition over the last twenty or thirty years. This is a well-founded and rational approach as the ICT revolution of the 1980s provided an interesting basis for research on the impact of new technology on the labor market. Analyses that use historical data or examine alternative technological changes are rare, although they could provide a useful perspective for recent findings.[2] Second, the observed rise in overall wage inequality, particularly in the US and UK labor markets, has been generally accounted for by skill-biased technological change (SBTC). According to this view, technological advances raise the relative demand for skilled labor, and thus skilled laborers' wages, in every task. The skills are, in turn, typically measured by schooling or by the white- versus blue-collar distinction. Occupations or well-defined tasks are seldom used, although one could argue that employers post their vacancies and employees apply for jobs by specifying first the occupation and only second the level of education.[3] Third, evidence suggests that the bulk of the change in skill composition and wage inequality has taken place within industries and firms rather than between industries.[4] This calls for a detailed industry-level analysis that combines employee information with workplace information. Such analyses are, again, in short supply.[5]

In this study, we analyze linked employer-employee data on the Swedish maritime industry. The panel data are collected by pooling individual labor contract data from historical archives and contain information on individual wages, occupations, job attributes and workplace characteristics. The data span from the 1860s to the early 1910s, containing information on more than 1,500

[2] See Katz & Autor (1999) for a review of the literature of the 1980s and 1990s. For a short review of recent studies, see e.g. Autor, Katz & Kearney (2008). Atack, Bateman & Margo (2004), Chin, Juhn & Thompson (2006) and Goldin & Katz (2008) are rare examples of the use of historical data. In Goldin & Katz (2008), the data span 1915–2005. Atack et al. consider the period from 1850-1880 using establishment data, and Chin et al. make use of data on merchant marines from 1891–1912.

[3] For evidence, see Bound & Johnson (1992), Katz & Murphy (1992), Juhn (1999), Acemoglu (2002), and Autor, Levy & Murnane (2003.) For broader and richer views, see Card & DiNardo (2002), Lemieux (2006), and Autor, Katz & Kearney (2008). See also Eckstein & Nagypal (2004) and Goos & Manning (2007) for the use of data on tasks and occupations.

[4] See Berman, Bound & Machin (1998), Machin & van Reenen (1998) and Bartel & Sicherman (1999). For example, Bartel & Sicherman report that the wage premium associated with technological change is primarily due to the sorting of better workers into those industries.

[5] For the use of establishment-level data, see Dunne, Haltiwanger & Troske (1997), Dunne et al. (2004).

vessels and 38,000 crew members. The dataset at hand is outstanding in three ways. First, the introduction of the steam engine caused gradual replacement of sail-only vessels by steam-powered vessels. This technological change was clearly a major one. It not only changed the capital intensity of the industry but also created new occupations in the industry, including engineers and engine room operatives.

Second, the employer-employee panel data ensure that there is a precise link between the worker (seaman), the establishment (vessel) and the prevailing technology. The possibility to control for observed and unobserved individual and workplace characteristics in a detailed manner provides a firm basis for an empirical analysis of the determinants of relative wages across occupations in this particular industry. Third, the data allow us to identify over 5,500 seamen who experienced a change in the technology of their workplace, i.e., who moved from a sail-only vessel to a steam-powered vessel or vice versa. This subsample provides, at best, unbiased estimates of the wage impact of steam technology in different occupational groups over the adaptation period of the new technology.

The structure of the paper is as follows: Section 2 outlines theoretical starting points of the study by discussing the role of production technology in the demand for skills in the context of maritime industry. We combine Goldin and Katz's (1998) model of technology changes and demand for skills with recent findings of polarization of the labor market (Autor, Levy & Murnane, 2003; Autor, Katz & Kearney, 2006; Goos & Manning, 2007; Goos, Manning & Salomons, 2009). Section 3 describes trends in technology, occupational structure and wages in the industry. The adoption of the new steam-based technology was sluggish. It took almost 40 years before 80 percent of the total capacity of the vessels was steam-operated. We report how the occupational composition of the crew, and thus the skill composition, changed substantially over the transition period.

Section 4 reports results on the evolution of wage premiums across occupations and the impact of technological innovation (steam) on these premiums. We use a regression framework and panel data methods to explain individual wages. We find that highly skilled mates and unskilled ordinary seamen benefited from technological change in two ways. Their relative employment shares grew over the transition period, and they also earned a considerable steam premium. Skilled able-bodied seamen, in turn, suffered. In addition to that their employment share diminished their relative wages on steam vessels fell. The findings suggest that the polarization of the labor market is not a new phenomenon. Finally, Section 5 concludes.

2. A framework

2.1 Technological change and demand for skills

Goldin and Katz (1998) present a model where shifts between production processes change the relative demand for skill. Manufacturing is assumed to have two distinct stages: a machine installation and maintenance segment and a production or assembly portion. At the first stage of production, skilled labor and raw capital create workable machines, which are then used by unskilled labor to create the final product in the second stage. Goldin and Katz argue that capital and skilled labor always complement each other in the machine-maintenance stage in any technology, whereas substitutability between capital and unskilled labor could be substantial in the production portion.

Formally, in a two-level CES production function, workable machines (K^*) are produced by skilled labor (H) and raw capital (K) in the first stage. On steam vessels, raw capital was the steam engine, boilers to create steam and coal to fuel the boilers, while on sailing vessels, the raw capital consisted of the masts, spars, sails and ropes; see Chin et al. (2006) for a similar interpretation.

$$K^* = [\beta_i (\lambda_i^K K)^{\theta_i} + (1-\beta_i)(\lambda_i^H H)^{\theta_i}]^{1/\theta_i}\text{, } \theta_i \leq 1\text{, } i = SAIL, STEAM \qquad (1)$$

In the second stage, unskilled labor (U) and K^* are used to make the final product (Q) (miles of safe and timely passage in the ocean):

$$Q = A_i[\alpha_i (K^*)^{\rho_i} + (1-\alpha_i) U^{\rho_i}]^{1/\rho_i}\text{, } \rho_i \leq 1\text{, } \rho_i > \theta_i \qquad (2)$$

Restriction $\rho_i > \theta_i$ indicates that the elasticity of substitution between skilled labor and raw capital is lower than that between unskilled labor and workable machines. If very strong complementarity is assumed between skilled labor and raw capital, $\theta_i \to -\infty$, the first stage follows Leontief production technology. If $\rho_i = 0$, the second stage follows Cobb-Douglas technology.

Steam vessels employed more raw capital and less skilled labor in the production of workable machines (the installation and maintenance of the steam engine required less labor than ropes and sails). Steam technology, thus, increased the productivity of skilled labor in the first stage, $\lambda^H{}_{STEAM} > \lambda^H{}_{SAIL}$, decreasing the demand for able-bodied seamen while increasing demand for new skills, namely those possessed by engineers.

The second stage of production was also affected by the technological change. Tasks that had previously been performed by the capital/skilled labor aggregate began to be performed by unskilled labor (Chin et al., 2006). More unskilled workers were needed to keep the steam engine running continuously on a steam vessel than to handle ropes on sailing vessels. As a result, steam technology was more intensive in its use of unskilled labor, $(1-\alpha_i)_{STEAM} > (1-\alpha_i)_{SAIL}$. Technological change also created the new unskilled occupation of engine room operative. The demand for ordinary seamen decreased with the advent of the steam technology, while the demand for engine room operatives increased. Provided that $(1-\alpha_i)_{STEAM}$ was sufficiently larger than $(1-\alpha_i)_{SAIL}$, the gross effect of steam technology on the demand for unskilled seamen was positive.

