

ECON 699 Proposal:  
Was Technology Skill-Biased in the Atlantic  
Merchant Marine, 1863 to 1913?

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## 1. Introduction

Both economists and policy makers over the past twenty years have had great interest in the notion of skill-biased technical change. One source of this interest has been in issue of whether the spread of computers and information technology had had a major impact on wage structure and income distribution. According to one view skill-biased technical change increases the demand for relatively skilled workers (Autor, Katz and Krueger, 1988). With the introduction of new technology, many tasks that were previously performed by unskilled labors entail certain skills, and substitute skilled for unskilled labors. A higher demand for skills would boost the wage premium, and then exacerbate the wage inequality between skilled and unskilled workers. Skill-biased technical change is supported in some previous studies. (*see* Griliches 1969; Nelson and Phelps, 1967; Welch, 1970; Schultz, 1975; Tinbergen, 1975)

In Figure 1, the effect of skill-biased technical change on wage structure is illustrated graphically within a constant elasticity of substitution (CES) production model.<sup>1</sup> Suppose a two-input production function has the form,  $V = [(\alpha H_1)^\rho + (\beta H_2)^\rho]^{1/\rho}$ , where  $\alpha$  and  $\beta$  capture technological progress,  $H_1$  and  $H_2$  represent skilled and unskilled labor respectively. The elasticity of substitution between skilled and unskilled labor is  $\sigma = 1/(1-\rho)$ .  $W_1$  and  $W_2$  are wages paid to skilled and unskilled labor respectively. Assume profit maximization, wage premium  $\omega$  in equilibrium is given by:

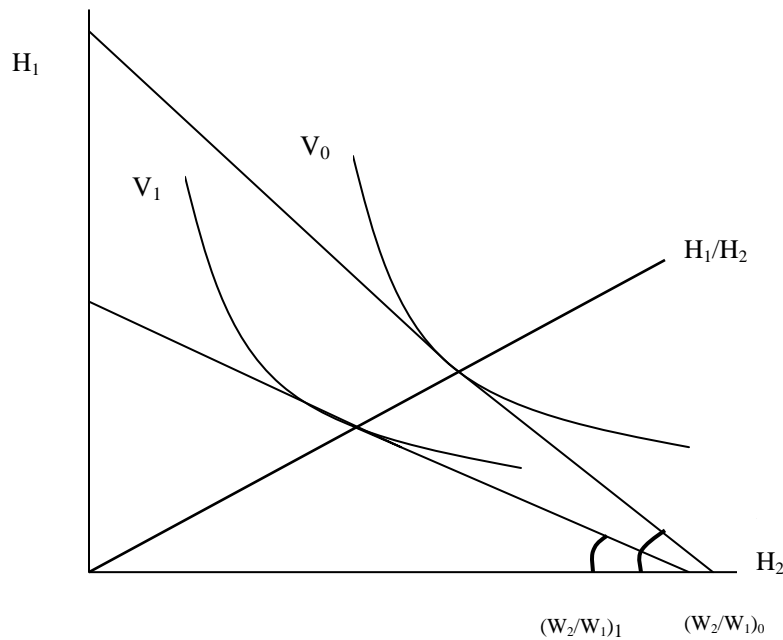
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<sup>1</sup> For a formal discussion, see Sanders, M. and Weel, B. (2000) 'Skilled-Biased Technical Change: Theoretical Concepts, Empirical Problems and a Survey of the Evidence,' DRUID working paper, number 00-8.

$$(1) \quad \omega = \frac{W_1}{W_2} = \left( \frac{\alpha}{\beta} \right)^\rho \left( \frac{H_1}{H_2} \right)^{\rho-1}$$

In this simple scenario, Hicks-neutral technical change can be defined as an increase in productivity that impacts relative wages holding the labor ratio constant; or equivalently impacts relative labor employment holding wages constant. Equation (1) implies that technical change is Hicks neutral as long as  $\alpha$  and  $\beta$  change proportionately.

(Sanders and Weel, 2000)



**Figure 1: Skill-Biased Technical Change Holding the Factor Ratio Constant**

Figure 1 assumes  $\alpha > \beta$ , that is, technical change is skilled biased against unskilled labor. Holding the factor ratio  $H_1/H_2$  constant, as shown by a straight ray from the origin, technical change shifts the production frontier to the left,  $V_0$  to  $V_1$ . From the slopes of tangent lines, we can easily tell a decline in relative wages  $(W_2/W_1)$ , which is against unskilled labors. Alternatively, we could show an increase in the employment of

skilled labors holding relative wages constant.

