Human Capital on the High Seas - Job Mobility and Returns to Technical Skill During Industrialization

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Abstract

This paper examines the effects of engineer-oriented and/or technical experience on job mobility during an era known for its rapid technological innovation and capital advancements: the late nineteenth and early twentieth century. Using longitudinal data on British and American naval officer- and engineer-careers, we demonstrate how *ceteris paribus* increases in the distribution of current earnings decrease the probability of job switching. We also show how different forms of technical experience affect probabilities of job switching. Combining both insights and following from a Topel and Ward (1992) based framework, we find various rates of return to engineering and technical experience comparable to rates of return found today. These are the earliest historic estimates of returns to any type of technical skill for an advanced economy.

Keywords: human capital; job mobility; technological change; military personnel; U.S. economic history; skill premium

JEL Classifications: J6, J45, J62, N31.

1 Introduction

Modern economies tend to have a highly skilled workforce, where technical jobs and experience earn relatively high rates of return (Lagakos 2012). What these returns were historically, and how they evolved over time, however, remains a mystery.[1] In times of rapid innovation with skill-enhancing technology, firms and economies alike must develop and improve human capital to keep pace. Workers need training and experience in the use of new technology, and firms must develop ways to retain high-skill workers. If retention mechanisms do not keep pace, quality workers walk.

Linking specific tasks and skills to job switching remains under-explored in economic history, yet an understanding of these links is crucial to fully understand the long-term evolution of human capital development and use (Acemoglu and Autor 2012). And the identification of the effects of general and firm-specific human capital on labor market outcomes is best addressed with the analysis of longitudinal data (Abowd and Kramarz 1999). This paper helps fill the gap in this literature by disentangling the longitudinal effects of different kinds of human capital accumulation on the probability of job switching. We focus on groups of highly skilled workers in an environment of rapid technological change—British and American naval officers during the Second Industrial Revolution.

Navies in general were technical and engineer-oriented bureaucracies during the nineteenth century, and epitomized leading sectors of the economy (Harley 1993). Both the Royal and American navies used and experimented with many of the new technologies of the day, and their respective officer corps developed high levels of technical human capital necessary to implement these technologies. All naval officers during this era began their careers at the lowest possible grade (so one could not switch *in* to the Navy from an outside industry while in mid-career). Using our data entire careers can be followed with measures of initial human capital as well as human capital accumulated over time. Further, naval

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[1] For example, Bessen (2012) suggests that learning-by-experience was important in 19th weaving, but cannot quantify the effect due to data limitations.

pay scales were remarkably rigid and consistent, and officer exits were essentially one-sided decisions during this period.[2] This provides us an exceptionally clean measure to gauge how alternative incentives and individual disaggregated factors of human capital directly impact worker decisions about career changes. This also allows us to impute rates of return for a sub-set of measures for general human capital and technical skill.

The results presented in this paper support three conclusions. First, certain kinds of technical education and experience appear to produce large and powerful incentives for job switching. Engineers were fifty per-cent more likely to switch careers than non-engineers, while each additional year of experience in a technical job increased the probability of a switch by 6 per-cent. Second, for the U.S. case, the imputed rate of return to a year of technical experience rises from near zero during the 1870s and 1880s, when the American Navy was a technological laggard, to around 3 percent by the turn of the century, when it had become a technology powerhouse.[3] Consistent with findings from contemporary labor literature, this return is even larger for younger officers. These are the earliest known empirical estimates of returns to technical skill for any advanced economy.[4] Finally, we show that workers respond to wage changes with remarkable consistency. Modern theoretical models of job search, developed in a different era for presumably different workers, generate surprisingly similar

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[2] A handful of officers resign due to "disability" or for being un-promotable. A few egregious cases of misconduct force others from the service, but the net impact of these observations on results is negligible.

[3] While other works suggest fairly high rates of return to skill in the early 20th century, prior studies have been unable to pinpoint precisely when during the 19th century the rise occurred (Goldin and Katz 2008).

[4] More recently, Grogger (2009) looks at welfare recipients and estimates they receive the return of roughly 5.6 percent per year of work experience. Gladden and Taber (1999) study respondents to the National Longitudinal Survey of Youth (NLSY) who received no education beyond high school. Over a 10-year study period, women in Gladden and Taber's sample enjoyed returns to experience of about 4 to 5 percent per year. Loeb and Corcoran (2001) followed a different cohort of NLSY women ranging in ages between 27 and 34 years old. They find that they received on average an annual return to experience of 6.8 percent. Both Lynch (1993) and Ferber and Waldfogel (1998) follow NLSY women over the same period as Loeb and Corcoran and estimate their annual returns to experience to be about 11 percent and 5 percent, respectively. Light and Ureta (1995) analyze a sample of women from the young women's cohort of the National Longitudinal Surveys (NLS), estimating an average return to experience of 7 percent. Finally, Zabel, Schwartz, and Donald (2004), Card, Michalopoulos, and Robins (2001), and Card and Hyslop (2005) all analyze wage data from the Self-Sufficiency Program (SSP), a Canadian experiment that offered welfare recipients a substantial wage subsidy if they were willing to leave welfare and work full-time. Each study finds annual rates of return to experience of 8.3 percent, 2-3 percent, and 0 percent, respectively. It is not clear why estimates from the same experiment differ so much.

results across time. That is, young naval personnel in the 1880s and 1890s reacted to labor market incentives and search for better matches in similar ways to the young workers studied by Topel and Ward (1992) a century later.

Why Naval History?

At first blush it might seem peculiar to look to 19th century naval history to gleam insights into technological and labor-market developments in advanced economies. We would argue British and American naval personnel during this period are ideal subjects to study for a number of reasons.

First, as we alluded earlier, navies tend to be at the forefront, developing and using the latest technologies of the day. Indeed, “in virtually all times and places where there were such things, warships have been the most expensive, the most complicated, and the most technologically advanced human artefacts in existence.”[5] The navies of the late 19th century in particular epitomized the wrenching changes of the second Industrial Revolution occuring across Western economies.

Naval officers during this time had a wide array of possible jobs, from the fairly non-technical to the most technologically sophisticated. Naval officers served not only on ships, but also potentially on land as ship-builders and repairers in shipyards, as diplomats, staff officers and bureaucrats, inspecting machinery and lighthouses, or more generally as civil engineers or project managers. For personnel in either navy, human capital included not only formal schooling (e.g. naval colleges or external universities) but also the acquisition of training within the fleet. Such heterogeneous experiences allow us to see how different types of human capital affect job switching. This follows from Jovanovic (1979b) and a lineage of research that merges separation theories based on job-search with those based on the accumulation of firm-specific human capital. Our results focus on the heterogeneous effects on earnings from both firm-specific and more general, adaptable and transferable human

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[5] from Tim Shutt’s course ”High seas, high stakes - naval battles that changed history.”

capital. Of course, experience on the job is a powerful determinant of earnings (Mincer 1974), but evidence on skill premia and rates of return to human capital during the early twentieth century has been scarce and controversial (Goldin and Katz 2008, Galor 2011).[6]

Combine these insights with the fact that this era was one of relative peace - there were no serious international conflicts, no mass conscriptions, no overt acts of bellicosity by the major powers. A period of such calm may bore naval historians but should excite labor economists - technologies were advancing rapidly, but the naval environment was stable enough for one to study changes in human capital, technical experience, rates of return and job switching. We suggest this is in fact an ideal time and place to study these questions.