2.2 Job polarization and the rise in wage inequality

In order to emphasize the concurrent skill-augmenting and skill-replacing roles of the steam engine, we separate the group of skilled seamen into two categories: high-skilled (mates, engineers) and skilled (able-bodied seamen). The group of unskilled workers consists of ordinary seamen and engine room operatives, a new occupation among the unskilled.

The model presented above does not take into account possible polarization of the labor market as a result of technological change. This possibility can be illustrated by a model of Autor, Levy & Murnane (2003), who present a framework in which technological change decreases the demand for routine tasks, which are usually located in the middle of the skill distribution.[6] The demand for non-routine tasks (abstract and manual), in turn, increases, and these tasks are located at the bottom and the top of the skill distribution. An increase in the demand for both unskilled and high-skilled workers together with a decrease in the demand for skilled labor hence polarizes the labor market[7] and weakens the relative position of those in the middle of the skill distribution.

To formalize their model, they assume that output is produced using the aggregate Cobb-Douglas production function, where the inputs consist of abstract (A), routine (R) and manual (M) tasks (see Autor, Katz & Kearney, 2006):

$$Q = A^{\alpha} R^{\beta} M^{\gamma} \text{ with } \alpha, \beta, \gamma \in (0,1), \alpha + \beta + \gamma = 1 \qquad (3)$$

[6] Goos & Manning (2007) is a recent empirical application of this hypothesis.

[7] Acemoglu (1999) explains the polarization by search frictions in the labor market. If the supply of skilled labor increases, firms start to eliminate jobs in the middle of the distribution, replacing these jobs with vacancies for both highly skilled and unskilled workers.

In the context of maritime labor, it can be assumed that abstract tasks on vessels are performed by high-skilled workers (H), - mates or engineers – and manual tasks by unskilled workers (U) - ordinary seamen or engine room operatives. According to the model, routine tasks can be performed either by skilled (S) able-bodied seamen or by the steam engine, which is a perfect substitute for the able-bodied. The steam engine is supplied perfectly elastically to routine tasks at price p, which is falling at an exogenous rate. Because the steam engine is a perfect substitute for sails and further for the able-bodied-seamen, a decline in the price of steam technology decreases the wages of the able-bodied.

We assume that educational supply is exogenous and that workers capable of doing the tasks of mates or engineers are each endowed with one efficiency unit of abstract skill, which they supply inelastically to abstract tasks on vessels. Furthermore, we assume that the able-bodied seamen do not possess any abstract skills and that each is endowed with one efficiency unit of manual skill and η_i efficiency units of routine skill, where η is distributed continuously on the unit interval with positive mass at all points $\eta \in [0,1]$ (see Autor et al., 2006). Ordinary seamen and engine room operatives are only capable of doing manual tasks.

Self-selection determines how the able-bodied seamen supply their labor input to manual and routine tasks. Let w_U and w_S denote the wages paid for unskilled manual and skilled routine work, respectively. Each able-bodied seaman i chooses to supply one efficiency unit of labor either to manual tasks or to routine tasks. The decision is based on the relative wage of each kind of work. If $\eta_i < w_U / w_S$, the skilled seaman chooses manual tasks, and he chooses routine tasks otherwise. The labor supply to manual tasks in w_U / w_S is upward sloping and that to routine tasks is downward sloping.

When the price of the steam engine (p) (and thereby w_S) falls, those able-bodied seamen who are endowed with relatively low η_i self-select from routine to manual tasks. The additional demand for routine tasks on vessels (induced by the decrease in p) is now filled by the steam engine. Due to q-complementarity of routine and manual tasks on vessels, the steam engine raises the marginal productivity of manual task labor input, signifying an increase in the wages of ordinary seamen. A shift of additional labor from routine to manual tasks, however, works against the beneficial effect of steam technology on manual wages. It is possible that both w_U and w_S could fall with the decline in p, despite the fact that the unskilled wage relative to skilled wage, w_U / w_S, unambiguously rises[8].

The effect of steam technology on high-skilled wages follows the SBTC hypothesis. Due to q-complementarity, workers in abstract tasks also benefit from an increase in routine task input. Unlike manual tasks, however, there is no additional labor supply response from the skilled labor force because the able-bodied seamen are not capable of performing the tasks of mates or engineers. As a consequence, the steam engine unambiguously increases w_H, both absolutely and relative to w_S and w_U.

Complementarity between high-skilled labor and new technology is much stronger than it is between unskilled and new technology. The complementarity between engineers and steam technology was reinforced by the Merchant Shipping Act, which required all steam vessels to carry a specified number of certified engineers that depended on the power of the ship's machinery (Chin et al., 2006). The assumption of strong complementarity is included in equations (1) and (2), where the first stage of the production could be realistic to present even as a Leontief production function with perfect complementarity between high-skilled labor and raw capital.

When the polarization hypothesis of Autor et al. (2003; 2006) is connected to the production function of Goldin and Katz (1998), the labor input of skilled able-bodied seamen on sailing vessels (together with the labor input of high-skilled mates) complements raw capital (K) at the first stage of the production, where the workable capital (K^*) is produced. On steam vessels, in turn, the labor input of the able-bodied is a substitute for K. Hence, equation (1) on steam vessels consists of two kinds of labor inputs: high-skilled mates and engineers and skilled able-bodied seamen. Skilled labor (S) is now a perfect substitute for K, whereas high-skilled labor (H) perfectly complements K. The production function in the first stage, where K^* is produced, takes the form:

$$K^*_{STEAM} = \left[\beta_{STEAM}(\lambda_{STEAM}{}^{K} K) + (1-\beta_{STEAM})(\lambda_{STEAM}{}^{S} S)\right] + \min(\lambda_{STEAM}{}^{K} K, \lambda_{STEAM}{}^{H} H) \quad (4)$$

The second part of production, which produces the final product (Q) (miles of safe and timely passage in the ocean), still follows equation (2):

[8]The role of self-selection is important: Due to a composition effect, the observed wage of workers in routine tasks can either rise or fall ‑ although the wage measured in efficiency units unambiguously falls - because the remaining routine workers have above-average routine skills (Autor et al., 2006).

$$Q = A_{STEAM}[\alpha_{STEAM}(K^*)^{\rho_{STEAM}} + (1-\alpha_{STEAM})U^{\rho_{STEAM}}]^{1/\rho_{STEAM}}, \ \rho_{STEAM} \leq 1, \quad (5)$$

where those able-bodied seamen who perform the manual tasks on steam vessels are perfect substitutes for the unskilled labor input (U) and as substitutable for K^* as ordinary seamen, as determined by parameter ρ_{STEAM}. The model indicates that the adoption of the steam engine fundamentally weakened the relative position of skilled able-bodied seamen in the maritime industry while benefiting the low-skill and high-skill occupations. In the following sections, we use a unique dataset to test the empirical relevance of this hypothesis.

