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

Glaser, Darrell and Rahman, Ahmed

United States Naval Academy

November 2015

Human Capital on the High Seas - Job Mobility and Returns to Technical Skill During Industrialization[1]

Darrell J. Glaser
Department of Economics
United States Naval Academy
dglaser@usna.edu

Ahmed S. Rahman
Department of Economics
United States Naval Academy
rahman@usna.edu

December 6, 2015

---

[1] Many thanks to participants at the NBER Summer Institute in Boston, the BETA Workshop in Strasbourg, the Economic History Association meetings in Columbus, the European Historical Economic Society meetings in Pisa, and seminar participants at George Mason University for all their valuable suggestions. All comments welcome.

Abstract

This paper examines the effects of engineer-oriented and technical experience on job mobility during an era known for its rapid technological innovation and capital advancements: the late nineteenth and early twentieth centuries. We first develop an on-the-job search model to help us understand factors leading to job switching under rigid payment systems. Then, using longitudinal data on British and American naval officer- and engineer-careers, we demonstrate how *ceteris paribus* earnings-increases through promotions can 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 a Topel and Ward (1992) based empirical framework, we find various rates of return to engineering and technical experience comparable to rates of return found today. To our knowledge these are the earliest historic estimates of returns to any type of technical skill.

Keywords: human capital; job mobility; search theory; technological change; military personnel; naval history; skill premium

JEL Classifications: J6, J45, J62, N31.

1 Introduction

Modern economies have highly skilled workforces, where technical jobs and experiences earn relatively high rates of return (Lagakos 2012). What these returns were historically, and how they evolved over time, however, remain deep mysteries.[1] In times of rapid innovation with economy wide skill-enhancing technological growth, firms need to understand what these returns are to better retain high-skilled workers. If retention mechanisms do not keep pace, quality workers walk.

Linking specific tasks and skills to job switching remains under-explored, especially 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 effects of general and firm-specific human capital on labor market outcomes is best addressed using longitudinal data, often unavailable in many studies (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

---

[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 a number of conclusions. First, we develop a simple model to demonstrate that certain kinds of technical experience can produce powerful incentives for job switching. We follow this with a unique empirical study that supports this suggestion — in general technical and bureaucratic office positions (conceivably involving skills employable in other industries) increase the probability of a job switch, while more naval-specific sea duties lower the probability of a job switch. For both naval organizations, the imputed rate of return to a year of technical experience rises from essentially zero during the 1870s and 1880s, when navies experienced technological uncertainty, to 3–10 percent by the turn of the twentieth century, when navies had become technological and engineering powerhouses.[3] Consistent with findings from contemporary labor literature, these returns were 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

---

[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.

to wage changes with remarkable consistency. We suggest that modern theoretical models of job search, developed in a different era for presumably different workers, generate surprisingly similar results across time. That is, young naval personnel in the late 1800s reacted to labor market incentives and searched 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, often transitioning to adopt 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 offer a unique opportunity to observe rapid transition, from technological backwardness to technological leader within a generation.

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, inspectors of 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. Our framework builds from Jovanovic (1979b), which merges separation theories based on job-search with those based on the accumulation of

---

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

firm-specific human capital. Our results focus on the heterogeneous effects on earnings from both firm-specific and more general, adaptable and transferable human 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, worker pay in both navies during this time was very rigid and consistent. This helps formulate our theoretical and empirical strategies, as well as help us accurately link workers with pay. 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 proceeds as follows. To help formalize ideas we first sketch an on-the-job search theory with different types of human capital in section 2. We then provide some historical background in section 3 and a description of the data in section 4. Section 5 presents the empirical model and section 6 discusses results and sensitivity checks. Section 7 provides a brief conclusion.

---

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

2 A Model of Human Capital and Retention

Here we develop a simple on-the-job search theory. It is in essence an extension of Jovanovic (1979b) that allows for different types of human capital and internal promotions. We will apply the insights of the theory to naval personnel in the late 19th and early 20th centuries, but one could find application here for any rigid bureaucracy employing different types of human capital.

Firm production is given by:

$$y = z\left[vh_t^{\sigma} + (1-v)h_m^{\sigma}\right]^{1/\sigma} \tag{1}$$

h_t is the human capital of traditional workers, and h_m is the human capital of modern workers. These workers are imperfectly substitutable in production.[7] v proxies for the relative importance of traditional production. We can here consider "modernization" the case where v is lowered.