Finally, exits here are essentially one-sided decisions. That is, officers generally exited the service voluntarily. On occasion they were forced out due to disability, age or misconduct. This study focuses on the former, but with careful consideration to the latter. As workers increasingly used the technologies of the second Industrial Revolution, conditions grew ripe for the most highly trained and skilled officers to abandon military careers for more lucrative opportunities in the private sector. Our study allows us to gauge just how lucrative these opportunities were.

The rest of the paper provides historical background in section 2 and a description of the data in section 3. Section 4 presents the empirical model and section 5 discusses results and sensitivity checks. Section 6 provides a brief conclusion.

2 Background

As discussed in Blank and Stigler (1957) and more recently and extensively in Edelstein (2009), a great demand arose during the second industrial revolution for engineering-based skilled labor to manage and facilitate production using new technologies. While college educated metallurgical and chemical engineers were needed in their respective growing in-

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[6] See also early century studies in Reynolds (1951), Ginzberg (1951) and Parnes (1954).

dustries, other sectors of the economy needed workers with technological understanding in the applied sciences. The technically educated also participated in various processes of innovation and patenting (Usselman 1999), and even went into areas of business management and the bureaucracy of industrial organizations, particularly before the rise of explicit business degrees in the 20th century (Calvert 1967).

Historically, military academies began training future officers for skilled work earlier than most private and public institutions, especially given the need to formalize education in mathematics (for projectile trajectories as well as surveying), chemistry (for explosives and ordnance), metallurgy (for weapons, vehicle and systems production), steam (for propulsion), and the general skills necessary for bureaucratic administration. The first institutions devoted to the development of technical human capital in Europe during the latter part of the 18th century were heavily geared towards military operations and funded for both the promotion of domestic industry and the defense of sovereign interests (Edelstein 2009). Not surprisingly, the same focus spilled over to the United States, where the nation's first engineering school was established at West Point in 1802 in the form of the United States Military Academy. Other private and public schools followed with similar curricula, including the United States Naval Academy in 1845.[7]

As discussed in O'Brien (2001), navies historically have served as laboratories and vanguards of technological progress. This was especially true for the latter 19th century Royal Navy, starting in 1869 when the Devastation class of battleships were launched, becoming the prototype for all subsequent RN ships for the rest of the century. The U.S. on the other hand experienced a much more protracted transition during its post-bellum period, moving towards the technological frontier set by England in earnest only by the 1890s (Glaser and Rahman 2014). Technological advances changed nearly every aspect of naval operations, and these changes coincided with economy-wide technological advances in steel manufacturing,

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[7] Although the Naval Academy was not specifically an "engineering" school at its outset, its curriculum included numerous "technical" courses in mathematics, chemistry, ordnance and navigation. Separate engineering-focused tracks in the curriculum followed nearly three decades after its inception.

chemicals and electricity during the second industrial revolution (Mokyr 1990). The corps of officers in both navies not only had the experience to work with this technology, but their experience and education gave them a head start towards understanding the physics, mechanics and chemistry that was accelerating nationwide industrial growth. Their accumulated technical human capital propitiously positioned them to take advantage of changes in the economy.

One often thinks of a naval officer as a master of seamanship, navigation and gunnery. Beyond this, latter 19th century naval officers had opportunities to develop skills as liaisons to iron and steel foundries, ship building yards, supply-chain managers, electrical and lighthouse inspectors, lawyers, engineers and bureaucrats. This training enabled them to develop skills in the art of diplomacy and negotiation, mathematics, chemistry, electricity, telecommunications and numerous other fundamental tools useful in private industry. Their military jobs undoubtedly enhanced their general human capital, and made them attractive candidates for jobs in other rapidly expanding private sectors. This is supported by words from the Navy Chief of the Bureau of Construction and Repair in 1913, who blamed the loss of human capital principally on the private sector's preference for the technically proficient (McBride 2000).[8] Just as officers today have the option to exit after the fulfillment of initial service obligations, historically officers could freely take their human capital elsewhere.

2.1 Training and Human Capital

During this period the overall officer corps of modern navies were comprised of two fairly distinct groups - regular line-officers and engineering officials (henceforth to be called 'officers' and 'engineers,' respectively). Each group had different background skills, and would perform different operations aboard vessels or on shore duty. Each would also have opportunities for

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[8] This is also supported by our cursory examination of U.S. census records for those few ex-officers we can track after they leave the service. Self-reported professions include such skilled jobs as banker, "capitalist" (presumably this meant he was an independent businessman), lawyer, moulder, consulting and civil or mechanical engineers.

specific naval and engineering training. In England the Royal Naval College was established in 1873 to bolster engineering education for all officers, and the Engineering Academy was formed in 1876 to further this goal. In the United States Secretary of the Navy Gideon Welles argued back in 1864 that all Naval Academy students should study engineering (McBride 2000). But unlike England, it would take America a few more decades to fully transform and provide officers proper technical education, through an evolutionary process that involved everything from executive orders, to acts of Congress and even rulings by the United States Supreme Court (Glaser and Rahman 2011).

Through these technological upheavals, officers and engineers followed different career paths and accumulated different kinds of human capital. Aboard vessels, officers managed their complements of sailors, developed strategy and performed certain navigational and technical operations. Engineers on the other hand performed vastly more technical operations, typically below decks.[9] On shore duty, each corps would perform a variety of managerial and bureaucratic functions in naval bureaus or dry-docked vessels.

In short, each person accumulated a unique portfolio of experiences based on their time in naval college, on active or inactive ships, and on shore duty. These experiences allow us to better understand the degree to which each type of human capital helped or hindered job growth mobility, as well as the implicit pecuniary rates of return of each experience.

2.2 Wages and Promotions

An important source of consistency in our study are the officer and engineer compensation schedules, which change only slightly during our period of study. Such stability in payment structure meant personnel could confidently gauge the internal pecuniary rewards of each task and position.

For both navies, the primary way to get a wage raise was to get promoted. Thus if

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[9] These would include, beyond the actual operation of steam engines, operating gun turrets, steering pumps, electric generators, air compressors for torpedoes, bilge pumps, fan blowers, and internal lighting generators.

personnel responded to wage incentives (as we shall demonstrate in the empirical section), meritocratic promotions were crucial to retain employees. This proved more challenging for the U.S. - a glut of officers competed for limited positions on a declining number of ships. This influenced earnings not just through promotions, but also since serving at sea (or at an international station) resulted in wage bumps for American officers and engineers. While the very best officers could find themselves on a career fast-track (Glaser and Rahman 2011), the bulk of officers remained stuck in an archaic system of promotion partly weighted by within-class rank but heavily weighted on seniority (Bartlett 2011). With few promotions available and few open slots in these higher paying duties, exiting the Navy for the private sector would become many officers' best means to increase earnings.

Table 1 provides a glimpse of the structure of U.S. officer ranks. Each column represents the conditional frequency of ranks by tenure within the Navy. For example, 5.5% of all line officers with 15 years of tenure achieved the rank of O-4 (Lieutenant Commander). At this same point in a career, the rank of O-3 (Lieutenant) was attained by 72% of officers, while 22% only made it to O-2 (Lieutenant Junior Grade).[10] With common frequency, officers stagnated at the rank of Lieutenant for 15 or 20 years without promotion[11].

Wages for English officers and engineers are somewhat more involved than for American personnel (pay was often a function of ship assignment, seniority aboard the ship, and qualification of certain navigation or gunnery duties). Nonetheless, promotions constitute the bulk of wage increases.[12]

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[10] Details on the data used to construct these frequencies appears in section 3 of the paper.

