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Jari Ojala, Department of History and Ethnology, University of Jyväskylä

Jaakko Pehkonen, School of Business and Economics, University of Jyväskylä and Government Institute for Economic Research, Helsinki; University of Jyväskylä, PL 35, 40014 Finland; email: jaakko.pehkonen@jyu.fi

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Abstract

This study analyses the evolution of wages and occupational composition of labour over three centuries, from 1755 to 1914, using worker-workplace data. The data from one industry offers a unique view on long-term trends in skill composition, wage inequality and occupational wage premiums. A major shift in the production technology, a shift from sail-only vessels to steam-operated vessels, in turn, allows the examination the popular skill-biased technological change (SBTC) hypothesis in a well-defined setting. We find that (i) technological change had both a new-skill-demanding aspect, showing up as an increase in the demand for skilled engineers, and a skill-replacing aspect, resulting in a decline in the demand for skilled able-bodied seamen and an increase in unskilled engine room operatives, (ii) increasing wage inequality in the latter part of the 18th century was associated with the emergence of new skilled occupations and rising wages of skilled seamen, and (iii) wage inequality evolved slowly over time and there were different, declining and rising phases in wage inequality.

Key words: wage inequality, skill composition, technological change

JEL classification numbers: J31

Tiivistelmä

Tutkimuksessa tarkastellaan palkkahajonnan ja ammattirakenteen muutosta yhdellä toimialalla (merenkulku). Yksilötason sopimustietoihin (pestaukset) perustuva tilastoaineisto viiden ruotsalaisen kaupungin merimiehistä ja heidän työpaikoistaan (laivat) kattaa poikkeuksellisen pitkän ajanjakson, alkaen vuodesta 1755 päättyen vuoteen 1937. Tarkasteltava ajanjakso pitää sisällään toimialalla tapahtuneen merkittävän teknologisen muutoksen, siirtymisen purjelaivateknologiasta höyrylaivateknologiaan.

Tutkimus osoittaa, että 1870-luvulla alkaneella teknologisella muutoksella oli työvoimarakennetta muovaavia vaikutuksia. Uusi teknologia loi toimialalle kaksi uutta ammattikuntaa, konemiehet ja lämmittäjät. Höyryteknologia lisäsi sekä korkean että matalan osaamisen työntekijäryhmien työpaikkaosuuksia. Palkkaosuuksilla mitattuna korkean osaamisen henkilöstön (perämiehet, konemiehet) osuus palkkasummasta nousi noin 8 prosenttiyksiköllä, 28 prosentista 36 prosenttiin. Keskitason osaamisryhmän (pursimiehet) osuus laski noin 5 prosenttiyksikköä 15 prosenttiin ja matalan osaamistason henkilöstön (lämmittäjät ja matruusit) nousi 30 prosentista 35 prosenttiin.

Palkkahajontaa kuvaavat mittarit osoittavat, että teknologinen muutos lisäsi palkkahajontaa toimialalla. Noin puolet palkkahajonnan kasvusta selittyy uusien ammattien palkkatasoilla, erityisesti korkeaa ammattitaitoa vaativien konemiesten muita korkeammilla palkoilla. Palkkaerot eri ammattiryhmien välillä ovat olleet varsin pysyviä. Muutoksia on ollut, mutta ne ovat tapahtuneet hitaasti vuosikymmenten aikana. Ammattitaitoiset merimiehet ovat ansainneet keskimäärin 35 prosenttia enemmän kuin ammattitaidottomat merimiehet. Vastaavasti ammattitaitoiset perämiehet ovat ansainneet keskimäärin 20 prosenttia enemmän kuin ammattitaitoiset merimiehet. Uuden osaavan ammattiryhmän palkkataso oli noin 40 prosenttia perämiesten palkkatasoa korkeampi. Alustava tilastoanalyysi viittaa siihen, että sekä korkean että matalan osaamisen ammattiryhmät hyötyivät palkallisesti teknologiamuutoksesta: molemmat ryhmät ansaitsivat paremmin höyrylaivoilla kuin purjelaivoilla. Keskitasolla tätä teknologiapreemiota ei ollut.

Asiasanat: ammattirakenne, palkkahajonta, teknologinen muutos, pitkä aikaväli

JEL-luokittelu: J31

Contents

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, since the ICT revolution of the 1980s provided an interesting basis for research on the impact of new technology on the labour market. Analyses that span over longer time periods or alternative technological changes are rare, although they could provide a useful perspective for recent findings.[1] Second, the observed rise in overall wage inequality, particularly in the US and in the UK labour market, has been generally accounted for by skill-biased technological change (SBTC). According to this view, technological advances raise the relative demand for skilled labour, and thus their 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 first specifying the occupation and only second the level of education.[2] Third, evidence suggests that the bulk of the change in skill composition and wage inequality has been going on within industries and firms, rather than between industries.[3] This calls for a detailed industry-level analysis that combines employee information with that on the workplace. Such analyses are, again, in short supply.[4]

In this study we analyze linked worker-workplace data that contain information on individual wages, occupations and workplace characteristics. The data are collected by pooling individual labour contract data from historical archives and span an exceptionally long time period, from the mid-1750s to the early 1900s, containing individual and vessel information on about 30 000 vessels and 247 000 crew members in the Swedish maritime industry. The data provide information on skill composition and wage inequality in an industry that experienced a major change in the production technology, namely a shift from sail-only vessels to steam-operated vessels. Thus, they provide a unique view on

[1] See Katz and 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 and Kearney (2008). Atack, Bateman and Margo (2004), Chin, Juhn and Thompson (2006) and Goldin and Katz (2008) are rare examples of the use of historical data. In Goldin and Katz (2008) the data run from 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.

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

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

[4] For the use of establishment-level data, see Dunne, Haltiwanger and Troske (1997), Dunne, Foster, Haltiwanger and Troske (2004).

long-term trends in skill structure and wage dispersion within one industry. In particular, the data allows us to examine the impact of technological change on wage and skill distributions and occupational premiums in a well-defined setting: there is a precise link between the worker (seamen), the firm (vessel) and the old (sail) and new (steam) technology. In our case, the technological change that emerged in the mid-1800s is clearly a major one, namely the introduction of steam engines caused sail-only vessels to be gradually displaced by steam-powered vessels. This technological change not only changed the tasks performed by workers in their jobs, but also created new occupations in the industry, including jobs for engineers and engine room operatives.[5] As we show later, we observe that technological change 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 mariners and an increase in unskilled engine room operatives.

The structure of the paper is as follows. Section II describes trends in technology, occupational structure and wage inequality in the maritime industry. We show that the adoption of the new steam-based technology was sluggish, taking more than 30 years before 80 per cent of the total capacity of the vessels was steam-operated. In addition, we show that the occupational composition of the crew, and thus the skill composition, changed substantially over the sample. The years of sail-only vessels, from 1750 to 1850, was a period of deskilling, skilled able-bodied seamen being substituted by less skilled mariners. In the late 1800s, changes in the skill composition mainly stemmed from technological change. We find that the new technology increased wage inequality and a part of the observed increase can be associated with new occupations. Although engineers were the highest paid group on steam-operated vessels, the unskilled engine room operatives, a new group of unskilled labour created by steam technology, also earned well on steam vessels.