However, technical change can be unskill-biased as well. During the nineteenth century in Britain, products normally made by skilled artisans started to be produced in factories by relatively unskilled workers using machines. Formerly complex tasks were greatly simplified with machines involved in the production, reducing the demand for skilled workers. (James and Skinner, 1985; Goldin and Katz, 1998; Mokyr, 1990) Since technical change has an important impact on wage structure and employment, it is worthwhile to explore whether technical change is skill or unskill biased.

In Hudgins and Mitch's capstone paper (2003), they mainly examined the trends in the premium to literacy in the Atlantic Merchant Marine from 1863 to 1913, and found that the premium is higher for steam crew than sail, based on which they argue that the introduction of steam could be viewed as skill-biased technical change. Nonetheless, they failed to provide an explanation of why the change in the wage premium to literacy is attributed to skill-biased technical change rather than some other factors. Neither did they discuss why it is the case that the technical change in Atlantic Merchant Marine is skill-biased. This question serves as an immediate goal in this paper.

Acemoglu (2002) has developed a model in which elasticity of substitution  $\sigma$  between skilled and unskilled labor can be used to determine whether or not technical change is skill-biased. He has shown that elasticity of substitution  $\sigma$  determines slopes of the relative labor demand curve. In general,  $\sigma > 1$  indicates that technology is skill biased;  $\sigma < 1$  unskill biased. This model will be presented in detail in the next section.

Using the same dataset in Hudgins and Mitch's paper (2003), I will attempt to estimate the elasticity of substitution  $\sigma$  in the Atlantic Merchant Marine from 1863 to 1913, and test the null hypothesis  $\sigma > 1$ , that is, technical change is skill-biased. Since most previous studies apply data to a whole economy level, it is also intriguing to see how  $\sigma$  performs within an industry facing a concrete type of technical change.

The rest of this proposal will be organized as follows. Section 2 will discuss the role of elasticity of substitution in labor supply and demand, and lay out a methodology framework, modeling voyages in the Atlantic Merchant Marine in a general production function. Then, I will look closely at the dataset, produce some descriptive statistics, and discuss empirical models. Finally, I will discuss the remaining tasks for the fulfillment of the final paper.

## 2. Methodology and Hypothesis

It is beneficial to discuss elasticity of substitution in a partial equilibrium. Recall the production function derived in the first section. By taking natural logs of both sides of Equation (1) and substituting  $\sigma = 1/(1 - \rho)$ , I obtain:<sup>2</sup>

$$(2) \quad \ln \omega = \frac{\sigma - 1}{\sigma} \ln \left( \frac{\alpha}{\beta} \right) - \frac{1}{\sigma} \ln \left( \frac{H_1}{H_2} \right)$$

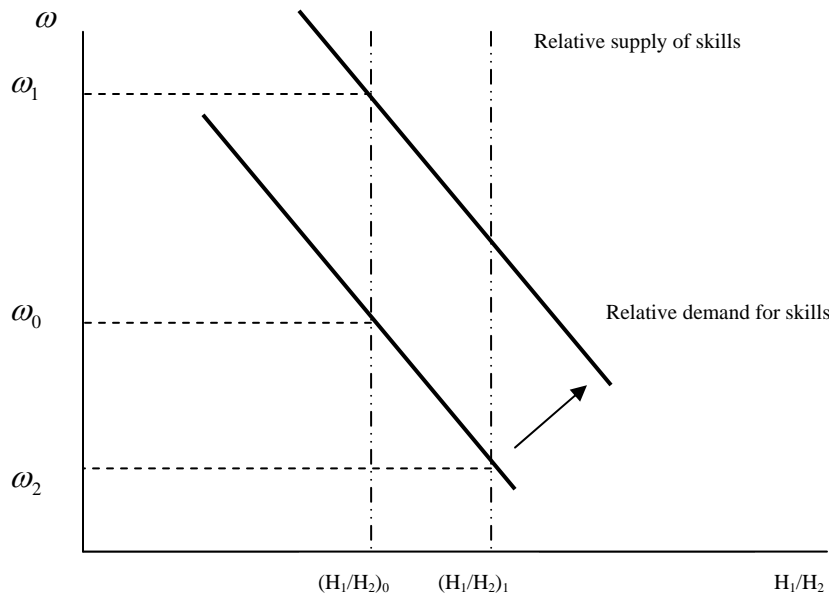
In general, skill premium increases when skilled labor becomes scarcer, indicating a negative slope for the relative demand curve with the value of  $1/\sigma$ , that is:

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<sup>2</sup> For detailed derivation, see Acemoglu, D. (2002), 'Technical Change, Inequality, and the Labor Market,' *Journal of Economic Literature*, Vol. XL: 7-72.

$$\frac{\partial \ln \omega}{\partial \ln H_1 / H_2} = -\frac{1}{\sigma} < 0$$

$\alpha / \beta$  captures technical change over time. In this model, elasticity of substitution  $\sigma$  determines the slope for the relative demand as well as the intercept term. Graphically, I can show the relationship between skill premium and relative labor demand in Figure 2.



**Figure 2: Skill Premium, Relative Labor Ratio and Labor Market in Equilibrium**

Skilled biased technical change (i.e.  $\sigma > 1$ ) would shift the relative demand curve to the right, and increase skill premium from  $\omega_0$  to  $\omega_1$ . On the contrary, if  $\sigma < 1$ , an improvement in the relative productivity of skilled labors,  $\alpha / \beta$ , would move the relative demand curve to the left and reduce skill premium. On the supply side, it is worth mentioning that skill premium falls when there is an increase in the supply of relative skilled labor, which shifts the supply curve to the right and reduces skill premium to  $\omega_2$ . In a case study, Angrist (1995) shows that the sharp fall in the premium to college

graduates relative to high school graduates in Palestine can be largely explained by a very large increase in the supply of skills. With both supply and demand curves moving at the same direction, it is hard to tell what skill premium would result, dependent upon the relative strength of both supply and demand side.

The underlying assumption in Figure 2 is that the relative supply of skills is not respondent to the change in relative wages, which would be a reasonable one if the labor force is disaggregated by age, since supplies of some types of labor may respond to changes in wages, but it is relatively unimportant for many age groups, so that on the net the age groups of the labor force is better treated as exogenous. (Hamermesh and Grant, 1979)

Relaxing the CES restraint on the production function, a general approach is discussed below, which is similar to the general form in Hamermesh and Grant's paper (1979). Consider voyage as a process of production, in which the output is the amount (or value) of cargo that has been successfully carried over to the destination as stipulated in the voyage contract. I assume human capital (skilled crew and unskilled crew) can be separated from physical capital (ships and other fixed investments), which leads to a two-input production function having the form  $V = f(H_1, H_2)$ , where  $H_1$  is skilled crew and  $H_2$  is unskilled crew. I write the transcendental logarithmic production function as:

$$(3) \quad \ln V = \ln \alpha_0 + \sum_{i=1}^2 \alpha_i \ln H_i + 1/2 \sum_{i=1}^2 \sum_{j=1}^2 \gamma_{ij} \ln H_i \ln H_j$$

where I assume  $\gamma_{ij} = \gamma_{ji}$ , and  $\alpha_0$ ,  $\alpha_i$  and  $\gamma_{ij}$  are technology parameters. The general cost function with constant returns to scale is  $C = V \cdot g(W_1, W_2)$ , having the corresponding trans-log form as:

$$(4) \quad \ln C = \ln V + \ln \beta_0 + \sum_{i=1}^2 \beta_i \ln W_i + 1/2 \sum_{i=1}^2 \sum_{j=1}^2 \delta_{ij} \ln W_i \ln W_j$$

where  $\delta_{ij} = \delta_{ji}$ , and  $\beta_0$ ,  $\beta_i$  and  $\delta_{ij}$  represent technology parameters.  $C$ ,  $W_1$  and  $W_2$  are total cost, wage bills for skilled crew and unskilled crew respectively.

I also assume perfect competition in both product and labor markets. The rational behavior of how much of each input should be employed in production is to maximize profit, subject to a given level of total cost defined by the cost function described above. The profit minimization implies that  $\partial V / \partial H_i = W_i$ ,  $i = 1, 2$ . Therefore, Equation (3) implies:

$$(5) \quad \partial \ln V / \partial \ln H_i = W_i H_i / V = S_i$$

where  $S_i$  is the cost shares of human capital in the total cost of producing  $V$ , and the price of output is unity. If I take partial logarithmic derivatives for the production function (3), I can get:

$$(6) \quad S_1 = \alpha_1 + \gamma_{11} \ln H_1 + \gamma_{12} \ln H_2$$

$$S_2 = \alpha_2 + \gamma_{12} \ln H_1 + \gamma_{22} \ln H_2$$

It is worth noticing that the production and cost functions are dual to each other, which provides a foundation of defining the partial elasticity of substitution. The Allen Elasticity of Substitution,  $\sigma_{ij}$ , captures the effect on relative input quantity demanded of a change in the relative input prices, holding output and other input prices constant. For

detailed information of the Allen and the Hicks Elasticity, see Allen (1938) and Hicks (1970). In general, two inputs are determined as gross substitutes if  $\sigma > 0$ , and gross complements if  $\sigma < 0$ .