[11] In contrast to this, officers in the modern U.S. Navy typically spend 5 to 6 years at the rank of Lieutenant before either receiving a promotion to Lieutenant Commander or being forced into retirement.

[12] The full digitized annual wage schedules for English and American naval personnel (from the Navy Lists and the U.S. Navy Registers, respectively) are available upon request. For the Royal Navy, ranks for officers ascend from cadet or midshipman, to sub-lieutenant, lieutenant, commander and captain. Ranks for engineers ascend from assistant engineer, to engineer, chief engineer, staff engineer and fleet engineer.

Table 1a: U.S. Navy Distribution of Officers by Rank
(conditional on year of service)

	years of service				
rank	10 yrs	15 yrs	20 yrs	25 yrs	30 yrs
ensign	29.67	-	-	-	-
lieutenant junior grade	22.78	22.25	-	-	-
lieutenant	47.56	72.11	87.55	48.35	3.17
lieutenant commander	-	5.49	12.08	50.63	55.28
commander	-	0.14	0.38	1.01	41.55
# line officers	900	692	530	395	285

Frequencies reported for line officers serving from 1866 to 1905.

The extent to which naval officers switched into technical jobs in the private sector remains opaque, with no specific records that track retirees. We have some knowledge, however, of the market for West Point graduates during the first half of the nineteenth century. In 1802, the United States Military Academy at West Point was established as the first school of engineering in the United States. A West Point education at this time included a curriculum on canal, bridge and fortress construction, not to mention chemistry (necessary to understand explosives) and mathematics. It also seems that the private sector had at least some appetite for the engineer training provided at West Point, with 12 to 15% of graduates from 1802-1850 ultimately moving into careers in civil engineering in the private sector (Edelstein 2009). We do not know however the specific factors behind these erstwhile officers' decision to leave the service. In this study we focus on wages, seniority and specific types of accumulated human capital to get a better sense of the factors leading to job switching, and how these ultimately lead us to determine rates of return for skills.

3 Data

Data is compiled from publicly available naval officer career records stored in the National Archives and in the historical archives of the United States Naval Academy library. Published annually, the *Royal Naval List* and the *U.S. Navy Register* contain data on the job assignments, rank and duty station of every officer for every year of their career, and also the deployment status of the ships on which officers served. Wage tables which outline how rank, station and job assignment affect annual pay for English and American personnel are available in the *Navy List* (confusingly a distinct volume from the *Royal Navy List*) and the *U.S. Navy Register.* These data also enable the construction of measures for year-specific and cumulative human capital. Wage profiles for English and American personnel are displayed in figure 1. Data also exist for each officer's time in school (generally either the Royal Naval College or the U.S. Naval Academy). These include specific measures of academic performance, including overall ranking within class, useful as a standardized measure of academic ability.

Summary statistics of measures of accumulated human capital appear in tables 2*a* and 2*b*. For both navies, we are able to distinguish between personnel serving aboard ships on international tours versus those aboard docked or in domestic waters. For the Royal Navy we also have information regarding specific ship characteristics (for example, tonnage and horsepower). What we lack for Royal naval personnel, but have for American naval personnel, is information regarding their jobs when on shore duty.

For the U.S. we also track whether an officer applied for or received a pension due to disability or infirmity. This serves as an important check to our results, as we wish to focus on voluntary departures from naval service. Results from these checks are discussed in section 5.2.1.

Table 2a: Royal Navy Descriptive Statistics (conditional on years of service)

	years of service				
rank	10 yrs	15 yrs	20 yrs	25 yrs	30 yrs
annual log(earnings)					
mean (std. dev)	5.34 (0.19)	5.51 (0.22)	5.74 (0.25)	5.34 (0.19)	6.30 (0.26)
engineer share of sample					
percent of total (std. dev)	0.38 (0.49)	0.37 (0.48)	0.33 (0.47)	0.19 (0.39)	0.01 (0.10)
“modern” ship experience (local)					
mean years (std. dev)	0.23 (0.68)	0.19 (0.60)	0.37 (0.88)	0.43 (0.93)	0.54 (1.08)
% of years served	0.023	0.013	0.014	0.017	0.018
other ship experience (local)					
mean years (std. dev)	1.17 (1.34)	1.70 (1.69)	2.42 (2.00)	2.72 (2.21)	2.81 (2.01)
% of years served	0.117	0.113	0.121	0.109	0.093
“modern” ship experience (international)					
mean years (std. dev)	0.46 (1.08)	0.40 (1.11)	0.52 (1.20)	0.61 (1.34)	0.75 (1.28)
% of years served	0.046	0.027	0.026	0.024	0.025
other ship experience (international)					
mean years (std. dev)	3.53 (2.33)	4.58 (3.03)	5.71 (3.14)	5.99 (3.09)	7.14 (3.05)
% of years served	0.353	0.305	0.285	0.240	0.238
drydock experience					
mean years (std. dev)	0.51 (0.99)	0.86 (1.51)	1.38 (2.19)	0.96 (1.95)	0.20 (0.49)
% of years served	0.051	0.057	0.069	0.038	0.001
experience, senior ship officer/engineer					
mean years (std. dev)	0.58 (1.10)	1.85 (2.27)	3.84 (3.70)	5.02 (4.00)	7.05 (2.85)
% of years served	0.058	0.123	0.192	0.201	0.235
years of additional school/training					
mean years (std. dev)	0.61 (0.77)	0.46 (0.70)	0.42 (0.68)	0.43 (0.71)	0.71 (0.80)
% of years served	0.061	0.031	0.021	0.017	0.024
years in same rank					
mean years (std. dev)	6.27 (2.28)	6.74 (4.30)	5.95 (5.21)	7.32 (4.48)	8.26 (3.14)
average tonnage on ships served					
mean (std. dev)	3690 (2118)	3489 (1912)	3681 (1701)	3572 (1641)	3654 (1517)
average horsepower of ships served					
mean (std. dev)	3446 (2199)	3011 (1865)	3192 (1692)	3021 (1612)	3579 (1683)
# observations	1843	1505	968	411	102

Table 2b: U.S. Navy Descriptive Statistics (conditional on years of service)

	years of service				
rank	10 yrs	15 yrs	20 yrs	25 yrs	30 yrs
annual log(earnings)					
mean (std. dev)	7.426 (0.219)	7.576 (0.156)	7.640 (0.155)	7.721 (0.118)	7.882 (0.128)
engineer or constructor					
percent of total (std. dev)	0.158 (0.365)	0.134 (0.341)	0.140 (0.348)	0.134 (0.341)	0.082 (0.275)
experience in “technical” jobs					
mean years (std. dev)	0.634 (1.321)	1.321 (1.895)	2.215 (2.542)	2.927 (2.882)	3.897 (3.066)
% of years served	0.063	0.088	0.111	0.117	0.096
experience in steam bureaucracy jobs					
mean years (std. dev)	0.056 (0.365)	0.120 (0.651)	0.207 (0.994)	0.207 (1.031)	0.189 (1.017)
% of years served	0.006	0.008	0.010	0.008	0.006
experience in other bureaucracy jobs					
mean years (std. dev)	0.149 (0.490)	0.338 (0.876)	0.504 (1.202)	0.590 (1.309)	0.898 (1.641)
% of years served	0.015	0.023	0.025	0.024	0.030
ship experience (domestic)					
mean years (std. dev)	1.849 (1.499)	2.815 (2.059)	3.810 (2.564)	4.697 (2.827)	5.633 (3.000)
% of years served	0.185	0.188	0.191	0.188	0.188
ship experience (international)					
mean year (std. dev)	4.285 (1.700)	5.782 (2.129)	7.139 (2.392)	8.905 (2.655)	10.58 (2.844)
% of years served	0.429	0.385	0.357	0.356	0.353
command experience					
mean years (std. dev)	0.063 (0.315)	0.128 (0.521)	0.244 (0.723)	0.426 (1.025)	0.996 (1.543)
% of years served	0.006	0.009	0.012	0.017	0.033
Academy order of merit percentile					
mean (std. dev)	0.518 (0.282)	0.525 (0.282)	0.535 (0.281)	0.531 (0.290)	0.525 (0.288)
# observations	1104	829	606	455	281