Section III reports results on the evolution of wage premiums across occupations and the impact of technological innovation (steam) on the demand for skills. We use a regression framework to explain the differences in individual wages. We control for differences in skills, in addition to occupation, by work experience. Compensating differences stemming from differences in workplaces are controlled for by observable characteristics of the vessel and voyages. We find that occupational premiums vary over years and that there are substantial within-occupation premiums in the new technology. One of the main findings of the study is that highly skilled mates and unskilled ordinary seamen benefited from technological change in two ways. First, their relative employment share grew over the transition period and second, they earned a considerable steam premium.

[5] Autor et al. (2003) provide an example of a model where the rapid adoption of computer technology is associated with changes in tasks (routine, non-routine) and thus with changes in the task composition of jobs.

Skilled able-bodied seamen, in turn, suffered: their employment share diminished and their relative wages on steam vessels fell. In this respect, the findings provide support for recent views on the impact of technological changes on the demand for different tasks and polarization of the labour market. Finally, Section IV concludes.

2. Changes in technology, occupational composition and wage dispersion

2.1 Data

In this study we exploit seamen's house documents collected from six major port towns in Sweden.[6] These are, in alphabetical order, Gävle, Härnösand, Hudiksvall, Karlskrona, Söderhamn and Visby. The total sample consists of more than 247 000 individuals employed in 30 000 vessels over the period 1755–1937. On average, there are more than 2 300 annual observations on mariners. Prior to 1817, the number of annual observations vary between 400 and 1 300. The peak years in observations are 1881 and 1882, when there are more than 7 000 individuals in the sample. Due to a decrease in observations after the First World War (1914–1917) and given the turbulence of the 1930s, we limit our sample to the year 1914. Furthermore, as the new maritime labour law was introduced in Sweden at the turn of the 1920s and 1930s the figures are not comparable from the late 1920s onwards (see Borggård and Sjösted 1975 and Kallio 2007).

Our data comprise one of the earliest examples of worker-workplace information.[7] 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 on every seaman listed. The name, tonnage, type, and the likely destination of the vessel on which each sailor worked are also documented. A major advantage of the data is that they document individual wage and occupation and that information is linked to the characteristics of the voyage and workplace (vessel), including its technological status. Over the sample period we can identify three major occupational groups with a significant number of observations in each year. These are mates, able-bodied seamen, and ordinary seamen.[8] In addition, two new occupations created by the new technology,

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[6] The Seamen's house (sjömanhus) was a public institution introduced into 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 the date of arrival and information about the voyage, including possible deaths, sicknesses, and desertions. Our database includes seamen rolls from ten Swedish towns. See the Arkion database at http://www.arkion.ra.se

[7] The data examined in Chin, Juhn and Thomson (2006), 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 1891–1912.

[8] We also have the group "the rest, which includes several, less numerous occupations, such as cooks, stewards and deck boys. The relative share of this group stays at around 10 per cent of the whole crew. Concerning maritime labour during the time period, see Royen, Bruijn, et al. (1997), Fischer (1994), Ommer and Panting (1980) and Kindleberger (1992).

engineers and engine room operatives working on steam-operated vessels, are identified from 1875 onwards.[9]

2.2 Technological change and occupations

We begin the empirical investigation by documenting our measure of the pace of technological change in the maritime industry (Figure 1). This is followed by an examination of the general trends in occupational composition (Figures 2–4) and in wage dispersion (Figures 5–8).

Figure 1 depicts the percentage share of steam vessels of all vessels over the investigation period. Both the weighted and unweighted measures are plotted. The former (solid line) 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 around 1875 and it took about twenty years before steam vessels achieved a 20 per cent share of the total capacity. The adoption pace was rapid from 1890 to 1910, and by the year 1914 steam vessels accounted for about 80 per cent of the capacity. In total, it took more than three decades before steam became the preferred technology in the maritime industry.

The hypothesis of skill-biased technology change posits an increase in the demand for skilled labour relative to the less skilled. We start looking at this issue by reporting the occupational composition of the crew over time and in relation to technologies. Since 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 well the analysis of changes in skill composition. When we explore the whole data (Figure 2), the decline in the share of able-bodied seamen is striking, falling from 75 per cent in 1750 to around 20 per cent in 1915. The decline coincides with an increase in the share of ordinary sailors, which grows from 15 per cent of the crew in the 1780s to 50 per cent in the late 1800s. The proportion of the crew consisting of mates stays constant from 1750 to 1900. The shares of all these three groups decline in the early 1900s. This is associated with increases in new occupations, engineers and engine room operatives. In short, the steam period from 1870 onwards is characterized by the emergence of new occupations, partly highly skilled (engineers) and partly unskilled (engine room operatives), associated with a decline in other occupations of roughly the same proportion.

[9] In the steam period the average size of a crew on a voyage was 9. Thus, we cannot perform voyage/plant level analysis in the same manner, for example, as Dunne et al. (1997, 2004).

In sail-operated vessels (Figure 3), the development in the occupational composition of the crew follows that of the whole data in one respect: the share of able-bodied seamen declines steadily over time. The increase in the share of ordinary seamen continues over the entire period, contrary to the decline from 1890 onwards observed in the whole sample. In addition, there is a modest increase in the proportion of mates over the late 1890s and early 1910s. In short, there is a substantial shift from skilled able-bodied seamen to unskilled ordinary mariners and a modest shift to highly skilled mates over the period. In steam-operated vessels (Figure 4), changes are less marked. The share of highly-skilled mates and engineers is stable at 11–13 per cent, whereas the share of unskilled engine room operatives grows steadily. By 1915 the group reaches a 30 per cent share of the crew. This suggests that in steam-operated vessels, skilled able-bodied seamen, whose share declines from 30 per cent in 1870 to below 20 per cent in the 1910s, were substituted by unskilled operatives.

The data indicate that the period of sail-only vessels, from 1750 to 1875, was a period of deskilling, skilled able-bodied seamen being substituted by less skilled ordinary seamen. We associate this development with a change in the typical establishment size: the average size of sail-only vessels increased from about 170 tons to 350 tons over the period (see data in Appendix 1).[10] This finding is in line with Atack et al. (2004) for U.S. manufacturing. They report that in the mid-1850s, skill intensity decreased as establishment size increased. The period from 1875 onwards was more complex. From the late 1870s onwards, both skilled and unskilled mariners were replaced by unskilled operatives and highly skilled engineers. This suggests that the technological change related to steam 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, average wages (kronas) and wage bill of the average sail voyage and average steam voyage over the period 1875–1914. The differences are substantial. The proportion of mates and able-bodied seamen in the crew is 7–8 percentage points lower in steam vessels than in sail, declining from 17–18 per cent to around 10 per cent. The change in the proportion of ordinary mariners is even more marked, the share falling from 42 per cent of the crew to 24 per cent. These decreases were offset by increases in the share of engineers (17 per cent) and engine room operatives (23 per cent). Wage bill shares confirm these differences. The wage bill share of mates (28 per cent), able-bodied seamen (21

[10] The growth in average vessel size mainly reflects the relative rise in the proportion of three-masted ships in the data. This change, of course, can be interpreted as a technological change. In the preceding wage analyses we control for both the capacity and type of the vessels to separate their impact from that of steam technology.

per cent) and ordinary seamen (31 per cent) fell in all cases to 14–16 per cent of the total wage bill. As a whole, technological advances resulted in deskilling in steam vessels, the ratio of skilled to unskilled workers falling from 1.0 in 1875 to around 0.8 in 1915. As above, this finding can be partly related to the average establishment size. In our case, the average size of establishments, measured by the vessel capacity, doubled in the late 1800s when steam-powered vessels became the prevailing technology.