For the trans-log production function employed here:

$$\sigma_{ij} = |H_{ij}| / |H|$$

where  $|H|$  is the determinant of the symmetric matrix:

$$H = \begin{bmatrix} 0 & H_1 & H_2 \\ H_1 & H_{11} & H_{21} \\ H_2 & H_{12} & H_{22} \end{bmatrix}$$

$|H_{ij}|$  is the determinant of the cofactor of  $H_{ij}$ , that is:

$$H_i = S_i$$

$$H_{ii} = \gamma_{ii} + S_i^2 - S_i$$

$$H_{ij} = \gamma_{ij} + S_i S_j, \quad i \neq j$$

And

$$c_{ij} = (\gamma_{ij} + S_i S_j) / S_i S_j, \quad i \neq j$$

The main interest in this paper is to test the null hypothesis that technical change in the Atlantic Merchant Marine from 1863 to 1913 is skill biased.

### 3. Data and Empirical Models

The datasets, compiled by the Maritime History Archive based in Memorial University of Newfoundland, St. John's, Newfoundland, Canada in 1998, consist of 85,600 crew agreements from 18,800 voyages between 1861 and 1913 on vessels registered in non-Canadian ports (mostly English). See Smith et al. (1998) and Maritime History

Archive (1998) for further details.

In the main dataset, there are four separate datasets: vessel registries, crew agreements, ship masters and ports. The vessel registry dataset provided records on whether a vessel was sail or steam (if the horsepower value for a given ship is missing, the vessel is treated as sail), vessel tonnage and horsepower, the destination of a given voyage and its duration, and the number of crew on board. The crew agreements dataset recorded seaman characteristics such as age, birth place and signature ability (literacy), as well as specific terms of agreements including monthly wages and capacity ranks. Both of these two datasets have the voyage identification number in common, which facilitate the link between the datasets.

**Table 1: Age, Wage and Sample Size of Non-Canadian Crew Agreements<sup>3</sup>**

Year	Age			Wage			# of obs.
	Min.	Max.	Mean	Min.	Max	Mean	
1863	12	66	27.94	0.5	300	67	365
1868	12	62	28.55	0.33	260	72.68	1189
1873	13	61	28.88	1	1132	86	1676
1878	14	62	29.91	0	380	86.14	1816
1883	14	68	30.55	1	1510	89.25	2809
1888	13	88	31.45	0	940	89.51	2791
1893	15	68	32.21	1	900	92.16	2495
1898	14	66	30.85	1	2270	86.41	2022
1903	15	66	31.22	0.83	1050	89.24	1379
1908	13	70	33	1	400	97.09	1178
1913	14	70	32.29	1	10180.17	140.83	519
Total	12	88	30.81	0	10180.17	89.22	18239

<sup>3</sup> The wage range may be subject to adjustments, since it is probable that extreme values of wages may arise from report errors.

I chose samples by a five-year interval starting 1863. Table 1 provides some basic statistics on the restricted datasets. It seems that the mean age increases slowly during those years, but can be viewed as roughly stable. Crew start working on board as early as age 12, and leave around age 66. Without decomposing the sample by vessel types, wage is more volatile, and can go to extreme. Mean wages increase a lot in the first twenty years, but remain stable since 1883.<sup>4</sup>