Of particular interest is the raw difference in the technical human capital of officers who leave relative to those who stay in each naval organization. These differences are highlighted in tables 3*a* and 3*b*. As one can see there are a fair number of exits for each naval organization. Out of nearly 4000 men in the Royal Navy for which we have at least five years of naval history, over 1300 exit during the period 1879-1900. Out of over 1200 men in the U.S. Navy for which we have at least five years of naval history, over 500 exit during the period 1872-1905.

Table 3a: Engineers and Separations in the Royal Navy

	1879-1890		1891-1900		1879-1900	
	stayers	leavers	stayers	leavers	stayers	leavers
engineer share of sample						
fraction	0.357	0.477	0.346	0.293	0.351	0.391
(std. dev)	(0.479)	(0.500)	(0.476)	(0.455)	(0.477)	(0.488)
# observations in group	18643	725	20320	629	38965	1354

Table 3b: Engineers, Tech Experience and Separations in the U.S. Navy

	1872-1890		1891-1905		1872-1905	
	stayers	leavers	stayers	leavers	stayers	leavers
experience in tech jobs (years)						
mean years	0.678	0.682	2.394	2.994	1.668	2.085
(std. dev years)	(1.090)	(1.176)	(2.805)	(2.932)	(2.420)	(2.651)
engineer/constructor share of sample						
fraction	0.103	0.140	0.159	0.188	0.135	0.169
(std. dev)	(0.304)	(0.348)	(0.365)	(0.391)	(0.341)	(0.375)
# observations in group	7266	214	9901	330	17167	544

4 Econometric Model

The labor literature contains a number of theoretical and empirical studies which highlight the job switching process, including a useful and extensive meta-discussion in Gibbons and Waldman (1999). That being said, the empirical model we use follows from the work of Mortensen (1988) and most importantly Topel and Ward (1992).[13] In general, this model connects job switching decisions to a number of key factors: the distributions of external and internal job offers, human capital acquired over time, internal wages and job tenure.

4.1 Topel and Ward job separations

The model begins with the primal assumption that naval officers base mobility decisions on the maximization of the net present value of lifetime wealth. Wage offers from private-sector firms generate from a known distribution and vary as careers progress due to the nature of work experience. The distribution of *private*-sector offers depends on the amount of observable experience, x, and is defined by

$$Prob(w^p < z; x) = G(z; x) \ . \tag{1}$$

If $G_x(\cdot) < 0$ then wage offers increase with the accumulation of experience. The *occurrence* of new job offers from the private-sector for officers follow a Poisson distribution with parameter π.

Within the Royal and American navies of the late 19th century, wage changes for individual personnel occur through one of three basic mechanisms. First, promotion guarantees an increase in wages. A deterministic mechanism for promotions does not exist on record, with only anecdotal discussions that relate it to seniority, merit and availability of openings. Promotions were also likely related to the type and amount of fleet experience as demonstrated

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[13] Additional work from Bernhardt (1995) and McCue (1996) on promotions proved especially helpful for developing ideas.

in tables $2a$ and $2b$. Glaser and Rahman (2011) highlight the factors that most affected American officer promotions during this period, noting especially how the post-bellum period was plagued with an overall lack of promotions within the U.S. Navy. In this study we analyze, among other things, the effects of wage changes on job exits for both the Royal and American navies - promotions play a vital role in these wage changes for both organizations.

Without a promotion, officers faced stochastic year-to-year changes in wages based on their job assignments serving on ships at sea, in international embassies/consulates, at domestic shore stations (bureaucratic or technical), or awaiting further orders without a current assignment. These wage changes differed between the U.S. and U.K., and often depended as well on one's rank. For members of the Royal Navy, pay also depended on if an officer was licensed in navigation, gunnery or torpedoes. British officers in command often received a wage bump. For British engineers pay was sometimes a function of the horsepower of their assigned vessel.

Finally, even without promotions, officers and engineers generally received wage increases when they stagnated *within* the same rank. For the U.S. this happened for pentennial intervals (after 5, 10, 15 or 20 years in the same rank). For the U.K. wage increases from stagnation depended on the rank and to some extent the period (full details available upon request). In any case, these within-rank interval wage changes were well known to all officers.

The distribution of internal *navy* wage offers (job assignments), w^n, depends on current wages, w, experience, and the overall number of years in the Navy (years since commissioning), t. We further control for wage increases due to promotion stagnation through the variable s. Hence the distribution of internal offers is defined by:

$$Prob(w^n < y; w, s, x, t) = F(y; w, s, x, t) \ . \tag{2}$$

As Mortensen (1988) details, a higher current wage increases the entire distribution of internal offers such that stochastically $F_w(\cdot) < 0$. If internal wage growth is non-increasing (concave) with tenure and experience, then stochastically $F_t(\cdot) \geq 0$ and $F_x(\cdot) \geq 0$. The automatic pay raises due to officers who stagnate within rank implies that $F_s(\cdot) < 0$ during the pentennial years. The probability of an internal wage change is also assumed to be Poisson.

Assuming a discrete choice between extending his career in the Navy or separating, the offer distributions given by (1) and (2) jointly capture the characteristics of the current career outcome of the officer, given his set of alternatives. With both sides of the labor market defined, the value function, $v(w, s, x, t)$, represents the expected present discounted value of lifetime wealth for officers paid a wage of w at year t. Given a private-sector offer w^p, a job switch occurs when $v(w, s, x, t) < v(w^p, s, x, 0)$. That is, an exit from the Navy occurs when the outside job (with experience set at $t = 0$) has greater expected wealth than the current naval job. On the margin, a reservation wage exists, $r(w, s, x, t)$, such that $v(r(w, s, x, t), s, x, 0) = v(w, s, x, t)$. Any private sector offer, w^p, exceeding the reservation wage leads to a job separation from the Navy.

Topel and Ward (1992) define the hazard as the product of the probability of receiving a new offer, π, and the probability that the new wage exceeds the reservation wage. In other words, the hazard at time t is

$$h(w, s, t, x) \;=\; \pi Prob(w^p > r(w, s, t, x)) \;=\; \pi \left[1 - G(r(w, s, t, x))\right] \; . \tag{3}$$

For comparative statics and empirical predictions, assume that $r(\cdot)$ is differentiable, and let $g(z; x) = G_z(z; x)$ define the density of wage offers. A change in the current wage affects the hazard by

$$h_w(w, s, t, x) = \; -\pi g(r; x) r_w(w, s, t, x) \; . \tag{4}$$

A larger current Navy wage increases the net present value of the current job and bumps-up the reservation wage. This implies that $h_w(w, s, t, x) < 0$.