Table 1. Wages, employment and wage shares in relation to occupation, 1875–1914

	Employment share		**Average wage**		**Wage bill share**	
Occupation	Sail	Steam	Sail	Steam	Sail	Steam
Mate	17.9	10.4	58.4	80.3	27.8	15.9
Able-bodied seaman	17.2	10.0	46.5	45.3	21.2	15.1
Ordinary seaman	42.9	23.7	27.2	30.7	31.0	14.1
Engineer	-	17.6	-	107.5	-	20.3
Operative	-	24.1	-	45.0	-	20.4
Rest	23.0	14.2	25.0	28.1	20.0	14.2

Note: the occupation category ‘rest’ includes captains, stewards, cocks and deck-boys

Figure 1. Technological change in maritime industry, the proportion of workers on steam vessels, five-year moving averages over 1875–1914

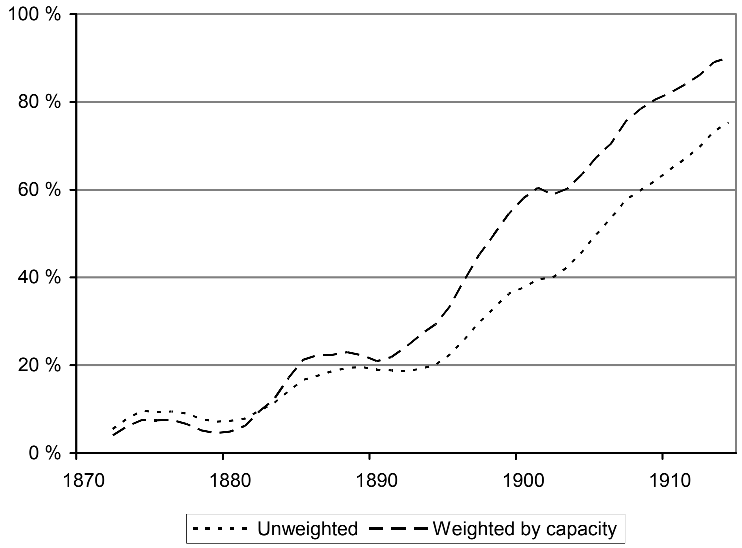


Figure 2. Crew composition, all vessels: proportions of mates (PE) able-bodies (AB), ordinary mariners (OS), engineers (S-AB) and engine room operatives (S-OS), five-year moving averages over 1755–1914

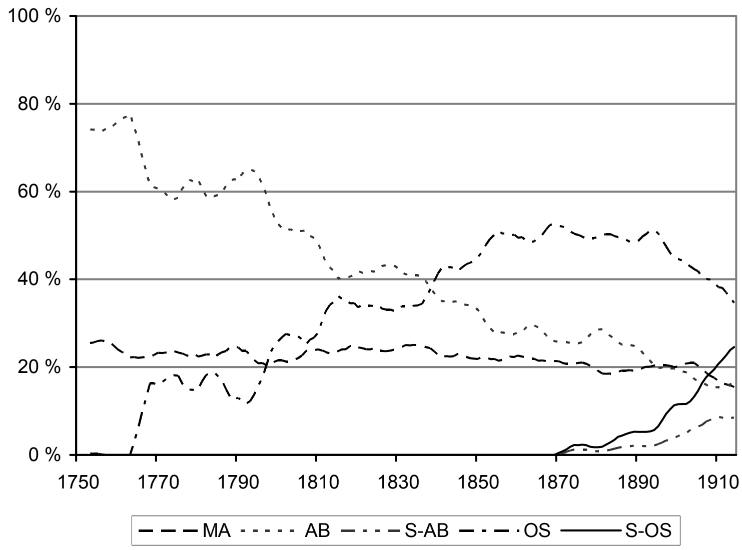


Figure 3. Crew composition, all vessels: proportions of mates, able-bodied seamen and ordinary seamen, five-year moving averages over 1755–1914

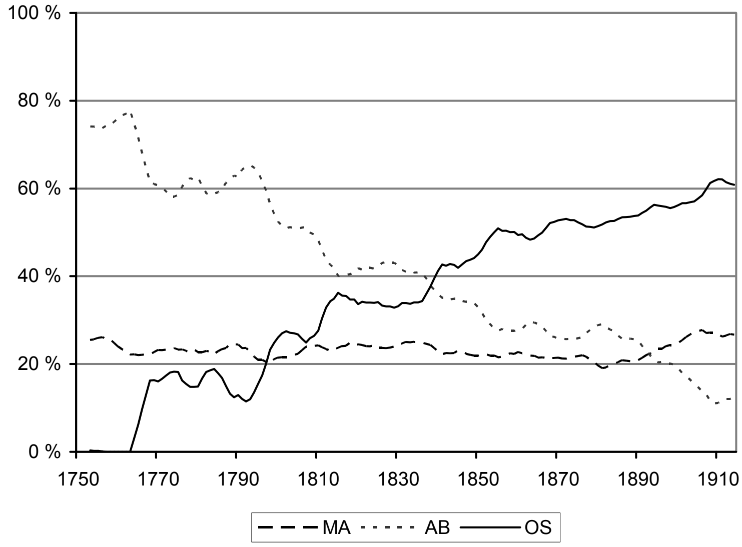
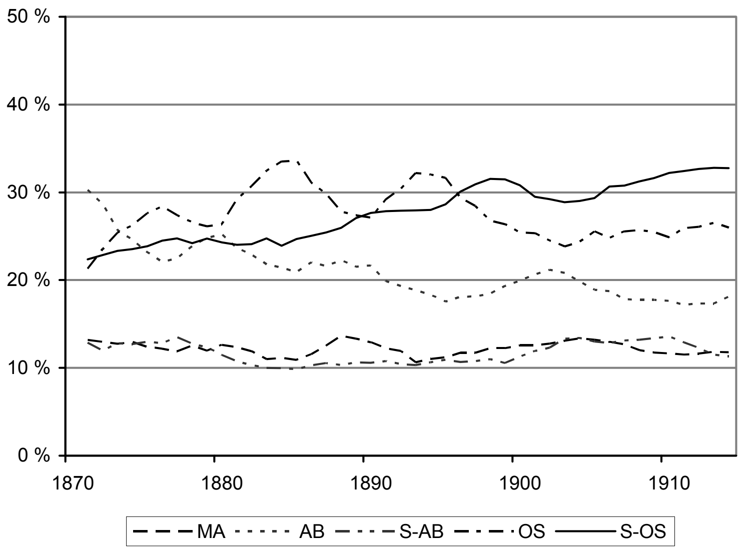