We will assume that workers specialize, and work in either traditional or modern production. They can also exert effort to search for an external job, where they take a portion of their human capital (conceivably accumulated on the job) for use in a different industry. We will assume these external opportunities are 'modern,' in that human capital for modern workers is more transferable than for traditional workers. Specifically, a modern worker who exits will retain $0 < \delta_m < 1$ units of human capital in the new job, and a traditional worker who exits will retain $0 < \delta_t < 1$ units of human capital in the new job. The existence of modern external industries means that $\delta_m > \delta_t$. We also assume a known distribution of external wage offers exogenously given.

In competitive and flexible-wage environments, workers are always paid their marginal

---

[7] In our case of naval personnel we can think of these two worker "types" a number of ways. One is to consider h_t as traditional line officers and h_m as engineers. Another is to think of these as different *tasks* — here h_t would be traditional (navy-specific) jobs, and h_m would be more general (technical or bureaucratic) jobs. In the empirical sections we will make both distinctions in differentiating forms of human capital.

products. Most industries however face some form of wage rigidity. Often these come in the form of rigid salary schedules, including wages for administrative and managerial positions, health and education, and all government and military positions. In these cases, worker pay is determined by a rigid schedule based on position and tenure. Assume here that pay is determined strictly by rank — higher rank means higher pay. So the only way personnel can receive a wage increase is if they get promoted. Let p_t be the hazard of promotion for a traditional worker, and p_m be the hazard of promotion for a modern worker.

We wish to endogenize the search intensity of workers while on the job. Similar to Ljungqvist and Sargent (1998), let $c(s_i)$ be the cost of search for worker-type i. Let $\pi(s_i)$ be the hazard of the worker discovering one external job offer from the distribution that at least equals his reservation wage. Note that this hazard will be a positive function of the degree of human capital transfer. Thus $e^{-\pi_i(s_i)t}$ is the instant probability at time t that worker of type-i remains in his original industry.

Finally we can define some lifetime values. V_t and V_m are the values of being a traditional and modern worker for a given rank, respectively. V_p is the lifetime value of a job promotion within the industry. V_e is the lifetime value of an external job.

The Bellman equation for a traditional job will thus be given by:

$$V_t(t) = \int_{j=t}^{t+\Delta t} \left[e^{-\rho j} e^{-\pi(s_t)j} e^{-p_t j} \left(w_t - c(s_t)\right)\right] ds + e^{-\rho(t+\Delta t)} \tag{2}$$

$$\left[e^{-(p_t+\pi_t(s_t))(t+\Delta t)} V_t\left(t+\Delta t\right) + \left(1 - e^{-\pi_t(s_t)(t+\Delta t)}\right) V_e(t+\Delta t) + e^{-\pi_t(s_t)(t+\Delta t)}(1 - e^{-p(t+\Delta t)}) V_p(t+\Delta t)\right]$$

The first term is current period wages minus search costs. The wage is exogenous, both to the worker and to the firm. The next terms are future potential states discounted by rate ρ — the traditional worker can continue working in his current position, or he can exit for an external job, or he can receive a promotion.[8] We abstract away from other possibilities such

---

[8] We do not allow the possibility for workers with an external option to renegotiate with their current

as death or exogenous firings. Given this, we can solve for the asset-price form of the value of the traditional job as:

$$\rho V_t = w_t - c(s_t) + p_t \left(1 - \pi_t(s_t)\right)\left(V_p - V_t\right) + \pi_t(s_t)\left(V_e - V_t\right) \tag{3}$$

Using similar logic, the asset-price equation for the value of the *modern* job will be given by:

$$\rho V_m = w_m - c(s_m) + p_m \left(1 - \pi_m(s_m)\right)\left(V_p - V_m\right) + \pi_m(s_m)\left(V_e - V_m\right) \tag{4}$$

2.1 On-the-job search by workers

To understand how much workers exert search effort, it helps to have functional forms. Let us assume the simple forms of $c(s_i) = \gamma s_i$ and $\pi_i(s_i) = \delta_i s_i^\alpha$, where $\gamma > 0$, $0 < \alpha < 1$, and δ_i is the human capital retained by worker-type i upon exit. Plugging these in and rearranging gives us the value of a traditional job as:

$$V_t = \frac{w_t - \gamma s_t + p_t \left(1 - \delta_t s_t^\alpha\right) V_p + \delta_t s_t^\alpha V_e}{\rho + \left(1 - \delta_t s_t^\alpha\right) + \delta_t s_t^\alpha} \tag{5}$$