3. Change in technology, occupational composition, and wages

3.1 Data

In this study, we exploit seamen's house documents collected from six major port towns in Sweden. These are, in alphabetical order, Gävle, Härnösand, Hudiksvall, Karlskrona, Söderhamn, and Visby. The seamen's house (sjömanhus) was a public institution introduced in Sweden in the mid-18th century. They were established to collect data on the number of sailors available for military use. In practice, the houses played an important role in the labor market. Practically every seaman going abroad would have been enrolled at a seamen's house. When a ship returned, documents were completed with its date of arrival and information about the voyage, including possible deaths, sicknesses, and desertions. [9]

Our sample consists of more than 22,800 individuals employed on over 1,500 vessels over the period of 1869–1914. The data comprise one of the earliest examples of employer-employee information.[10] They contain detailed individual-level information, including the name, date and place of birth, age, marital status, salary, occupation on board and date of hire, for every seaman listed. The name, tonnage, type, and likely destination of the vessel on which each sailor worked are also documented. A major advantage of the data is that they document individual wages and occupations and that information is linked to the characteristics of the voyage and workplace (vessel), including its technological status. We can identify three major occupational groups with a significant number of observations in each year. These are mates, able-bodied

[9] See the Arkion database at http://www.arkion.ra.se.

[10] The data examined in Chin, Juhn & Thompson (2006), which were taken from the Maritime History Archive, are of a similar type. Their analysis focusing on the merchant marine of ten major Atlantic Canadian ports covers the period of 1891–1912.

seamen, and ordinary seamen. In addition, two new occupations created by the new technology - engineers and engine room operatives - working on steam-operated vessels can be identified.

We exclude captains from the analysis because their wage compensations typically include unidentifiable profit shares. Similarly, we omit less frequent occupations, such as cooks, stewards and deck boys. In addition to the employer-employee characteristics, we use emigration and the relative size of the transport and communication sector as proxies for the demand and supply of labor in the maritime industry[11]. The basic descriptive statistics are given in the Appendix.

3.2 Technological change in the maritime industry

Figure 1 depicts the evolution of steam technology as a percentage share of steam vessels among all vessels over the investigation period. Both the weighted and unweighted measures are plotted. The former measure weights the vessels by their capacity (tons). The figure reveals one important point. The transition from the prevailing technology (sail) to the new technology (steam) was a long-lasting process. The first steam vessels carrying the Swedish flag in this sample started to operate in1869, and it took over 20 years before steam vessels achieved a 20 percent share of the total capacity. The adoption pace was rapid from 1890 to 1910, and by the year 1914, steam vessels accounted for about 86 percent of the capacity. In total, it took around three decades before steam became the preferred technology in the maritime industry.

[Figure 1 about here.]

3.3 Occupational composition and wages

The hypothesis of skill-biased technological change posits an increase in the demand for skilled labor relative to less-skilled labor. We begin examining this issue by reporting the occupational composition of the crew over time. Because tasks are generally directly linked to occupations, the classification of occupations into three groups, namely highly-skilled mates, moderately skilled able-bodied seamen and unskilled ordinary seamen, serves the analysis of changes in skill composition well.

The decline in the share of ordinary seamen in the maritime industry was continuous over the period, falling from 43 percent in 1869 to 29 percent in 1914 (Figure 2). The share of able-bodied seamen declined from 21 percent to 13

[11] The aggregate measures are collected from Grigg (1980).

percent. The share of high-skilled mates also declined, from 18 to 14 percent. These declines coincided with an increase in the shares of unskilled engine room operatives and high-skilled engineers. In short, the steam period from 1869 onwards is characterized by the emergence of new occupations, some highly skilled (engineers) and some unskilled (engine room operatives), as well as a decline of roughly the same proportion in other occupations.

[Figure 2 about here.]

The technological change related to steam power had both a new-skill-demanding aspect, showing up as an increase in the demand for highly skilled engineers, and a skill-replacing aspect, resulting in a decline in the demand for skilled able-bodied seamen and unskilled ordinary seamen and an increase in unskilled engine room operatives. This is confirmed in Table 1, which reports the occupational composition of the crew, as well as the average wages and wage bill shares of the average sail voyage and average steam voyage over the period 1869–1914. The differences are substantial. The proportion of mates and able-bodied seamen in the crew is 7 percentage points lower on steam vessels than on sailing vessels, declining from 35 percent to around 28 percent. The change in the proportion of ordinary mariners is even more marked, falling from 42 percent of the crew to 24 percent. These decreases were offset by increases in the shares of engineers (11 percent) and engine room operatives (27 percent). Wage bill shares further confirm these differences. The wage bill shares of mates (28 percent), able-bodied seamen (21 percent) and ordinary seamen (29 percent) fell to 12.5–15.4 percent of the total wage bill.

Comparison of mean wages across occupations reveals at least three points. First, the wage differentials across occupations for sail-operated vessels are notable. Highly skilled mates earned more than skilled able-bodied seamen, and able-bodied seamen earned more than unskilled ordinary seamen. These facts remain true throughout the whole investigation period. Second, the mean wages of engineers, the highly skilled group on steam vessels, were higher than those of mates, a dominant group of highly skilled labor on sailing vessels. Engine room operatives, an unskilled group on steam vessels, earned more than their counterparts, ordinary seamen, on sailing vessels. The wages of unskilled engine room operatives matched those of skilled able-bodied seamen.[12]

Third, mean wages were higher on steam-operated vessels. The uncontrolled steam premium calculated from the data varied from 30–47 percent over the

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12 As Chin et al. (2006) point out, premiums from working on steam vessels may include a compensating differential for the unpleasant work environment as well as for skills gained from training. The former explanation is fitting for engine room operatives, who often worked under poor conditions below the deck, whereas the latter better suits engineers, who also had work opportunities on land.

period of 1869-1914. The data indicate that the new-skill-demanding aspect of technological change accounts for the observed increase in the mean wage. If engineers and engine room operatives are excluded from the sample, the mean wage premium on steam-operated vessels would decrease, on average, to 13-30 percent over the research period. Another obvious explanation for the rise in the mean wage is related to the production technology and higher productivity. Capacity, measured by gross tons, was considerably higher for steam-powered vessels than for sail-only vessels. As we see later, a 10 percent increase in vessel capacity increases wages by 0.2 percent.[13]

Regarding the wage inequality, the data indicate that variations over the decades are modest within technologies but substantial across technologies. The average coefficient of variation over the investigation period is 0.43 for the sail and 0.56 for the steam technology, i.e., 30 percent higher for steam. The increase in overall wage inequality in the maritime industry may be associated with the emergence of a new technology that resulted in new occupations: if we exclude engineers from the steam sample, the average value of the coefficient of variation for steam technology declines from 0.56 to 0.47. This provides indirect support for the SBTC hypothesis.

[Table 1 about here.]

The polarization hypothesis of the labor market predicts an increase in the demand for both highly skilled labor in abstract jobs and unskilled labor in manual jobs at the expense of skilled routine task jobs. To illustrate the possible wage polarization in the maritime industry, Figure 3 depicts the average wage growth by deciles from the slow period of adaptation of the steam engine, 1869-1890, and from the fast period, 1890-1914. Three notes are worth mentioning here. First, the average wage growth in all deciles is high in the latter period. This indicates a positive impact of new technology on average wages. Second, the wage evolution in the first period indicates relatively higher wage growth for the third and fourth deciles as well as for the ninth decile. Third, although no perfect U-shaped distribution was found, the wage growth in the second period reveals signs of polarization, with the fastest wage growth in the first and ninth deciles.

[Figure 3 about here.]

[13] These results are in line with the findings of Chin et al. (2006) for the Canadian merchant shipping industry. They observed that the steam premium would decrease from 43 percent to 26 percent if engineers were excluded from the sample.