Figure 4. Crew composition, steam vessels: proportions of mates, able-bodied seamen, ordinary seamen, engineers and engine room operatives, five-year moving averages over 1875–1914



2.3 Technological changes and wages

The wage structure of the industry is illustrated in Figures 5–8. We begin with Figures 5 and 6, which depict the evolution of mean wages across occupations in relation to sail and steam technologies, respectively. The graphs make at least two points. First, wage differentials across occupations are clearly visible (Figure 5). Highly skilled mates earned more than skilled able-bodied seamen. Able-bodied seamen in turn earned more than unskilled ordinary seamen. This is a fact that carries over the whole investigation period. The mean wages of engineers, the highly skilled group on steam vessels, were higher than those of mates, a dominant group of highly skilled labour on sail vessels. Engine room operatives, an unskilled group on steam vessels, earned more than their counterparts, ordinary seamen, on sail. The wages of unskilled engine room operatives almost matched those of skilled able-bodied seamen. As Chin et al. (2006) pointed out, premiums from work on steam vessels may account for a compensating differential for the unpleasant work environment as well as for skills gained by training. The latter reason fits with engine room operatives, who often worked under poor conditions below the deck, whereas the latter suits engineers, who also had work opportunities on land.

Second, mean wages were higher in steam vessels (Figure 6). The uncontrolled steam premium varied from 20–40 per cent at the beginning of the era of steam-operated vessels to 50–70 per cent in the early 1900s. The data indicate that the new-skill demanding aspect of technical change accounts for the observed increase in the mean wage. If engineers and engine room operatives are excluded from the sample, the mean wage in steam vessels would decrease, on average, by 8 per cent over the years 1875–1914.[11] Another obvious explanation for the rise in the mean wage relates to the production technology and higher productivity. Capacity, measured by gross tons, was considerably higher in steam-powered vessels than in sail vessels.

Figures 7, 8 and 9 depict wage dispersion by two overall inequality measures, the coefficient of variation and the 90-10 log wage ratio. The 90-50 and 50-10 log wage ratios in turn illustrate developments in the upper- and lower-halves of the distributions. The overall inequality measures are also calculated in relation to technologies, i.e. both for sails-only and steam-operated vessels. The graphs record a number of interesting details.

First, there are periods of stable, increasing and decreasing wage inequality. Variations over the decades are substantial, the average value of coefficient of variation over the investigation period being 0.4 (Figure 7a). Dispersion in wages is modest over the period 1750–1780, then increases substantially and stays at a

[11] 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 per cent to 26 per cent if engineers were excluded from the sample.

high level until 1810. Inequality rapidly falls from the early 1800s to about 0.25 in the 1820s. From 1830 onwards, wage variation grows steadily, reaching the highest value of 0.55 in the mid-1910s.

Second, when we look at the data only from the steam period, i.e. from 1875 onwards, there is a distinct difference between sail- and steam-operated vessels (Figure 7b). According to the statistics, the average value of the coefficient of variation is 0.55 for steam and 0.42 for sail, i.e. 30 per cent higher. The rise in overall wage inequality in the late 1800s can be associated with the emergence of new technology and new occupations. If we exclude engineers and engine room operatives from the sample, the average value of the coefficient of variation for the period 1975–1914 declines from 0.56 to 0.47. This halves the total increase in wage variance.

Third, the evolution of wage differentials, measured by the 90-10, 90-50 and 50-10 log wage ratios, suggests that the pre-steam era can be divided into two periods (see Figure 8a). In 1770–1820, all inequality measures fluctuated considerably, reflecting the general turbulence of the period. The period during the late 18th and early 19th century witnessed a number of external shocks affecting the possibilities of shipping, including the Napoleonic Revolutionary wars (see Müller 1998, 2004). This affects our data: the number of yearly observations is considerably lower and there is more yearly variation in the data size in this period than after the mid-1820s. As a result, the estimates of log wage ratios for this period must be treated with caution.[12]

From 1820 onwards, all measures follow solid upward trends. The difference of 20–30 log points in the upper-end of the distribution increases to 40 log points by 1870. The lower-end of the wage distribution similarly grows from 35 log points to 60 log points by 1870. It is worth noting that there were no technological changes in the maritime industry over this period. The upsurge of the mid-1850s in wage inequality, however, coincides with a rapid growth and industrialization of the Swedish economy, which also increased international trade. Emigration to the United States and Canada was also significant. Both factors may have contributed to the rise in upper-tail wages: industrialization raised the demand for skills and also emigration was, at least to some extent, skill-biased in the sense that it reduced the supply of skilled labour.[13]

The increase in wage inequality from the 1870s onwards to the early 1910s stems almost solely from an increase in the upper-end wages. The highest wages increase substantially in relation to mean wages (90-50) as well as to lower-end

[12] The number of observations in wage deciles varies from 50–60 in the late 1790s to 500–700 in the mid-1880s.

[13] See Magnusson (2000) for an account.

wages (90-10). The 50-10 log wage ratio, in turn, remains more or less constant. This provides indirect support for the SBTC hypothesis: wages in highly skilled occupations grew in relation to wages in other occupations. Figure 8b further illustrates the wage rising effect of the technological change. When we measure wage inequality (90-10 log wage ratio) in relation to the technology, the rising inequality trend observed in the whole sample disappears. The new technology simply created new high pay jobs, raising wage inequality in steam vessels, and the observed inequality trend over the period reflects the rising share of steam-operated vessels in the sample.

Figure 5. Mean log wages in relation to occupation: mates, able-bodied seamen, ordinary seamen, engineers and engine room operatives, five-year moving averages over 1755–1914

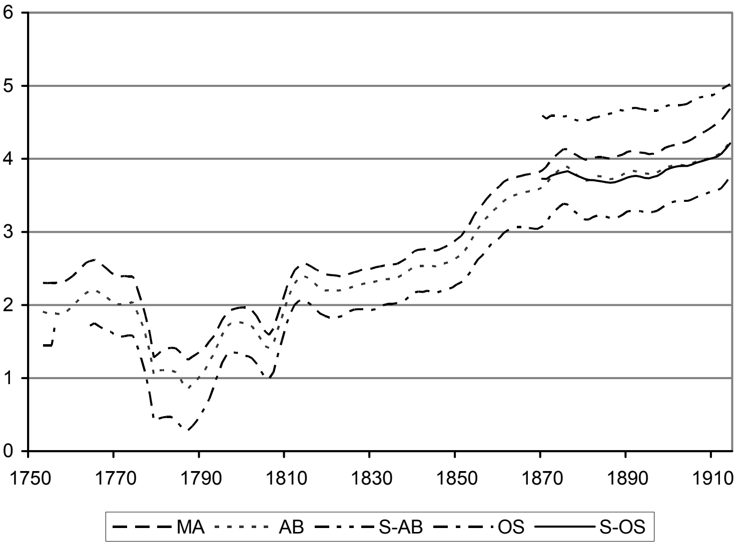


Figure 6. Mean log wages in relation to technology, sail and steam vessels, five-year moving averages over 1755–1914