Secondly, the effect of service time on the hazard appears as

$$h_t(w,s,t,x) = -\pi g(r;x) r_t(w,s,t,x) \ . \tag{5}$$

Given the assumption of concave wage-profiles over time from on-the-job general training, then $r_t < 0$ for $t > 0$. All else equal, switching jobs becomes optimal over time as private sector jobs offer larger growth in expected wages due to accumulated human capital. Indeed officers may choose to accept a wage cut with the separation simply because the potential for wage growth on the new job over time leads to higher lifetime wealth (see Bernhardt 1995). This indicates a result in which $h_t(w,s,t,x) > 0$. Related to both of these prior results, since the Navy guaranteed wage increases for every fifth year within-rank (lack of promotion), s should have a positive effect on the reservation wage, $r_s(w,s,t,x) > 0$. Therefore we expect that $h_s(w,s,t,x) < 0$ for each point in time one receives a wage increase without a promotion.

Finally, the effect of experience on the hazard is given by

$$h_x(w,s,t,x) \ = \ -\pi g(r;x) r_x(w,s,t,x) \ = \ -\pi G_x(r;x) \ . \tag{6}$$

We allow for the possibility that different types of experience (technical, bureaucratic, ship service and command) all may have different effects on the hazard. Presumably $G_x > 0$ for experience with more firm-specific human capital, and $G_x(\cdot) \leq 0$ for more generally transferable forms of human capital. If general human capital has a linear effect on the mean of log wage offers, and the reservation wage follows from an officer's current wage, then (4) and (6) can be combined to impute the rate of return to a year of experience. Holding other variables constant, the fraction $\frac{-h_x}{h_w}$ represents the annual growth in wage offers from experience.[14]

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[14] For discussion purposes later in the paper, the estimates for $h_w(\cdot)$ and $h_x(\cdot)$ are the partial derivatives of (7) with respect to internal wages, w, and years of general (technical) experience, x. See Topel and Ward (1992) for more detail on this method of imputation.

4.2 Estimation

Estimation of (3) follows from methods outlined in Gloeckler (1978), Kalbfleisch and Prentice (1980) and Heckman and Singer (1984). Kiefer (1988) provides a helpful and systematic summary as well. The semi-parametric likelihood function outlined below follows from Meyer (1990). The likelihood is defined by the conditional probability at time t that an officer separates during year $t+1$ of his career. During the postbellum period (and unlike today), the Navy did *not* have a defined mechanism to force officers from service until they were 62 years old or physically unable to perform. In most cases, separation decisions were one-sided.[15] Assuming covariates remain constant on the intervals between time periods t and $t+1$, the specification of the log-likelihood function used to estimate the model for N officers follows as:

$$log\ L(\gamma, \beta) \ = \ \sum_{i=1}^{N} [\delta_i log\,[1 - exp\,\{-exp\,[\mathbf{x}_i(T_i)'\beta_x + \gamma(T_i)]\}] \ - \ \sum_{t=1}^{T_i - \delta_i} exp\,[\mathbf{x}_i(t)'\beta_x + \gamma(t)]] \ . \tag{7}$$

This log-likelihood is a discrete time model with incompletely observed continuous hazards for censored ($\delta = 0$) and uncensored ($\delta = 1$) careers. Our estimates track careers from the beginning of year 6 until the beginning of year 36[16]. Step-function intervals define the experience spline for years $[6, 10), [11, 15), ..., [31, 35)$. The job tenure spline generates from estimates of γ[17]. Control variables at time period t are defined by the vector $\mathbf{x}(t)$ and include: the officer's wage, cumulative experience at sea or in command, a dummy variable to designate stagnation within rank, a dummy variable capturing status as an engineer, cumulative experience in various types of technical jobs, cumulative experience working in

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[15] Results are not sensitive to exclusion of the handful of cases that apparently were not one-sided.

[16] By Congressional stipulations at the time, officers could not continue working beyond sixty-two years of age or with forty years of service. Due to the limited number of observations remaining in the data beyond the thirty-fifth year and the impending forced retirements for this handful, we limit the career time-frame to thirty-five years.

[17] We choose five year intervals for tractability and for presentation, but the results presented throughout the paper are not sensitive to the choice of 5 year intervals.

a bureaucratic post, controls for physical constitution[18], and year fixed effects. Alternative specifications include controls for unobserved individual-specific heterogeneity.[19]

5 Results

Odds ratios estimated from (7) appear in tables 4*a*, 4*b*, 6 and 7. Table 4*a* covers the sample of Royal Navy officers and engineers during the years 1879-1900. Table 4*b* includes estimates on U.S. officers and engineers during the full sample of years from 1872-1905, and sub-samples from 1872-1890 and 1891-1905 to demonstrate differences in hazards between the "pre-modern" and "modernizing" U.S. Navy.[20] In table 4*b*, columns (**1**)-(**3**) include annual fixed effects, while columns (**4**) and (**5**) allow for unobserved individual-specific heterogeneity. Tables 6 and 7 include the results from sensitivity checks.

First, as indicated in equation (4), higher wages in the current job should decrease the probability of an exit from the Navy. Our results not only support this hypothesis, but outcomes remain remarkably robust across both navies for all specifications, time periods and worker-types. At the average wage and holding other variables constant (e.g. seniority and various types of experience, career-tenure splines), a 1 percent increase in wages decreases the odds of exiting by roughly 2 percent.

This provides us a consistent baseline to impute rates of return to different tyrpes of technical experience. This also suggests that *homo economicus* is alive and well in the fleets of the 19th century - individuals of different stripes respond very similarly to wage stimuli.

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[18] These include the cumulative years that an officer is designated for sick leave and a dummy variable indicating sick leave status in a specific year.

[19] Specifications of the likelihood with unobserved heterogeneity also follow from Meyer (1990) with gamma distributed heterogeneity. That is

$$log\ L(\gamma,\beta,\sigma^2)\ =\ \sum_{i=1}^{n} log\left[\left[1+\sigma^2\sum_{t=0}^{T_i-\delta_i} exp\left[\mathbf{x}_i(T_i)'\beta+\tilde{\gamma}(T_i)\right]\right]^{-\sigma^{-2}} - \delta_i\left[1+\sigma^2\sum_{t=0}^{T_i} exp\left[\mathbf{x}_i(t)'\beta+\tilde{\gamma}(t)\right]\right]^{-\sigma^{-2}}\right].$$

[20] Estimated hazards for Royal Navy on the other hand remain fairly consistent for various sub-samples. Results available upon request.

This strongly demonstrates the validity of Topel and Ward's argument for those working a century prior to their having made it - a key element leading to job durability is the wage. To our knowledge, these are the earliest groups for which Topel and Ward's framework have been tested.

5.1 Engineers and technical job experience

Engineers in the Royal Navy exhibit much higher exit rates than their fellow line officers. In the broadest specification (column (3) of table 4*a*), engineers exit 76% more often than line officers. Robustness checks from other specifications produce similar estimates, and all engineer coefficients are statistically significant. While not exiting as quickly as their counterparts in Britain, engineers in the U.S. Navy exit at rates that are 46% percent higher line officers. In models focusing on the latter time period and controlling for unobserved heterogeneity, this estimate rises to nearly 66 during the latter years of the sample.

One potential reason for different hazards between British and American engineers is that the British were handling the most technologically sophisticated equipment on the planet. The engineers' exposure to this experience would conceivably be most valuable to other industries. This was not the case for American engineers, but with naval modernization it was becoming more the case over time. As the last column for the U.S. makes plain, the rate of return for American engineers were converging to those of their English counterparts.