4. Change in technology and returns to occupations

4.1 Occupational premiums over time

We use a regression framework to provide a closer look at returns to occupations over the period during which both technologies were present. The purpose of the analysis is twofold. First, the evolution of occupational differences in wages over a period witnessing a major technological change is, in itself, worthy of an empirical analysis. Issues such as how new emerging occupations change the relative wage position of the old occupations and how occupational premiums evolve over the adoption phase are of particular interest. Second, the panel data at hand allow us to examine the impact of new technology on wages in old occupations in a well-defined setting. In particular, we can control for unobservable individual and vessel heterogeneity by panel data methods, in addition to a number of interesting observable factors. The observables are related either to individual workers (e.g., age, region of residence), their labor contracts (e.g., duration and destination of a voyage) or their workplace (e.g., capacity and type of the vessel).

We identify five major occupational groups according to type of labor: mates (highly skilled), able-bodied seamen (skilled), ordinary seamen (unskilled), engineers (highly skilled on steamships), and engine room operatives (unskilled on steamships). Because the written labor contract is the basic observation unit and the same individual may appear several times in the data, we identify individuals by name, year of birth and birth place to utilize the longitudinal characteristics of the data.

First, we examine the returns to occupation by estimating the following wage equation:

$$\ln w_{ijt} = \mu_i + \kappa_j + oOCC_{it} + \varsigma X_{it} + \tau Y_{jt} + \delta Z_{ijt} + \omega A_t + time + \varepsilon_{ijt}, \qquad (6)$$

where the (log) monthly wage[14] of individual i hired on vessel j in year t is regressed on individual (vector **X**), vessel (**Y**) and contract (**Z**) characteristics[15]. Occupation dummies (OCC) capture wage premiums for mates, engineers, engine room operatives and ordinary seamen, respectively, relative to able-bodied seamen, who serve as a reference group. The estimation period is 1869-1908 due to availability of data on the aggregate demand and supply in the transport and communication industry (vector **A**). The demand for labor in the

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[14] Wage in 1914 Swedish kronor.

[15] Wages and other contract characteristics on vessels were bargained at the beginning of each voyage when the staff was hired, and these contracts were in force during the whole voyage.

transport and communication industry is proxied by its share of total employment, which varies from 1.2 percent in 1869 to 4.2 in 1908. We use emigration as a proxy for over-supply of the labor force and hence aggregate unemployment. The variable for the unemployment rate is constructed by dividing the number of emigrants by the sum of emigrants and the employed labor force. The cyclical variation in wages is controlled by five-year dummies, $time$.

Table 2 reports results where the first specification (Column 1) is pooled OLS with no panel effects. The second specification adds individual fixed effects, μ_i, into the equation (Column 2). The third specification (Column 3) adds vessel-specific fixed effects, κ_j, together with the individual effects[16]. Pooled estimates of average occupation premiums over the period (see column 1) suggest that engineers earned 66 percent more than the able-bodied seamen. For mates, the premium is 26 percent. For ordinary seamen, the pooled regression estimates a 38 percent negative premium, and for engine room operatives, a 1.5 percent negative premium. Individual fixed effects capture a considerable amount of the wage differentials, and adding the vessel effects further decreases the premiums. For mates, the premium relative to able-bodied seamen falls by 11 percent and for engineers by 26 percent, to about 15 percent for mates and 40 for engineers (Column 3). The premium for the able-bodied seamen relative to ordinary seamen falls from 38 to 21 percent. The situation of the engine room operatives is interesting: the pooled regression predicts lower wages than for the able-bodied, while the panel data specification including individual and firm heterogeneity indicates a positive wage premium of about 9 percent.

The results indicate that there are considerable wage-size effects, with the average wage increasing with the size of the establishment (in our case, the size of a vessel). This is confirmed by the type and capacity of the vessel. A 10 percent increase in capacity measured by register tons increases wages by 0.2 percent. [17] Compensations also differ across the sailing areas: there are 2–5 percent premiums on voyages in the Atlantic Ocean, Mediterranean and Nordic Sea relative to those in the Baltic Sea. Individual and vessel fixed effects,

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[16] See Cornelissen (2008) for the estimation of the linear model with two high-dimensional fixed effects. We ignore the match-specific fixed effects suggested by, e.g., Woodcock (2008), which would capture the potential unobserved heterogeneity related to each of the matches between individuals and vessels as we have only one observation per match; i.e., we do not observe linked employer-employee pairs over particular tenures. Therefore, we settle for considering unobserved heterogeneity related separately to seamen and vessels.

[17] Mitchell (2005), using the U.S. college wage premium data of Goldin and Katz (2000) and updated in Goldin and Katz (2008), is a recent contribution in this field. He attributes the evolution of the skill premium to the specialization of production, as measured by the ratio of fixed to marginal costs of capital and proxied empirically by the plant size.

however, capture these premiums. The same applies to the role of the seamen's house: the premiums are captured by vessel fixed effects[18].

The estimate of the duration of the contract is positive, indicating a modest 0.1 percent increase in wages for every additional month of the contract. The effect of age, which proxies work experience, on wages is positive as expected, reflecting enhanced productivity and maturity. An additional year of age increases wages by 6-11 percent, the effects being stronger with individual and vessel fixed effects. The aggregate factors, namely the evolution of the transport sector and emigration, also contribute to wages. A one-tenth of a percentage point increase in the employment share of the transport and communications industry increases wages by 5 percent (Specification (3)). A similar increase in the share of emigrants of the total labor force contributes to wages by 0.8 percent. The pooled OLS estimates place an average steam wage premium at 8.1 percent. Controlling for the individual fixed effects increases the premium to 8.5 percent, but the vessel fixed effects decrease it to 5.8 percent. We will return to the steam premiums in the next section.

[Table 2 about here.]

Figure 4 depicts the time paths of the estimated wage premiums by occupation. The reference group is able-bodied seamen, and the results are based on specification (3) augmented by a full set of interactions between occupations and time dummies. The Figure illustrates that the premium of mates remains relatively stable, varying from 11 percent in the first period to 18 in the fourth period and then declining to 12-16 percent in later periods. The pay gap between the able-bodied and ordinary seamen varies more, from 30 percent in the first to 10 percent in the last period, suggesting the weakening of the position of skilled able-bodied seamen in relation to unskilled ordinary seamen.

The engineers, a highly skilled group on steam vessels, enjoy the highest premium, excepting the first years of the structural change towards steam-operated vessels. The premium exceeds that of the mates, a dominant group of skilled labor on sailing vessels, in the third period (1879-1883), peaks at 49 percent in the fourth period, slightly declines after that and finally peaks again at 51 percent in the last period. The engine room operatives, an unskilled group on steam vessels, also earn a considerable premium over the skilled able-bodied seamen. The highest premium, 28 percent, is obtained for 1884-1888, when it exceeds that of mates. Afterwards, the premium declines, and the wage evolutions of the two new occupations, engineers and engine room operatives, created by steam technology diverge. It is worth noting that the earnings of the skilled able-bodied seamen are less than or equal to those of the unskilled engine room operatives over the whole period.

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[18] There is only slight variation in seamen's house and in destinations within vessels.

[Figure 4 about here.]

4.2 Steam premiums over time and by occupation: results for technology switchers

The average steam premium with individual and vessel fixed effects estimated above across the whole sample was 5.8 percent. In order to unravel the direct wage effect of steam technology by occupation over the adaptation period, we estimate the steam premiums only for the occupations that existed in both technologies - mates, able-bodied seamen and ordinary seamen – and only for those mariners who switched between the two technologies during their career. We were able to identify 5,511 individuals who switched between sail and steam technologies in the period 1869-1908, accounting for 10,926 observations in total.