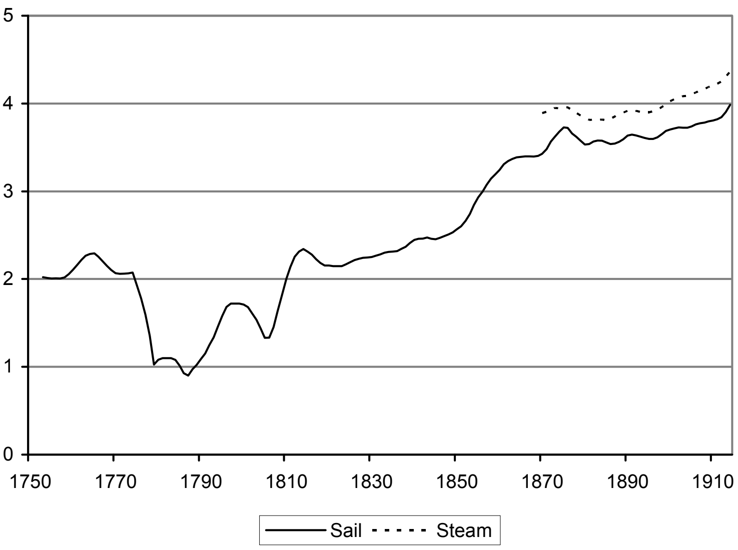


Figure 7a. *Wage dispersion; coefficient of variation, five-year moving averages over 1755–1914*

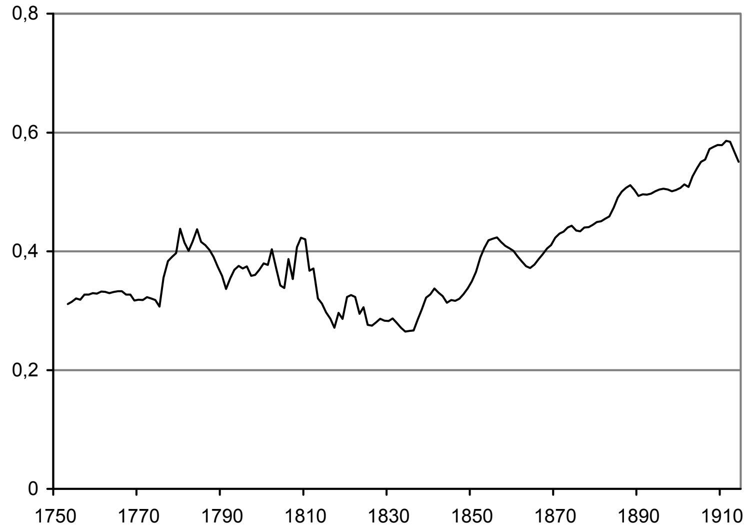


Figure 7b. *Wage dispersion; coefficients of variation in relation to technology, five-year moving averages over 1755–1914*

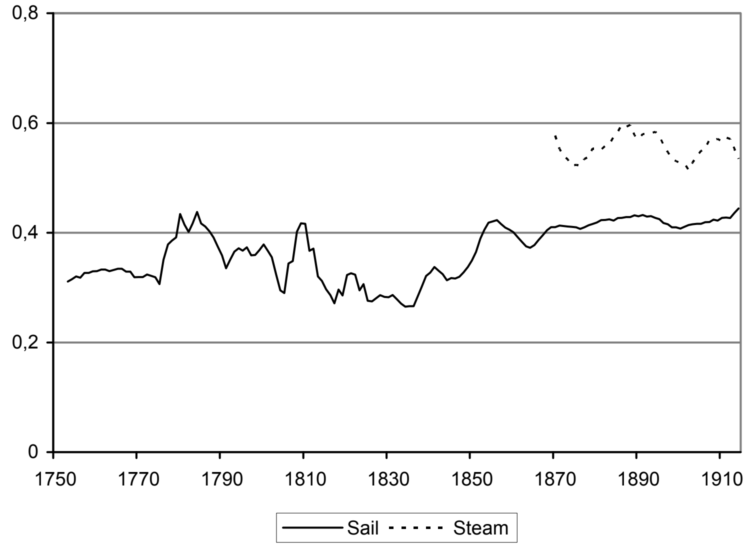


Figure 8a. Wage dispersion; 90/10, 90/50 and 50/10 log wage ratios, five-year moving averages over 1755–1914

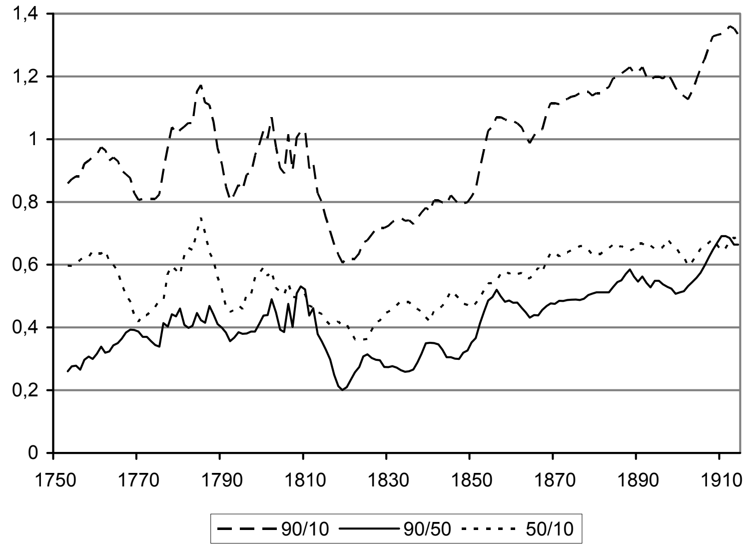
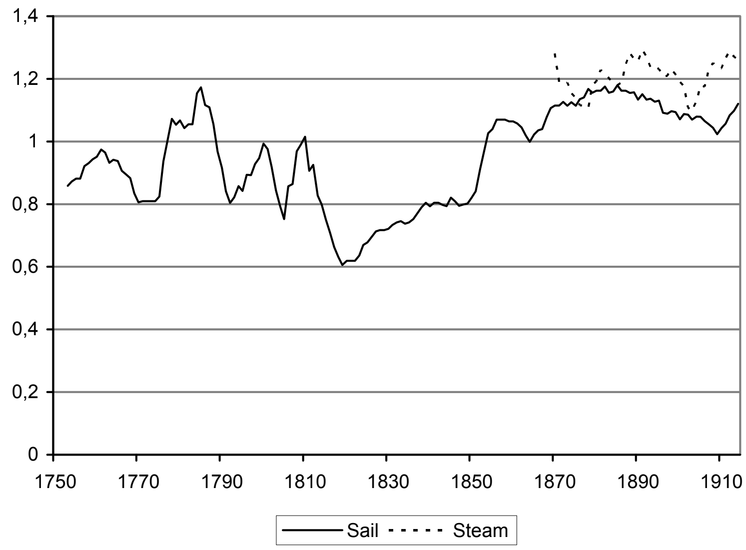