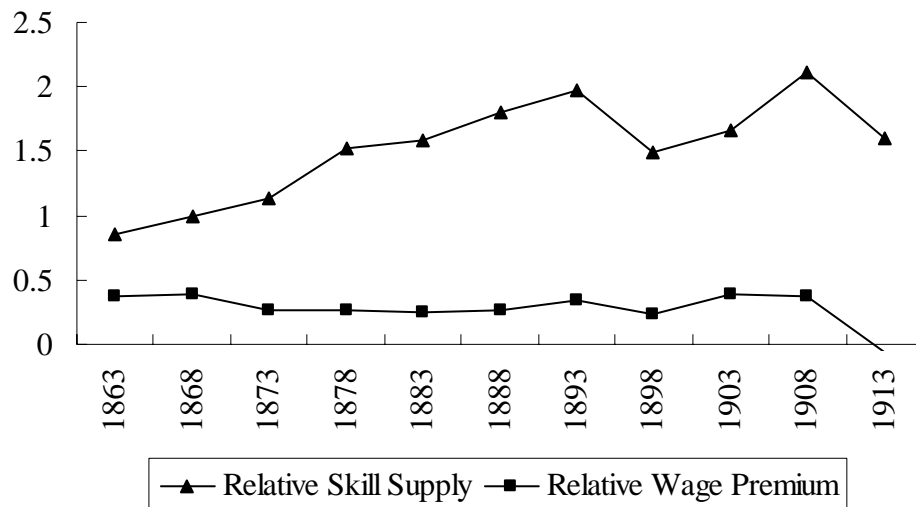
Table 2 summarizes the distribution of voyages of non-Canadian ships in sample years. Both sail and steam vessels existed during sample periods, but there was a clear trend of transition from sail to steam. Sail vessels were dominant before 1873, but declined at an increasing pace until completely faded away in 1913. This interesting phenomenon indicated an on-going technical change between 1863 and 1913.

**Table 2: Distribution of Voyages Non-Canadian Vessels**

Year	% Sail	% Steam
1863	90.91	9.09
1868	79.65	20.35
1873	57.76	42.24
1878	41.88	58.12
1883	18.45	81.55
1888	18.3	81.7
1893	10.8	89.2
1898	10.72	89.28
1903	6.6	93.4
1908	8.9	91.1
1913	0	100

<sup>4</sup> Nominal wages are employed in Table 1. Since deflation was a general phenomenon in the last quarter of the nineteenth century, real wages would be more accurate to capture the trends in mean wages. Therefore, I would use features in [www.eh.com](http://www.eh.com) to compute real purchasing power of pounds and make corresponding adjustments to wages.

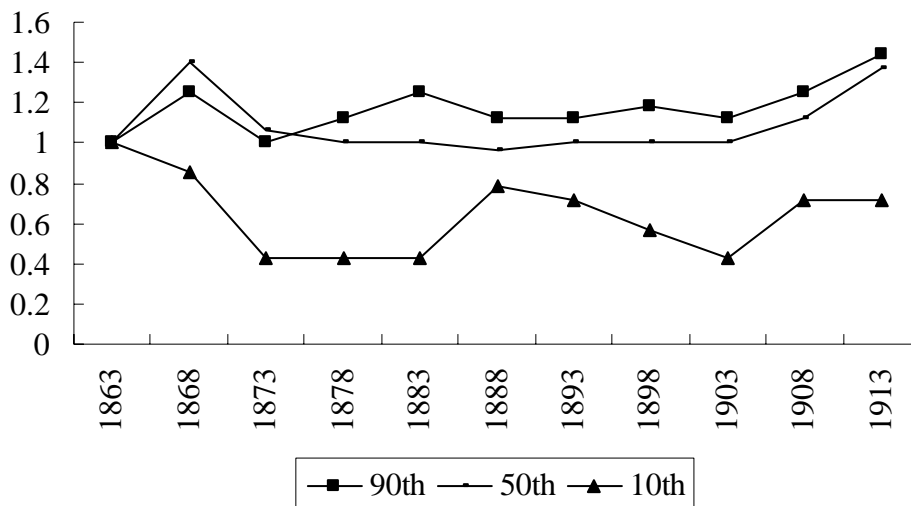
A critical issue centers on how to disaggregate the labor force into skilled and unskilled crew. If a crew member starts working on board at age 16, and after 10 years of hands-on experiences, he is assumed as skilled when he gets 26, no matter what types of occupation he pursues on board. Any crew younger than 26 are defined as unskilled. This approach follows the argument in Hamermesh and Grant (1979)'s paper of treating wages as exogenous if the labor force is divided by age groups. If it is the case that a seaman would normally enter the labor force at age 16, or even younger, then this approach would be largely justified. Another way to disaggregating the labor force is by occupation. I define the able-bodied seaman as skilled labor and the ordinary seaman as unskilled. This approach enjoys the advantage of providing a more direct measure of skills, but suffers from problems as well. For example, the labor supply may respond to wages and become endogenous, and sample sizes will be greatly reduced.