The wage equation for the steam premiums by occupation takes the following form:

$$\ln w_{ijt} = \mu_i + \kappa_j + o OCC_{it} + \vartheta_1 steam_{jt} + \vartheta_2 steam_{jt} * OCC_{it} + \varsigma X_{it} + \tau Y_{jt} + \delta Z_{ijt} + \omega A_t + time + \varepsilon_{ijt} \quad (7)$$

The estimates shown in Table 3 yield two important findings. First, steam premiums vary considerably between occupations. Second, the unobserved individual and vessel heterogeneities play a significant role in determining the magnitudes of occupational steam premiums. In sum, the results are in line with the polarization hypothesis: there is a clear technology premium for highly skilled mates and unskilled ordinary seamen, whereas the workers of the middle group suffer. Findings on the role of unobservable individual characteristics provide additional support for the polarization hypothesis.

For mates, the pooled regression predicts a 21.9 percent steam premium, which decreases to 11.5 percent with individual fixed effects and further to 8.7 percent when the vessel effects are added. Unobserved individual and vessel heterogeneity hence capture most of the premium. This indicates that more productive mates received better-paid positions on steam vessels than their less productive counterparts and, furthermore, they were employed, in general, on more productive steam vessels (Abowd, Kramarz & Margolis, 1999). The contribution of unobservable characteristics to the steam premium estimates of the ordinary seamen is similarly interesting. Their premium increases from 9.3 percent in the pooled OLS to 14.4 percent with the individual effects and decreases to 12.4 percent with the vessel effects. This suggests that a considerable proportion of the increased demand for the skills of ordinary seamen has been focused on the less-able mariners. This further underlines the polarizing nature of the technological change.

To explicate the evolution of the steam premiums over the period of adaptation to a new technology, we estimate Eq. 7 augmented by interactions with the occupation-steam dummies and time dummies. Figure 5 shows that the premiums are not stable but vary over time. In particular, they all seem to decline with the increasing dominance of steam technology. The ordinary seamen earn considerable 12-17 percent premiums from 1879 to 1898. Afterwards, the premium declines, becoming negative in the last period of 1904-1908. The last two sub-periods are not, however, significant. The able-bodied seamen suffer from the new technology; the steam premium is negative over the majority of the sub-periods, varying from 2 percent in the fourth sub-period to -10 percent in the last sub-period. The result is only tentative, however, because the coefficients reach statistical significance only in 1889-1893. The premium of mates shows a modest negative trend with considerable cyclical variation.

[Table 3 about here.]

[Figure 5 about here.]

To illustrate the effect of technological change on the relative positions of occupations, we calculate premiums for old occupations separately for sail-operated and steam-operated vessels. Table 4 presents the average premiums for mates and ordinary seamen in relation to able-bodied seamen, and Figure 6 depicts their evolution over the adaptation period. The estimates are based on the same regression equations as were used to estimate the steam premiums above, but in this case they are applied only to technology switchers. The results provide further evidence for the interpretation of the negative effect of technological change on skilled able-bodied seamen and, hence, a polarizing influence of the technological change on the labor market; the wage premium of mates over the able-bodied seamen is clearly higher for steam than for sail technology, rising from 16.2 to 27.9 percent. In addition, the wage premium of the able-bodied seamen over the ordinary seamen is 22.2 percent for sail technology but falls to 6.3 percent for steam technology.

[Table 4 about here.]

[Figure 6 about here.]

5. Conclusions

This study unravels the evolution of relative wages and the occupational composition of the labor force using linked employer-employee panel data from the maritime industry over the period 1869-1914. A major shift in the production technology from sail-only vessels to steam-operated vessels allowed us to examine the impact of a technological change on the labor market in a well-defined setting.

According to the analysis, the technological change substantially restructured the occupational composition of the maritime industry. The adaptation of the steam engine not only changed the capital intensity, but also created new occupations. The steam technology had both a new-skill-demanding aspect, showing up as an increase in the demand for highly skilled engineers, and a skill-replacing aspect, resulting in a decline in the demand for skilled able-bodied seamen and an increase in the demand for unskilled engine room operatives.

The panel data analysis implies that the unobserved individual and vessel heterogeneities capture a large part of the steam premiums. For mates, the 22 percent steam premium decreases to 11.5 percent with individual fixed effects and further to 9 percent when the vessel effects are added. This suggests that mates with the highest ability were employed in the highest-paid jobs on the most productive steam vessels. For ordinary seamen, the steam premium varies from 9 percent in the pooled OLS to 14.5 percent with the individual effects and 13 percent with the vessel effects. This implies that a large proportion of the steam premium for the ordinary seamen is due to an increase in the demand for workers with manual skills, and particularly for the lowest-skilled individuals among them. Able-bodied seamen endowed with routine skills did not gain any steam premium, causing their relative position to decrease in the context of the new technology.

In sum, our findings provide evidence for views of the impact of technological changes on the demand for different tasks as well as polarization of the labor market. In particular, the result that high-skilled labor experiences the largest increase in wage premium lends support to the conventional SBTC hypothesis, in which technological change is said to be skill biased. Along the lines of Autor et al. (2003; 2006), Goos & Manning (2007) and Goos et al. (2009), the finding that unskilled ordinary seamen obtain a clear positive premium supports the hypothesis of polarization of the labor market, with rising demand for labor in high-wage abstract and low-wage manual jobs at the expense of middle-skilled routine jobs.

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Figures and tables

FIGURE 1. —TECHNOLOGICAL CHANGE IN THE MARITIME INDUSTRY: THE PROPORTION OF WORKERS ON STEAM VESSELS, FIVE-YEAR AVERAGES OVER 1869-1914