Figure 8b. Wage dispersion; 90/10 log wage ratios in relation to technology, five-year moving averages over 1755–1914



3. Trends in returns to occupation over the centuries

We use a regression framework to provide a closer look at long-term trends in returns to occupations over the investigation period. Five major occupations are identified: mates (highly skilled labour), able-bodied seamen (skilled labour), ordinary seamen (unskilled labour), engineers (highly skilled labour on steamships), and engine room operatives (unskilled labour on steamships). To examine how returns to occupation vary over time, we estimate the following wage equation using a combined repeated cross-sectional and panel data:[14]

$$\text{Equation (1) } \ln(W)_{ijt} = \alpha_0 + \alpha_t Year + \boldsymbol{\beta X}_{it} + \boldsymbol{\gamma Z}_{jt} + \eta_{kt} OCC_{ik} * Year + \varepsilon_{ijt},$$

$$\varepsilon_{ijt} \sim \text{i.i.d.}$$

W denotes the wage of an individual at time t, α_0 is a constant and the year-dummy α_t captures the general evolution of wages over time. X is a vector of individual and contract characteristics, including occupation, age, duration of contract, and regional residence of a worker. Z denotes a vector of workplace characteristics measuring the vessel type, capacity, and the main operative area of a vessel. The parameter vector η_{kt} provides time-variant estimates on wage premiums across occupations relative to the omitted group (ordinary seamen).

3.1 Occupational premiums over time

Column 1 of Table 2 reports results where the individual (log) wage is regressed on the year of embarkation and occupation. Occupation variables capture average wage premiums for mates, able-bodied seamen, engineers and engine room operatives with respect to ordinary seamen, who serve as a reference group. The second specification adds vessel characteristics into the regression (column 2). The third specification (column 3) adds all possible controls into the equation. Columns (4) and (5) re-estimate specifications (1) and (2) by using the maximum number of observations available (247 133 and 159 277, respectively). All specifications include year dummies and yearly interactions with occupations.[15]

[14] The written labour contract is the basic observation unit and same individuals may appear several times in the data. However, we cannot identify individuals by name and year of birth only, and thus panel data methods are not applicable here.

[15] Estimates for occupational premiums (relative to ordinary mariners) shown in Table 2 refer to the end-year of the sample, i.e. 1914 in columns (1)–(3) and 1937 in columns (4) and (5).

The specifications explain the data well. In all cases the R^2 is 90 per cent or higher. The estimates on average premiums over the period (see column 1) suggest that engineers earn 112 log points more than the ordinary mariners. For mates, the premium is 85 log points. Engine room operatives and able-bodied mariners enjoy, in turn, a premium of about 50 log points over ordinary seamen.

The results of columns 2 and 3 suggest that the premiums reported in column 1 are partly due to differences in individual and vessel characteristics. For mates, able-bodied seamen and engineers the premiums over the ordinary mariners fall by 15 to 20 log points, to about 90 log points for engineers, 60 for mates and 40 for able-bodies. For engineer room operatives the impact is smaller, about 9 log points, resulting in a fall from 51 log points to 42 points in the premium. The estimates reported in columns 4 and 5, in turn, suggest that the results are robust with respect to attrition, the estimates being virtually unchanged when specifications 1 and 2 are re-estimated by using the maximum number of observations in the sample.

The results indicate that there are considerable wage-size effects, 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. An additional ton in capacity increases wages by about one log point. The average wage gap in favour of the biggest vessels (three-masted ships) varies from minus five log points (schooner) to minus 15 log points (coastal vessels).[16] Compensations also differ across the sailing areas: there are a 4–5 log point premiums on voyages in the Atlantic Ocean, Mediterranean and Nordic Sea over those in the Baltic Sea. These effects remain when we control for the duration of a wage contract. This suggests that voyages far away from home were rewarded by a compensating differential, perhaps reflecting the risks attached to such voyages. The estimate on the duration of the contract is positive, indicating a modest 0.2 log point increase in wages for every additional month of the contract. The effect of age, which proxies experience, on wages is positive as expected, reflecting enhanced productivity and maturity. An additional year in age increases wages by 4 to 5 log points. The results of column (2) show that wages increased with technological advances, average pay on steam-operated vessels being 8 log points higher than on sail-only vessels. When we control for individual characteristics, the steam premium declines to 6 log points.

Figure 9 depicts the time paths of the estimated wage premiums in relation to occupation. The reference occupation is ordinary seamen and the results are based on yearly regressions with all possible controls. The first point to notice is

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

that premium differences across the occupations are visible and they are relatively stable over time. For example, the premium of mates is always more than that of able-bodied seamen, and the premium of engineers exceeds that of engine room operatives.

Figure 9 illustrates that in the period from 1760–1910 the premium of mates declines gradually over the last decades of the 18th century, from 80 log points in 1760 to 40 log points by the early 1800s. The premium remains stable over the first four decades of the century. In the mid-1850s, the premium increases to 60 log points, then falling 10 log points and later going up by 10 log points.[17] Figure 9 similarly suggests that the evolution of the estimated pay premium for able-bodied seamen follows that of mates, with two differences. First, the basic premium level of the able-bodied seamen is 60–70 per cent of that of mates: when mates earn a premium of 60 log points, the premium for able-bodied seamen is 45 log points, and so on. Second, the premium does not fluctuate in the early-1900s but stays at a constant level of around 40 log points.[18]

The engineers, a highly skilled group on steam vessels, enjoy the highest premium. It exceeds that of the mates, a dominant group of skilled labour on sail vessels. If the 1870s is ignored, there is a clear declining trend in the premium over the period. The average premium level of around 110 log points in the 1880s declines to 95 log points by 1910. The engine room operatives, an unskilled group on steam vessels, also earn a considerable 35 points premium over their counterparts on sail, the ordinary sailors. Contrary to the skilled group working on steam-only vessels, the premium of this unskilled group of workers over ordinary seamen remains stable over whole phase of the adoption of new steam technology.

[17] The premium for mates is, on average, 10 log points higher over the period 1760-1880 if the observable individual, contract and vessel characteristics are not controlled for. Mates are more experienced than ordinary marines and they are employed, on average, on bigger vessels. The role of the observables in the premium from the late 1800s onwards is about 20 log points. The steam technology alone accounts for about 10 log points of the difference.

[18] As for the mates, the difference between the uncontrolled and the controlled premium is about 10 log points until the late 1890s. The gap widens in the late 1800s and early 1900s.