Another possible reason for different estimates may be due to our different measures of specific "technical" experience. Measures for technical jobs in the U.S. Navy include accumulated assignments to shipyards, jobs overseeing steel manufacturing, inspecting lighthouses or acquiring additional university-level schooling (typically graduate studies at universities in Europe and the United States). Both officers and engineers in the United States could accumulate technical experience. Particularly during the 1891-1905 period, each year of technical experience raises the hazard by a little more than six percent.[21] This same variable,

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[21] One might suggest that the U.S. macroeconomy was inherently weaker during the 1870s and 1880s

however, exhibits no effect from 1872-1890, again consistent with an organization having begun modernizing in earnest only after 1890.

With our broad specifications that include extensive control variables, we believe these hazard regressions provide lower-bound baseline estimates for the wage-gain from technical experience at the turn of the century in two of the most dynamic world economies. As noted in Topel and Ward (1992), the ratio of marginal effects on the hazard, $\frac{h_x(\cdot)}{h_w(\cdot)}$, provides an estimated rate of return to experience. We report these imputed effects in table 5. Since technical experience has essentially no impact on separations from 1871-1890 in the United States, this rate of return is approximately zero. For the U.S. sub-sample covering 1891 to 1905, the return grows to approximately 2.5 percent per year of technical job experience.

For engineers, the return appears to be higher. From the Royal Navy, the average rate of return for engineer training is a robust 33%, while in the U.S. this return is 24%. For the earlier sub-sample of U.S. engineers, when technical experience does not matter, an engineering degree exhibited a strong boon to external wages of 30% (similar to the U.K. sample). In later years, the effect diminishes slightly to 15%, perhaps mitigated by the increasing value of technical experience itself. These results strikingly conform with contemporary estimates of the rates of return to technical degrees (see for example Altonji 1993).

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compared with later on, thereby producing fewer opportunities for workers of all kinds to find alternative employment, including the technically trained. We would suggest that the facts do not bear this out. While we do not have data on vacancy rates for this period, we can calculate annual real GDP growth averages for each decade. These are (in percent growth) 5.2, 4.8, 3.1 and 2.7 for the 1870s, 80s, 90s and 1900s respectively (author's calculations based on Johnston, Louis and Samuel H. Williamson, 2011, "What Was the U.S. GDP Then?"). As it happens, annual fixed effects that we include in all specifications control for these broad macroeconomic factors.

Table 4a: Odds-Ratios for Separations from the Royal Navy
(sample years from 1879-1900)

	sample				
variable	**full**	**full**	**full**	**engineers**	**officers**
log(earnings)	0.983 (<0.000)	0.980 (<0.000)	0.983 (<0.000)	0.983 (<0.000)	0.989 (<0.000)
engineer	1.749 (0.002)	1.804 (0.001)	1.755 (0.002)	-	-
log(average horsepower) (of ships served)	-	0.999 (0.015)	0.999 (0.313)	1.000 (0.404)	0.999 (0.035)
log(average tonnage)	-	0.999 (0.055)	0.999 (0.041)	0.999 (0.495)	0.999 (0.277)
drydock experience (years)	0.963 (0.173)	-	0.976 (0.417)	0.940 (0.033)	1.030 (0.529)
other ship experience (international)	0.917 (<0.000)	-	0.924 (<0.000)	0.877 (<0.000)	0.948 (0.002)
"modern" ship experience (international)	0.887 (0.004)	-	0.901 (0.027)	0.859 (0.022)	0.929 (0.094)
other ship experience (local)	0.949 (<0.000)	-	0.963 (0.002)	0.931 (0.001)	0.984 (0.424)
"modern" ship experience (local)	0.913 (0.023)	-	0.934 (0.078)	0.888 (0.206)	0.951 (0.259)
years as senior officer/engineer on ship	1.060 (<0.000)	1.030 (0.005)	1.054 (<0.000)	1.016 (0.217)	0.984 (0.521)
years at same rank	1.109 (<0.000)	1.101 (<0.000)	1.109 (<0.000)	1.112 (<0.000)	1.144 (<0.000)
order within rank	1.001 (<0.000)	1.002 (<0.000)	1.001 (<0.000)	1.001 (0.469)	1.000 (0.273)
years of additional school/training	0.855 (<0.000)	0.837 (<0.000)	0.843 (<0.000)	0.756 (0.005)	0.886 (0.026)
year effects	yes	yes	yes	yes	yes
baseline splines (4 years)	increasing	increasing	increasing	increasing	increasing
log likelihood	-1898	-1910	-1891	-537	-1281
individual events	40085	40085	40085	13996	26089
officers and engineers : separations	3817 : 1353	3817 : 1353	3817 : 1353	1345 : 529	2472 : 824

Odds-ratios reported with p-values in parentheses.
Standard errors clustered by Cohort of First Year as a Sub-Lieutenant or Assistant Engineer.

Table 4b: Odds-Ratios for Separations from the U.S. Navy

	sample years				
variable	**1872-1905**	**1872-1890**	**1891-1905**	**1872-1890**	**1891-1905**
log(earnings)	0.984	0.987	0.976	0.989	0.982
	(<0.000)	(<0.000)	(<0.000)	(0.001)	(<0.000)
engineer	1.490	1.478	1.464	1.393	1.660
	(0.001)	(0.029)	(0.031)	(0.128)	(0.014)
tech job experience	1.044	1.000	1.062	0.999	1.064
	(0.082)	(0.995)	(0.021)	(0.992)	(0.033)
steam bureau experience	0.915	1.023	0.905	1.025	0.924
	(0.032)	(0.747)	(0.034)	(0.895)	(0.331)
other bureau experience	0.998	0.946	1.008	0.943	1.030
	(0.969)	(0.706)	(0.870)	(0.741)	(0.591)
in rank: $5, 10, 15$ or 20 years	0.666	0.754	0.553	0.778	0.556
	(0.002)	(0.071)	(0.002)	(0.242)	(0.019)
overall USNA class percentile	0.974	0.700	1.236	0.675	1.226
	(0.879)	(0.169)	(0.359)	(0.116)	(0.382)
ship experience (domestic)	1.022	0.953	1.041	0.939	1.057
	(0.323)	(0.326)	(0.102)	(0.176)	(0.046)
ship experience (international)	0.979	0.999	0.959	0.976	0.976
	(0.438)	(0.971)	(0.169)	(0.583)	(0.405)
command experience	1.061	0.733	1.102	0.720	1.097
	(0.192)	(0.014)	(0.031)	(0.114)	(0.082)
cumulative years of sick leave	1.371	1.355	1.456	1.362	1.543
	(<0.000)	(0.006)	(0.002)	(0.002)	(0.001)
sick	8.581	8.569	8.841	9.638	15.74
	(<0.000)	(<0.000)	(<0.000)	(<0.000)	(<0.000)
year effects	yes	yes	yes	no	no
unobserved heterogeneity	no	no	no	yes	yes
baseline splines (5 years)	concave	concave	concave	concave	concave
log likelihood	-626	-335	-277	-361	-323
individual events	16824	7362	9462	7362	9462
officers and engineers : separations	1213 : 510	766 : 209	998 : 301	766 : 209	998 : 301

Odds-ratios reported with p-values in parentheses.
Standard errors in columns (1)-(3) clustered by USNA graduating class.