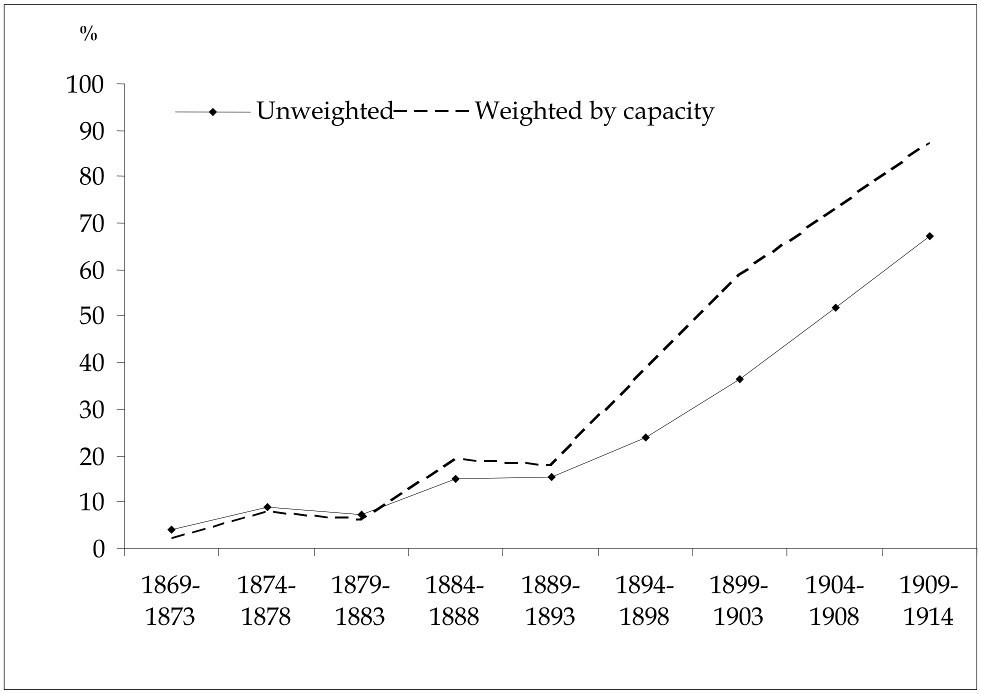


FIGURE 2. — CREW COMPOSITION, ALL VESSELS, FIVE-YEAR AVERAGES OVER 1869-1914

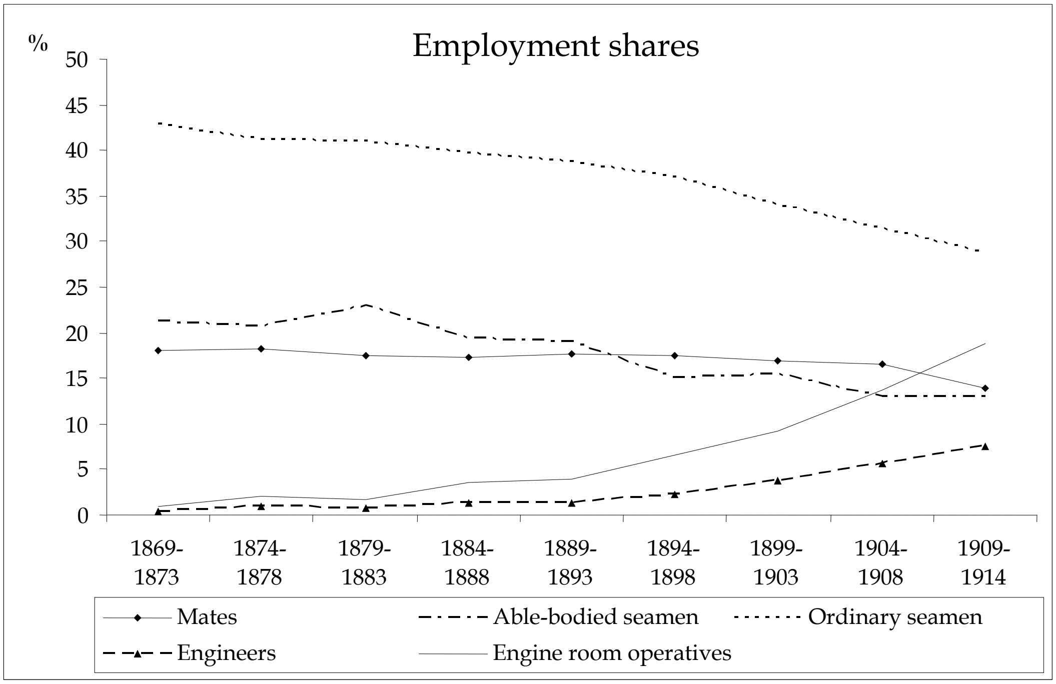


FIGURE 3. —AVERAGE WAGE GROWTH BY DECILES, 1869-1890 AND 1890-1914

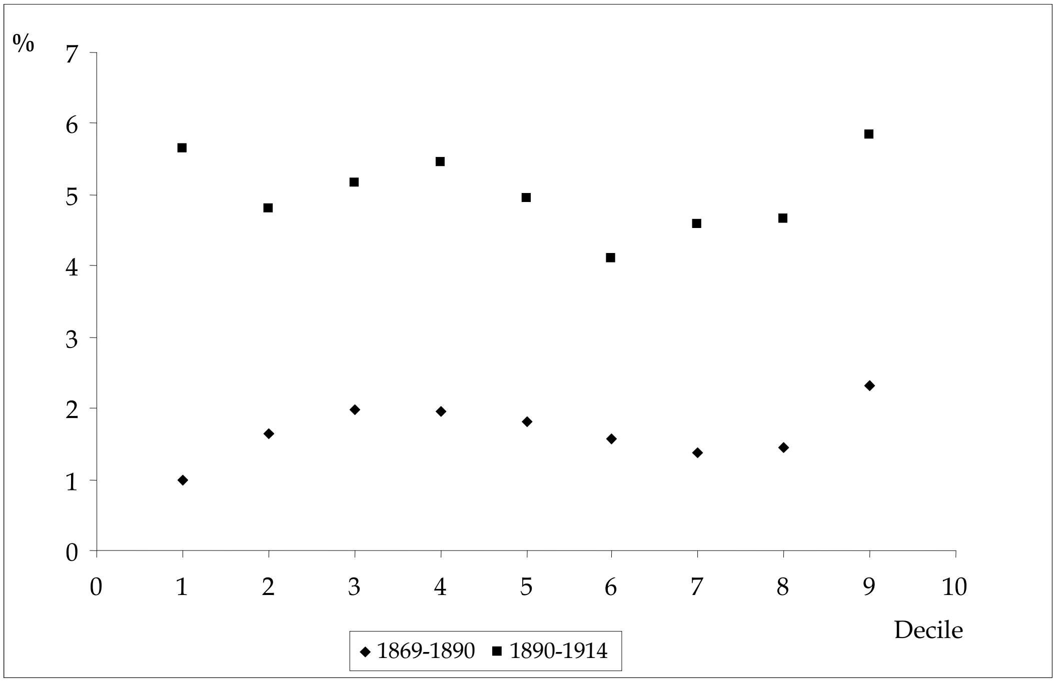
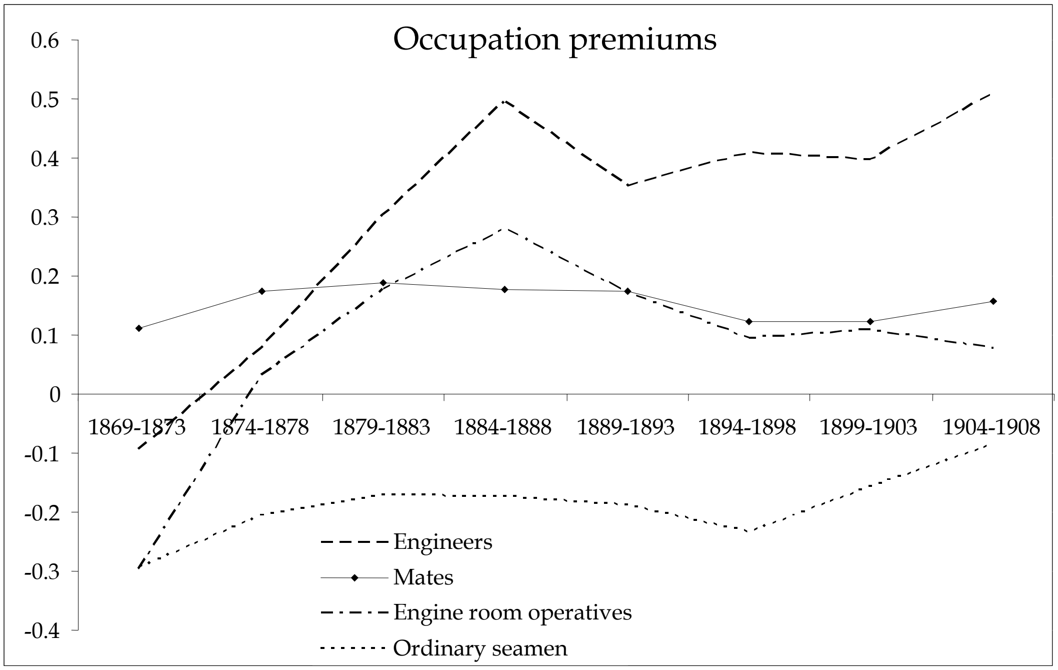
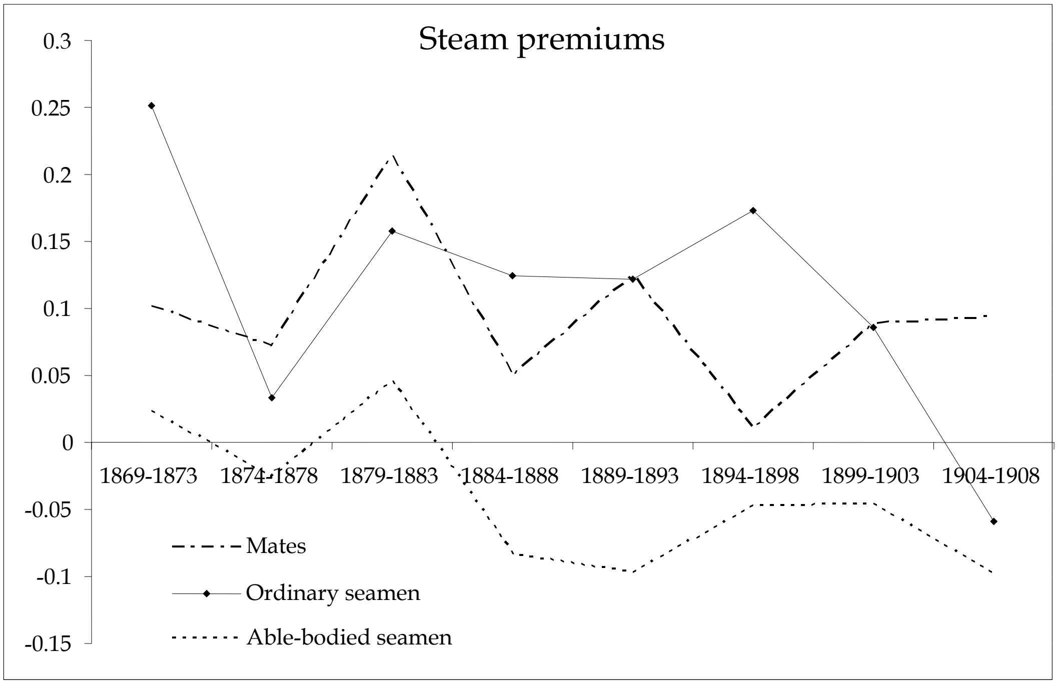