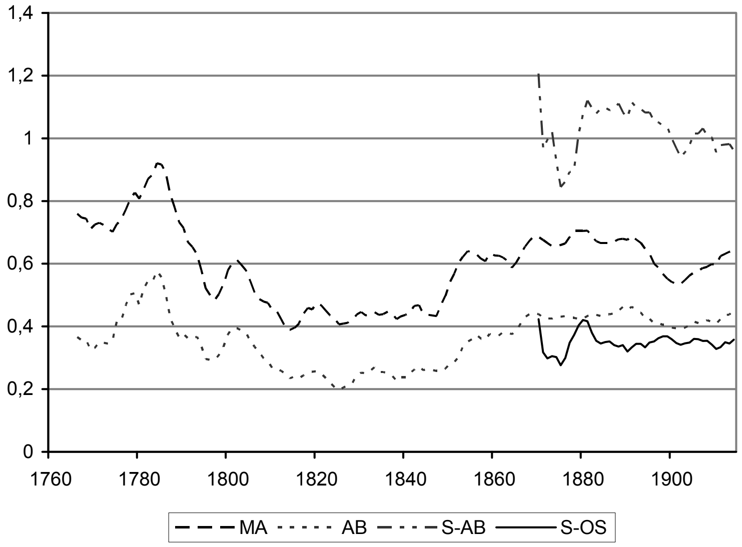
Table 2. Wage equations, dependent variable is log(W_{ijt}), 1755–1914/ 37

	(1)	(2)	(3)	(4)	(5)
Occupation					
Mate	0.847*	0.7940*	0.619*	0.836*	0.777*
Able-Bodied seaman	0.552*	0.542*	0.384*	0.538*	0.521*
Engineer	1.129*	1.109*	0.918*	1.134*	1.140*
Operative	0.515*	0.488*	0.421*	0.525*	0.505*
Age			0.048*		
Age ^2*100			-0.068*		
Vessel characteristics					
Steam		0.082*	0.057*		0.051*
Capacity*1000		0.019*	0.019*		0.015*
Brigg		-0.010*	-0.001		0.010*
Schooner		-0.055*	-0.050*		-0.061*
Coastal vessel		-0.167*	-0.156*		-0.173*
Contract characteristics					
Destination					
- North Sea		0.032*	0.029*		0.043*
- Mediterranean		0.051*	0.042*		0.058*
- Atlantic Ocean		0.071*	0.059*		0.069*
- Other		0.060*	0.040*		0.058*
Seamen’s house					
- Hudiksvall			-0.035*		
- Härnösand			-0.018*		
- Karlskrona			-0.001		
- Söderhamn			-0.001		
- Visby			-0.036*		
Duration			0.012*		
Constant	1.66*	1.77*	0.96*	1.68*	1.76*
Yearly dummies	Yes	Yes	Yes	Yes	Yes
Yearly interactions by occupation	Yes	Yes	Yes	Yes	Yes
Diagnostics					
R2	0.918	0.923	0.932	0.915	0.928
Number of obs.	101 765	101 765	101 765	247 133	159 277

Note: Reference groups are: ordinary seamen; sail-on vessel; three-masted ship; Baltic Sea; Gävle.

* denotes statistical significance at 1 per cent level. The estimation period is 1755–1914 in columns (1)–(3) and 1755–1937 in columns (4)–(5).

Figure 9. Evolution of occupational premiums: mates, able-bodied seamen, engineers and engine room operatives versus ordinary seamen, controlled estimates, five-year moving averages over 1755–1914



3.2 Steam premiums over time

We continue the analysis by estimating steam premiums for mates, able-bodied seamen and ordinary seamen. We do this by estimating wage equations for each occupation separately with yearly steam-dummies. The yearly estimates on steam premiums in the sail occupations are shown in Figure 10. Two points are worth noting here.

First, the estimates imply that there is a steam premium for mates and ordinary seamen, whereas able-bodied seamen suffer a small negative premium. The premium obtained by mates differs statistically from those of able-bodied as well as ordinary seamen (see Table 3 for the test results). Second, premiums are not stable but vary over time. In particular, the premiums decline with the increasing dominance of steam technology. This shows up in the higher variation in steam premiums across occupations in the early phase of the adoption of the new technology. In the 1880s and 1890s, mates and ordinary sailors earn a premium of around 30 and 10 log points, respectively, whereas able-bodied seamen suffer a negative premium of around 10 log points. In the early 1900s the corresponding figures are considerably smaller, being 20 log points for mates, 5 log points for ordinary mariners and zero for able-bodied seamen.

Finally, we examine possible determinants of cross-technology differences in wages in relation to occupation (see Table 4 for regression results). As above, we compare occupations that exist both on sail and steam vessels, namely mates, able-bodied seamen and ordinary seamen. Following Chin et al. (2006), the basic equation controls for age (which serves as a proxy for experience) and year of embarkation. Column 2 controls for the area of residence (a proxy for outside opportunities) of seamen. Column 3 controls for vessel characteristics (capacity and type of the vessel) and column 4 for characteristics of wage contracts (duration and destination of the voyage). All preceding controls are added in Column 5.

As we reported earlier, there is a significant difference in wages between the technologies. The average gross steam premium is 31 log points for mates and 10 log points for ordinary seamen. Able-bodied seamen, in turn, suffer a small negative premium of around 4 log points. For mates, the steam premium declines to 22 log points when all controls are included. The vessel characteristics account for most of the difference. This indicates that two-thirds of the steam premium is due to unobserved worker quality/ increased demand for these skills. For able-bodied seamen the negative premium increases to seven log points when the vessel characteristics are controlled for. On the other hand, it completely disappears when we control for the contract characteristics, i.e. for the duration of the contract and destination of the voyage. The steam premium of ordinary seamen is, in turn, unaffected by the controls: the premium stays at 7–8 log points with all possible control combinations. This suggests that the main bulk of the steam premium for this group is due to unobservable worker quality and/or demand for these skills.

As a whole, the results indicate that the highly skilled mates and the unskilled ordinary seamen benefited from technological change in two ways. First, their relative employment share grew over the transition period and second, they earned a steam premium. Skilled able-bodied seamen, in turn, suffered: their employment share diminished and their relative wages on steam vessels fell.[19] In this respect, the findings provide indirect support for recent views on the impact of technological changes on the demand for different tasks and polarization of the labour market. The result that skilled labour obtains the largest rise in the premium lends support to the SBTC hypothesis, technological change being skill-biased. The finding that unskilled ordinary seamen also obtain a clear positive premium, in turn, supports the idea of polarization of the labour market along the lines of Autor et al. (2003) and Goos and Manning (2007).

[19] Chin et al. (2006) reported a positive premium for able-bodied seamen. In our case, the small negative premium of this group is associated with a substantial decline in the group's employment share.