Table 5: Rates of Return to Technical Skills: $\frac{h_x}{h_w}$

	U.S. Navy			Royal Navy
	1872-1905	1872-1890	1891-1905	1879-1900
engineer				
rate of return	0.248***	0.307*	0.155*	0.333***
(p-value)	(0.007)	(0.083)	(0.065)	(<0.000)
all technical experience				
rate of return	0.027*	0.000	0.024***	-
(p-value)	(0.043)	(0.995)	(0.036)	

All regressions included same control variables as table 4.
One-sided significance indicated as *** if $p \leq 0.01$, ** if $p \leq 0.05$ and * if $p \leq 0.10$.

Table 6 includes sensitivity checks for the U.S. Navy with technical experience subdivided along separate jobs. While exit rates vary by types of experience and time, the results are compelling. In earlier discussions, we establish that overall technical experience during later years increases the hazard by about 6%. The premium from post-graduate education leads to a 23% increase in the hazard across all years, and it appears to increase external wage offers by 36% for the early sub-sample and 8.5% in later years. Time serving as an electrical lighthouse inspector bumps the hazard by 7.2%, but has a smaller (not statistically significant) effect onexternal wage offers. The biggest effect appears for those who serve as ship constructors, where each year of experience increases exits by 85% and increases the rate of return by 23%. A year serving in Navy yards increases external wages by 1.3%. Prior to the 1890s officers assigned to Navy yards had more bureaucratic (firm-specific) than technical (general) work, so it is not surprising that this result appears negative in the early sub-sample. After 1895 in particular, Navy yard experience for these officers involves more duties related to engineering, steel manufacturing and the maintenance of yard-wide electrical systems.[22]

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[22] *U.S. Navy, Bureau of Yards and Docks: Annual Report.* Bound with *Annual Report of the Secretary of the Navy.* Washington: Government Printing Office, 1842-1940.

Table 6: *Any* Technical Experience or *Specific* Technical Experience?

	1872-1905		1872-1890		1891-1905	
	any	specific	any	specific	any	specific
all tech job experience						
coefficient	0.043**	-	-0.000	-	0.060**	-
(std. error)	(0.025)		(0.050)		(0.026)	
[odds ratio]	[1.044]		[0.999]		[1.062]	
additional university studies						
coefficient	-	0.206***	-	0.474***	-	0.228**
(std. error)		(0.084)		(0.130)		(0.102)
[odds ratio]		[1.229]		[1.606]		[1.256]
ship construction experience						
coefficient	-	0.533***	-	-	-	0.612***
(std. error)		(0.229)		-		(0.243)
[odds ratio]		[1.704]		-		[1.845]
navy yard experience						
coefficient	-	0.008	-	-0.050**	-	0.034
(std. error)		(0.031)		(0.288)		(0.035)
[odds ratio]		[1.008]		[0.951]		[1.035]
inspector experience						
coefficient	-	0.074*	-	0.232	-	0.072*
(std. error)		(0.046)		(0.196)		(0.044)
[odds ratio]		[1.077]		[1.262]		[1.074]

All regressions included same control variables table 4.
One-sided significance indicated as *** if $p \leq 0.01$, ** if $p \leq 0.05$ and * if $p \leq 0.10$.

5.2 Career milestones and tenure

The effects of career milestones subject to job tenure appear through estimates of time-based splines for the baseline hazard. In tables 4*a* and 4*b*, these are referenced by the term “baseline splines”. Importantly, splines control for omitted variables that are specific to block of time during officer or engineer careers. For example, we have no information on periodic reviews of performance within either Navy.[23] If the Royal Navy reviews all officers during year 12, and strongly encourages (or even forces) under-performers to find another profession, the spline covering year 12 captures this bump in exits on the baseline hazard.

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[23] We have each officer and engineer *order within rank* for the Royal Navy, which may partially capture these reviews. This is discussed later.

Specific results of these splines are extensive and available upon request from the authors.[24] All specifications are estimated with splines that cover 4 year blocks of time for the Royal navy and 5 year blocks for the U.S. Navy.[25] Results for Royal Navy splines demonstrate an increasing hazard over the entire career. Results for the U.S. Navy, on the other hand, do not contradict the hypothesis of a concave hazard (see Farber 1999), although we would expect the hazard to decline earlier in a career for results to be more congruent with other studies of labor markets (profile is displayed in figure 2). In both navies, career milestone/tenure effects generally appear small during the early years of a career but increase noticeably between years 20 and 30. After the $30th$ year in the U.S., tenure effects decline, perhaps as the remaining workers settle-down and wait for a forced retirement. Despite non-pecuniary benefits of military seniority, the wage stagnation that accompanies tenure appears to matter for most of a career[26]. Rather than appearing in the early part of a career, the effects of a concave tenure-separation relationship that drives searches for a better match occur rather late in a career. Without more information, the exact reasons remain elusive. A simple explanation is that jobs in the military simply take longer for the quality of the match to reveal itself. If true, then we would expect the tenure-separation relationship to grow at a later point in the time horizon. Another conjecture is that search costs decrease over time. Without more refined time-use data, we cannot measure exactly why but can think of two candidate reasons. First, officers with longer careers have more time to develop extensive contacts in private sector labor market networks. Another reason follows from the the time demands of daily job responsibilities. Perhaps as workers move higher up the chain of command *and/or* get shuttled into positions with fewer tasks and duties their daily time demands diminish.

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[24] Future drafts may include these as an appendix.

[25] Other regressors are robust to the use of different spline lengths of time.

[26] See Melese et al. (1992) and Hartley and Sandler (2007) for more discussion on the non-pecuniary benefits for military personnel.

5.2.1 Pensions

Another possibility for the U.S. Navy is that our measures of wages used to estimate the specifications reported in table 4*b* are mis-measured by not accounting for the possibility of pension income. The U.S. Navy Pension Fund is one of the earliest examples of a federally-run retirement system. For the time frame researched in this paper, the Navy formally set eligibility for pension funds (typically 75 percent of base pay) under two scenarios: an officer could apply for retirement and an associated pension after forty years of service, or a retirement board could find an officer incapable of service due to disability or infirmity (Clark et al. 2003). Since data limitations limit career lengths in the sample to less than forty years, only instances of the latter case are applicable for this paper. Thus we can consider pension payments here as a form of disability insurance. Importantly, one should note that the experience splines discussed previously discussed already control for pension *eligibility.* Indeed the spikes in these parameters after 20 years of experience may partially appear as a result of officers having access to this implicit insurance.

Of course not all officers eligible for pensions ultimately apply for them. We know this, since specific officers can be matched with Navy pension records housed in the *U.S. National Archives.*[27] Using this archival pension data, cases where erstwhile officers (and engineers) or their family members apply for pensions are filed into one of four categories - a family member applies and is either approved or disapproved, or the former officer himself applies and is either approved or disapproved.[28] Given that pension applications often occurred well after the conclusion of careers, one cannot ascertain with certainty whether officers separated with a pension in hand, an application in hand, or even a clear expectation that a pension application would ever receive approval from the retirement board.

That being said, we re-estimate the full model specification[29] without sub-sets of pension

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[27] These are also available electronically throughhttp://www.ancestry.com.

[28] These are respectively labeled as "Navy Widows' Certificates," "Navy Widows' Originals," "Navy Survivor's Certificates," and "Navy Survivor's Originals."