FIGURE 4. —EVOLUTION OF OCCUPATION PREMIUMS: MATES, ENGINEERS, ORDINARY SEAMEN, AND ENGINE ROOM OPERATIVES VERSUS ABLE-BODIED SEAMEN, FIVE-YEAR AVERAGES OVER 1869-1908



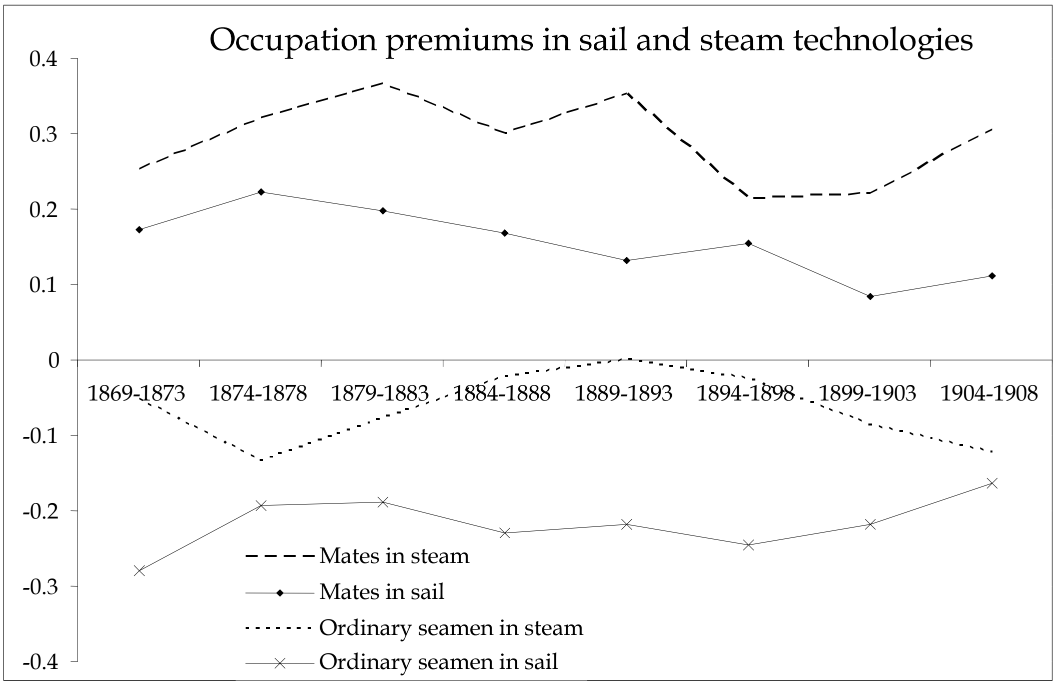
Notes: All sub-periods are statistically significant at least at the 5 percent level for mates as well as for ordinary seamen. 1869-1873 is not significant for engineers. 1869-1873 and 1904-1908 are not significant for engine room operatives.

FIGURE 5. ─EVOLUTION OF STEAM PREMIUMS, FIVE-YEAR AVERAGES OVER 1869-1908



Notes: For mates, 1879-1883, 1889-1893, 1899-1903 and 1904-1908 are statistically significant at least at the 5 percent level. For ordinary seamen, all sub-periods are significant, excepting 1874-1878, 1899-1903 and 1904-1908. For able-bodied seamen, 1889-1893 is significant at the 5 percent level.

FIGURE 6. —EVOLUTION OF OCCUPATION PREMIUMS WITHIN SAIL AND STEAM TECHNOLOGIES: MATES AND ORDINARY SEAMEN VERSUS ABLE-BODIED SEAMEN, FIVE-YEAR AVERAGES OVER 1869-1908



Notes: All sub-periods are statistically significant at least at the 5 percent level for mates and ordinary seamen in sail technology as well as for mates in steam technology. For the ordinary seamen in steam technology, 1874-1878 is significant.

TABLE 1. —EMPLOYMENT, AVERAGE WAGES, AND WAGE BILL SHARES BY OCCUPATION, 1869-1914

	Employment share		**Wage bill share**		**Average wages (Std. Dev.)**	
Occupation	Sail	Steam	Sail	Steam	Sail	Steam
Mates	18.9	11	28.1	15.4	46.0 (13.4)	78.6 (29.4)
Able-bodied seamen	18.5	17.5	21.4	13.5	35.8 (9.6)	43.5 (12.8)
Ordinary seamen	41.7	23.9	28.7	12.5	21.3 (7.8)	29.4 (10.5)
Engineers	-	10.7	-	19.7	-	103.1 (45.2)
Engine room operatives	-	27.1	-	21.4	-	44.4 (13.0)
Others	20.9	9.8	21.8	17.5	26.8 (15.3)	64.4 (58.0)

Notes: The occupation category 'Others' includes captains, stewards, cooks and deck-boys. Wages are monthly wages on voyages in 1914 Swedish kronor.