**Figure 3: Relative Supply of Skills and Skill Premium**

Figure 3 plots a measure of the relative supply of relative skills between 1863 and 1913 as the ratio of skilled to unskilled labor i.e.,  $H_1/H_2$ , as well as the relative skill premium i.e.,  $\log(W_1/W_2)$ . The labor force is disaggregated by age, that is, skilled labor is defined as 26 or above in age and unskilled is under 26. It is worth noting that the relative supply of skills increases over time, but skill premium remains quite constant. It can be interpreted as a higher demand for skills that corresponds to a higher supply, which basically leaves skill premium stable.

It is also interesting to provide some empirical trends on wage structure and income distribution. In Figure 4, I plot 90<sup>th</sup>, 50<sup>th</sup> and 10<sup>th</sup> percentiles of the overall wage (monthly earnings) distribution for those crew who were born in Great Britain and who worked only in steam vessels.<sup>5</sup>



**Figure 4: Changes in the Indexed Value of the 90<sup>th</sup>, 50<sup>th</sup>, and 10<sup>th</sup> Percentiles of the Wage Distribution for Crew Born in Great Britain (1863 values normalized to 1)**

<sup>5</sup> See Acemoglu, D. (2002), 'Technical Change, Inequality, and the Labor Market,' *Journal of Economic Literature*, Vol. XL: 7-72.

The earnings of the crew in the lowest 10<sup>th</sup> percentile are much more volatile, compared to those in the 50<sup>th</sup> and 90<sup>th</sup> percentiles groups. Even though the wage gap narrows down during the period 1883 to 1888, I find that inequality in income distribution between 10<sup>th</sup> percentile group and 90<sup>th</sup> percentile group was worsening in the other time periods.

The first empirical model is derived from equation (2), specifically,

$$(7) \quad \ln\left(\frac{W_1}{W_2}\right) = \theta_0 + \theta_1 \ln\left(\frac{H_1}{H_2}\right) + e$$

where  $W_1$  is calculated as weighted average of wages paid to skilled crew for a given voyage, and  $W_2$  is computed similarly.  $H_1$  and  $H_2$  are number of skilled and unskilled crew for a given voyage. Both approaches of the labor force disaggregation will be performed. And the elasticity of substitution is calculated by  $\sigma = 1/\hat{\theta}_1$ .

With relaxation of CES, I estimate equation (6), that is:

$$(8) \quad \begin{aligned} S_1 &= \alpha_1 + \gamma_{11} \ln H_1 + \gamma_{12} \ln H_2 + \nu \\ S_2 &= \alpha_2 + \gamma_{12} \ln H_1 + \gamma_{22} \ln H_2 + \varepsilon \end{aligned}$$

where  $S_1$  is defined as the wage share of skilled crew divided by total wage bills,  $W_1 H_1 / (W_1 H_1 + W_2 H_2)$ , a similar process applying to  $S_2$ . Then, elasticity of substitution is computed using the formula presented in the previous section.

The underlying assumption of a two-input production function is the separability between human capital and physical capital. Separability means that the marginal rates of substitution between skilled and unskilled labor is independent of vessel and other

physical inputs. For example, in the general production function,  $V = f(H_1, H_2, K)$ , if human capital  $H_1$  and  $H_2$  are separable from physical capital  $K$ , then the function can be written as  $V = f[g(H_1, H_2), K]$ , and a sufficient condition for separability is  $\sigma_{H_1, K} = \sigma_{H_2, K}$ . (Hamermesh and Grant, 1979)

Since there is no data available on the value of physical inputs, I would test the assumption by examining the variation of elasticity of substitution between skilled and unskilled labors conditional on different groups of voyages. Voyages are divided into five groups by gross tonnage at a 1500 interval, i.e., 0 to 1500, 1501 to 3000, 3001 to 4500 as so on. If there is little variation, i.e., elasticity of substitution is somehow stable between voyages groups, I would argue that the substitutability between skilled and unskilled crew is independent of physical capital, and therefore estimates from a two-factor production function assuming separability between human and physical capital should be legitimate.<sup>6</sup>

Up to this point, I stated my topic and its significance, and laid out a methodology framework, based on which empirical studies will be carried out later. I also described the datasets in my research. The major issue is to test the null hypothesis that technical change in the Atlantic Merchant Marine from 1863 to 1913 was skill biased.

My remaining tasks will focus on producing estimates of elasticity of substitution, as well as interpreting results and policy relevance.

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<sup>6</sup> It might also be worth using vessel as estimation unit, and see if elasticity of substitution is stable across voyages for a given vessel, which might be fulfilled in the final paper.

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