[29] This includes all variables outlined in column (3) of table 4.

applicants, and table 7 reports the sensitivity of key parameters to these sample exclusions. These sub-samples (corresponding with table 8 columns) exclude: (1) officers who apply for a pension ($n = 28$), (2) officers or family members who apply for a pension ($n = 112$), and (3) officers or spouses actually granted a pension ($n = 92$). Notably the key parameters, especially those with respect to job tenure (the "years experience" splines), remain robust to various sub-sample estimations.[30] The effect of cumulative technical experience increases slightly in the two re-estimations restricted to officers who never apply for pensions. These results appear to bolster the argument that more technical experience ultimately led officers to a faster exit.

Table 7: Sensitivity to possible pension-related exits

	(1)	(2)	(3)	(4)
tech job experience	1.071*** (0.009)	1.070** (0.016)	1.056** (0.047)	1.062** (0.021)
engineer	1.462** (0.033)	1.381* (0.073)	1.426** (0.041)	1.464** (0.031)
Navy earnings	0.976*** (<0.000)	0.977*** (<0.000)	0.977*** (<0.000)	0.976*** (<0.000)
log likelihood	-266	-239	-250	-277
individual events officers : separations	9129 970 : 291	8223 886 : 256	8414 904 : 263	9462 998 : 301

Same specifications as table 4, column (3) (all results not reported).
Odds-ratios with p-values in parentheses estimated on class clusters.
Column (1) excludes all officer pension applicants.
Column (2) excludes all officer and spouse pension applicants.
Column (3) excludes only successful officer or spouse pension applicants.
For comparison, column (4) re-reports baseline results from table 4a.

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[30] Other unreported parameters do not indicate changes notable for discussion and hence are excluded from the discussion.

5.2.2 Career malaise

In the United States, officers received pay increases through two basic avenues: promotion to a higher rank, or ironically by stagnating within the same rank for too long. That is in the absence of a promotion, a 10 percent pay-step increase occurs each time an officer achieves within-rank milestones of 5, 10, 15 or 20 years of service. Therefore we expect that 5 year bumps in earnings should influence decisions similarly to increases in w, in that officers pentennially increase their reservation wage in the absence of a promotion. This indicates a shift in the distribution of offers such that $h_s < 0$. When not in a pentennial year, officers expect zero growth from internal wage offers and thus $h_s \geq 0$. We control for this stagnation effect with a dummy variable for whether the officer/engineer is serving in his pentennial year within rank. Impending pay increases bump-up the reservation wage and decrease separations.[31] Evaluated at means for the entire U.S. sample, the impending increase to earnings decreases the hazard by 33%.

In the Royal Navy, we control for relative stagnation with the variable "years at same rank" (while wage bumps for Royal naval personnel do occur with stagnation, the time intervals depend on one's current rank and the time period). Since a bump in pay does not occur via stagnation, Royal Naval officers or engineers simply could languish for years without hope of a promotion-related raise. Indeed it seems that each additional year stuck at the same rank increases the exit probability by about 10 %. Supplementally the measure of "order within rank" is also statistically significant but immensely small in magnitude. For example, the highest rated lieutenant appears less likely to separate in any given year than the lowest rated lieutenant, but not by much.

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[31] In addition to the reported results in this paper that focus on the pentennial year, various alternative specifications that include additional indicator variables for other years preceding a pay bump provide no additional insight.

5.3 General and navy-specific measures of human capital accumulation

Finally, we look at other forms of experience. In the Royal Navy, ship-based experience includes the time an officer or engineer serves on ships in local seas (the Home Fleet and other stations around the British Isles) and international seas (all other seas and oceans). On an additional dimension, we divide this time into service on the most powerful and technologically advanced "modern" ships of the Royal Fleet. These include all active ships classified as a "battleship-first class" or a "cruiser-first class." In general and regardless of specification, each year of service with any of these specific platforms or stations drops the hazard by 5 to 10 percent. It thus appears that time aboard vessels constitutes a form of firm-specific human capital not particularly valued outside naval service.

It also appears that exit rates are higher for those who receive experience on local or domestic vessels. This is particularly true for the U.S., where time served on ships in domestic seas increases separation probabilities by about 5 percent. One conjecture is that time aboard domestic vessels implied more general human capital accumulation, such as managerial experience or greater dealings with various bureaus, which allowed officers to sell their human capital more readily.

Additional training in the Royal Navy typically meant attending the Royal Naval College; this appears to be another form of human capital not valued outside of the Fleet. This is unlike the result for additional University studies found for American officers. Each year of additional naval training by a (typically) young British man decreases the probability of his job separation by 18%. The result is stronger for engineers, who are 28% less likely to separate after training than before. Regular line officers exit 12% less frequently after additional job training. Differences between the two navies make sense - Royal naval officers were inculcated with a narrow navy-based education, while American officers were able to join private universities and experience a wider range of technical education.

Leadership in both navies appears to matter as a form of general training valued by external labor markets. Perhaps an absence of formal business schools during this time increased the value of management experience (Edelstein 2009). In particular for the Royal Navy, each year of service as the senior officer or engineer on ships at sea increases the probability of an exit by approximately 5 percent. Command experience in the more provincial U.S. Navy lowered the likelihood of exits by 25 percent from 1872-1890. After 1890, however, the sign flips and command experience increases exit rates by roughly 9 percent, again suggesting the importance of leadership in more technologically complex environments.

Finally, the evidence appears to suggest that service in shipyards impacts the careers of Royal Navy engineers, but not regular line officers. This can be seen in column (4) of Table 4a, which indicates that each additional year of drydock service lowers the exit rates of engineers by about 6 percent.

In summary, transferable job skills (general experience) appear to increase job switching through an exit, while other types of human capital support the extension of naval careers. This is consistent with outside firms perceiving (and paying for) general skills in high-tech and management sectors of the economy, presumably with a higher distribution of wage offers. Our results produce remarkably consistent empirical results for an earlier stage in modern labor history that also support more modern theoretical models of labor market job mobility (e.g. Becker 1964, Burdett 1978 and Jovanovic 1979a).

6 Conclusion

This paper models how naval officers with heterogeneous human capital leveraged technical skill into preferable job offers around the turn of the twentieth century. The most important and interesting conclusions relate to how accumulation of technical human capital and status as an engineer affects the likelihood of a job switch. The accumulation of very specific types of technical human capital alter job-separation probabilities by substantial margins, suggesting large rates of return to such human capital. Officers with general training as engineers at any point in time are almost 50 percent more likely to switch jobs. A lower bound estimate on the rate of return for engineers appears to be at least 15 percent. When we consider the effects of technical experience, it appears that each additional year of technical job experience increases the hazard by 4.5 percent with an annual rate of return at approximately 2.5 percent. Officers with technical experience, youth and training as engineers could easily expect to double their wages by selling their skills in the private sector. Experience as a bureaucrat or holding other firm-specific skills, however, did not similarly appear rewarded by the private sector.

The results here conform remarkably well to studies of contemporary labor markets. Factors affecting worker mobility decisions over a century ago remain relevant today. Skilled workers trained to work with new technologies continuously face the decision to take their human capital elsewhere or remain at their current job; this is true for workers in both the private sector and workers in military occupations.[32]

Further, our imputed rates of return to technical education and technical experience are quite comparable to estimates found today. This study suggests that the technological transformation of British and American industry during the 19th century was profound. In some ways the evolution of these economies into technically oriented ones was already complete by the turn of the twentieth century.

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[32] Empirical evidence of job mobility for military personnel remains scant, with only a few dynamic models such as Gotz and McCall (1984), Mattock and Arkes (2007) and Glaser (2011) that analyze job mobility decision of officers.

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