TABLE 2. — WAGE EQUATIONS WITH OCCUPATION PREMIUMS: MATES, ENGINEERS, ORDINARY SEAMEN, AND ENGINE ROOM OPERATIVES VERSUS ABLE-BODIED SEAMEN, 1869-1908

	(1) OLS	(2) Individual fixed effects	(3) Individual + vessel fixed effects
Individual factors			
Age	0.062*** (0.001)	0.110***(0.003)	0.109***(0.003)
Age squared	-0.001***(0.00001)	-0.002***(0.00003)	-0.002***(0.00003)
Married	-0.029***(0.004)	-0.077***(0.007)	-0.070***(0.007)
Occupation premiums			
Mate	0.261***(0.004)	0.155***(0.006)	0.153***(0.006)
Ordinary seaman	-0.384***(0.004)	-0.211***(0.006)	-0.207***(0.006)
Engineer	0.661***(0.010)	0.448***(0.037)	0.399***(0.040)
Engine room operative	-0.014*(0.007)	0.098**(0.029)	0.093**(0.030)
Vessel characteristics			
Steam vessel	0.081***(0.004)	0.085***(0.008)	0.058***(0.145)
Ln(register tons)	0.024***(0.002)	0.003 (0.003)	0.018*(0.006)
Contract characteristics			
Duration, months	0.001***(0.0002)	0.002***(0.0002)	0.001***(0.0002)
North Sea	0.020***(0.005)	0.006 (0.007)	0.001 (0.008)
Mediterranean	0.038***(0.006)	0.012 (0.008)	0.013 (0.010)
Atlantic Ocean	0.051***(0.009)	0.008 (0.014)	-0.009 (0.017)
Other	0.032***(0.006)	0.004 (0.009)	0.010 (0.010)
Seamen's house			
Hudiksvall	-0.042***(0.010)	-0.069*(0.031)	0.010 (0.040)
Härnösand	-0.016***(0.003)	0.002 (0.010)	0.021 (0.012)
Karlskrona	-0.008 (0.006)	-0.012 (0.015)	0.014 (0.018)
Söderhamn	-0.008 (0.006)	-0.0001 (0.014)	0.018 (0.017)
Visby	-0.080***(0.006)	-0.051**(0.018)	-0.017 (0.022)
Aggregate factors			
Employment share of transport and communication sector	0.355***(0.009)	0.492***(0.020)	0.510***(0.021)
Share of emigrants	0.058***(0.005)	0.078***(0.006)	0.078***(0.007)
Constant	1.636***(0.023)		
R-squared	0.75	0.70	0.74
N	38,860	38,222	38,222

Notes: Dependent variable is $log(W_{ijt})$. W_{ijt} is an individual wage per month on a voyage started in year t measured in 1914 Swedish kronor. Reference groups are: able-bodied seamen; sail-only vessel; Baltic Sea; Gävle; 1869-1873. All specifications include five-year dummies.* denotes statistical significance at the 5 percent level, ** at the 1 percent and *** at the 0.1 percent level.

TABLE 3. —STEAM PREMIUMS BY OCCUPATION, 1869-1908

Occupation	OLS	Individual fixed effects	Individual and vessel fixed effects
Mates	0.219***	0.115***	0.087***
	(0.011)	(0.015)	(0.024)
Able-bodied seamen	-0.035**	-0.001	-0.030
	(0.010)	(0.014)	-0.024
Ordinary seamen	0.093***	0.144***	0.129***
	(0.009)	(0.014)	(0.024)
All	0.082***	0.089***	0.067**
	(0.006)	(0.009)	(0.021)
N	11,050	10,926	10,926
R-squared	0.76	0.76	0.81

TABLE 4. —OCCUPATION PREMIUMS FOR THE SAIL AND STEAM TECHNOLOGIES: MATES AND ORDINARY SEAMEN VERSUS ABLE-BODIED SEAMEN, 1869-1908

Occupation	OLS	Individual fixed effects	Individual and vessel fixed effects
Mates - steam	0.481***(0.013)	0.281***(0.019)	0.279***(0.022)
Mates - sail	0.226***(0.008)	0.165***(0.011)	0.162***(0.012)
Ordinary seamen - steam	-0.261***(0.011)	-0.088***(0.018)	-0.063**(0.021)
Ordinary seamen - sail	-0.389***(0.008)	-0.233***(0.011)	-0.222***(0.011)
N	11,050	10,926	10,926
R-squared	0.76	0.76	0.81

Appendix. Data description

	1869-1873	1874-1878	1879-1883	1884-1888	1889-1893	1894-1898	1899-1903	1904-1908	1909-1914
Individual factors									
Age	26.1	25.2	25.7	25.8	26.0	25.8	25.4	25.5	25.9
Married, dummy	0.228	0.193	0.201	0.192	0.216	0.205	0.186	0.183	0.208
Occupations									
Able-bodied seaman, dummy	0.254	0.249	0.275	0.239	0.235	0.192	0.194	0.161	0.157
Mate, dummy	0.216	0.220	0.209	0.212	0.219	0.222	0.213	0.206	0.170
Ordinary seaman, dummy	0.514	0.495	0.489	0.489	0.480	0.472	0.428	0.390	0.351
Engineer, dummy	0.005	0.011	0.008	0.016	0.017	0.029	0.046	0.070	0.092
Engine room operative, dummy	0.011	0.024	0.020	0.043	0.049	0.084	0.118	0.172	0.230
Contract characteristics									
Baltic Sea, dummy	0.115	0.128	0.156	0.193	0.161	0.381	0.491	0.555	0.643
North Sea, dummy	0.648	0.621	0.438	0.451	0.485	0.432	0.432	0.388	0.330
Mediterranean, dummy	0.142	0.124	0.122	0.195	0.175	0.024	0.014	0.009	0.009
Atlantic Ocean, dummy	0.006	0.018	0.019	0.022	0.023	0.079	0.026	0.022	0.015
Other, dummy	0.088	0.108	0.265	0.139	0.156	0.083	0.037	0.026	0.003
Duration, months	9.747	9.455	9.489	8.401	8.313	7.871	6.886	6.942	7.109
Vessel characteristics									
Register tons	330.326	331.264	350.252	342.379	363.071	437.169	463.868	481.043	553.637
Steam vessel, dummy	0.047	0.098	0.082	0.170	0.172	0.265	0.395	0.554	0.705
Sailing vessel, dummy	0.953	0.902	0.918	0.830	0.828	0.735	0.605	0.446	0.295
Seamen's house									
Gävle, dummy	0.423	0.409	0.473	0.354	0.344	0.366	0.300	0.037	0.000
Hudiksvall, dummy	0.002	0.003	0.005	0.006	0.003	0.039	0.055	0.099	0.111
Härnösand, dummy	0.360	0.332	0.255	0.261	0.229	0.122	0.147	0.228	0.296
Karlskrona, dummy	0.048	0.068	0.072	0.069	0.100	0.094	0.122	0.166	0.176
Söderhamn, dummy	0.029	0.036	0.058	0.091	0.091	0.072	0.055	0.106	0.113
Visby, dummy	0.138	0.150	0.137	0.218	0.233	0.307	0.321	0.365	0.304
Aggregate factors									
(Workers in transport and communication sector)/all workers*100	1.407	2.104	2.473	2.362	2.572	2.745	3.279	3.916	4.335
Emigrants/(emigrants+workers)*100	0.603	0.580	1.271	1.714	1.329	1.027	1.033	1.058	