Table 3. Tests for steam premiums

Period (F-statistics)	1875–1890 F(19, 53 353)	1891–1914 F(24, 53 353)
Ordinary seaman	4.23*	11.1*
Able-bodied seaman	4.07*	1.46
Mate	12.8*	15.1*
Mate-Able-bodied	14.3*	9.19*
Mate-Ordinary	5.80*	4.66*
Able-bodied-Ordinary	5.24*	5.33*

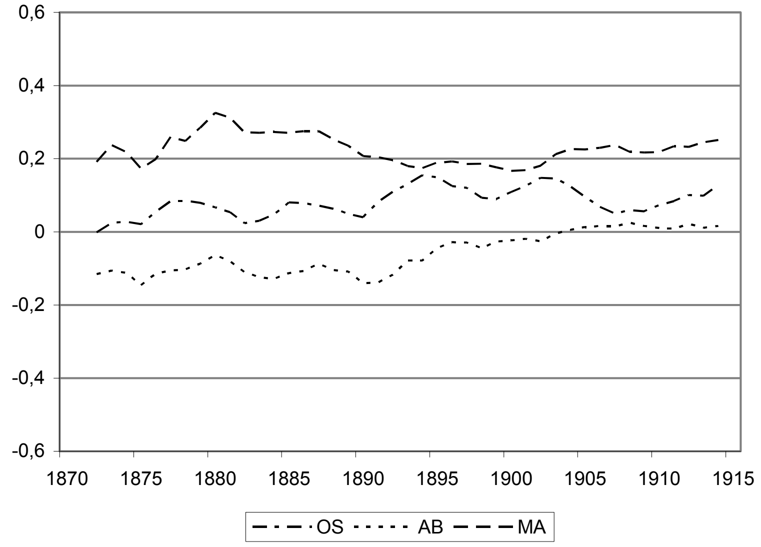
Note: the results of the F-tests for the hypothesis that controlled occupational wages do not differ across sail and steam technology (upper part) and the results of the F-tests for the hypothesis that steam premiums are equal across occupations (lower part)

Table 4. Controlled steam premiums in wages in relation to occupation, 1875–1914

Occupation	Basic	Individual	Vessel	Contract	All
Mate	0.319 (0.006)	0.250 (0.006)	0.182 (0.006)	0.316 (0.006)	0.224 (0.007)
Able-bodied seaman	-0.038 (0.004)	-0.045 (0.004)	-0.068 (0.005)	-0.006 (0.004)	-0.043 (0.005)
Ordinary seaman	0.087 (0.006)	0.079 (0.005)	0.084 (0.006)	0.090 (0.005)	0.085 (0.006

Note: Difference in log wage for steam. Standard errors are given in parentheses below the log difference. Each cell comes from a separate regression. The numbers of observations are 8741 (mates), 9546 (able-bodied seaman) and 20 476 (ordinary seaman)

Figure 10. Evolution of steam premiums: mates, able-bodied seamen and ordinary seamen, five-year moving averages over 1875–1914



4. Conclusions

This study analysed the evolution of wages and occupational composition of labour over three centuries, from 1755 to 1914, using linked worker-workplace data. The data offers a unique view on long-term trends in wage inequality, skill composition and occupational wage premiums within an industry. A major shift in the production technology, a shift from sail-only vessels to steam-operated vessels, allows the examination the skill-biased technology change (SBTC) hypothesis in a well-defined setting. We believe that the data and the empirical results of the study are of wider general interest.

There are three main points that we put forward on the basis of the data and the analysis. First, the occupational composition in the industry changed substantially over the investigation period. The years of sail-only vessels, from 1750 to 1850, were a period of deskilling, skilled able-bodied seamen being substituted by less skilled ordinary seamen. We relate this development to the average establishment size, measured by the vessel capacity, that doubled by the mid-1800s. This agrees with the model of Mitchell (2005) on the organization of production into large plants as well as the findings of Atack et al. (2004) for US manufacturing, who show that skill intensity decreases as establishment size increases. In the late-1800s, changes in the skill composition mainly stemmed from technological change. The technological change not only changed tasks performed by workers at their jobs but it also created new occupations in the industry, including jobs for engineers and engine room operatives. This change 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 mariners and an increase in unskilled engine room operatives. These findings are in line with the model of Autor et al. (2003, 2006) on the polarization of the labour market, with employment polarizing into high-wage (engineers and mates) and low-wage jobs (operatives and ordinary sailors) at the expense of middle-skilled jobs (able-bodied seamen) due to computerization (the emergence of steam technology).

Second, the new steam technology increased wage inequality within the industry. The data suggest that increasing wage inequality in the late 1800s and the early 1900s stemmed from an increase in the demand for skilled labour, partly resulting in new occupations and partly raising the wages of skilled mariners. The highly skilled labour (mates), in particular, earned a substantial steam premium. A significant part of the observed increase in wage inequality can be directly associated with new occupations: if we exclude engineers and engine room operatives from the sample, the wage dispersion for the period 1875–1914 declines by 20 per cent. This halves the total increase in variance occurring over the steam period. The findings that an increased demand for new skills yielded in an increase in the highest wages in relation to mean wages, while the lowest wages in relation to mean wages remained constant, provide indirect support for the SBTC hypothesis. As noted by Chin et al. (2006), the experience with steam after the 1870s appears to have much in common with the computer revolution of the 1970s and 1980s.

Third, the general finding of the exceptionally long investigation period is that wage inequalities evolve slowly over time. There are long-lasting periods of declining and rising phases in wage dispersion. The century-long data show that wage inequality also considerably increased in the early 1800s. This was a period when there were no apparent changes in technology. Thus, a change in the prevailing technology may be only one trigger for considerable changes in wage dispersion. This suggests an examination of changes in labour market institutions as well as changes in supply and demand factors in explaining changes in wage inequality over time, as stressed by Katz and Autor (1999) and Goldin and Katz (2008). Similarly, compositional effects or noisy data, as emphasized in Lemieux (2006), might be important sources of wage inequality.

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Appendix

Data descriptions, sail-only period (1755–1874), sail and steam periods. 1875–1885 versus 1896–1914

	1755–1874	1875–1895	1896–1914	1875–1895	1896–1914
Vessel technology	Sail	Sail	Sail	Steam	Steam
Occupation, %					
Ordinary sailor	38.0	52.7	57.7	30.0	26.0
Able-Bodied seaman	39.5	26.5	16.6	21.3	18.2
Mate	22.5	20.7	25.7	12.0	12.2
Operative	-	-	-	25.8	31.4
Engineer	-	-	-	10.9	12.2
Age. years	27.5	25.3	24.3	26.8	26.4
Married, %	35.1	18.4	16.2	22.5	20.2
Duration, months	8.1	9.1	6.4	5.9	7.3
Town*					
Gävle	8.9	34.1	17.8	52.4	14.2
Hudiksvall	3.2	3.4	7.9	1.6	10.8
Härnosand	28.6	28.9	18.8	7.8	26.6
Karlskrona	0.3	6.2	15.3	11.7	14.6
Söderhamn	6.6	13.6	10.4	13.6	13.7
Visby	52.4	13.9	29.8	12.9	20.1
Capacity, tons	176.3	351.7	319.5	414.0	728.2
Vessel type. sail					
Three-Masted ship	23.4	54.8	40.8	-	-
Brigg	20.9	13.2	8.6	-	-
Schooner	49.6	29.7	48.4	-	-
Coastal vessel	6.1	2.4	2	-	-
Destination					
Baltic Sea	48.5	9.1	36.8	29.5	35.9
North Sea	18.4	31.5	30.2	28.8	35.3
Mediterranean	7.1	8.9	1.0	0.6	2.2
Atlantic Ocean	0.2	1.7	2.5	0.5	1.4
Other	2.2	11.3	5.3	0.3	0.3
Missing	23.7	37.5	24.1	40.1	25.0

*Town = Seamen's House

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P.O.Box 1279
FI-00101 Helsinki
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