We suggest that workers maximize (5) with respect to search effort. Provided that $V_e > V_p$, we can propose the following:

Proposition 1 $\frac{\partial s_t^*}{\partial p_t} < 0$ *where* s_t^* *is the optimized search effort made by the traditional worker.*

Proposition 2 $\frac{\partial s_t^*}{\partial \delta_t} > 0$ *where* s_t^* *is the optimized search effort made by the traditional worker.*

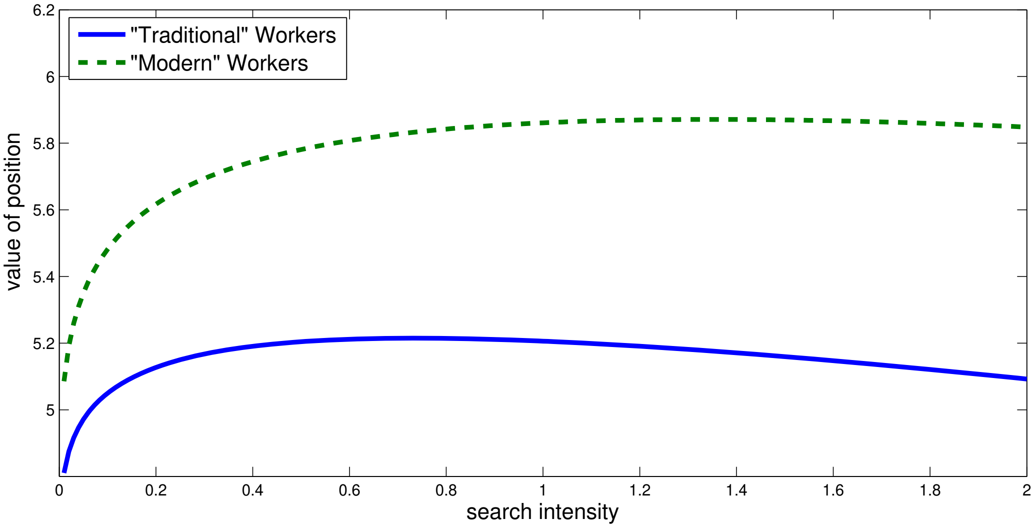
In words, the traditional worker will search less when the rate of internal promotion is higher, and he will search more when the transferability of his human capital is higher. Parallel results hold for modern workers.[9]

---

employer. Such a possibility would have been virtually nil in the context of 19th century navy personnel.

[9] Note that this is a result distinct from those in Jovanovic (1979b). In that model accumulation of more

Figure 1: Optimal Search Intensity for Given Promotion Rates



The figure plots V_t and V_m as a function of each worker's search intensity. As we can see optimal search is higher for the modern worker due to a higher transferability of human capital to an external job.

We can see the implications of Proposition 2 in figure 1, where $\delta_m > \delta_t$. In this case traditional and modern workers only differ in this one respect.[10] Modern workers derive more value from the job not because they earn more in their current job (they don't in this case), but rather because their human capital provides them a larger option value of exit. Because of this their optimal search effort is larger, and so they exit with greater propensity than traditional workers.

2.2 Promotion policy

Given this, we can think about the firm's optimal promotion strategy. One approach might be to retain all personnel. This could be accomplished by setting $V_i = V_e$ for each worker type $i = t, m$. This value V_i^{ns} can be described as the 'no-search boundary condition.' Consider

---

modern human capital (described as "general" human capital) would not affect job separations because such human capital would earn the same wage increase everywhere. But this is true only in the context where workers always earn their marginal product. In the (arguably more realistic) case of internal wage rigidity, fully transferable human capital can influence exit rates.

[10] Specific values for this exercise are the following: $w_t = w_m = 10$, $\delta_t = 0.5$, $\delta_m = 0.75$, $\gamma = 1$, $\alpha = 0.5$, and $p_t = p_m = 0.1$

modern workers for example. The promotion rate that reaches the no-search boundary, p_m^{ns}, is given by setting $V_m = V_e$ in (4) and setting s_m to zero. This yields:

$$p_m^{ns} = \frac{\rho V_m^{ns} - w_m}{V_p - V_m^{ns}} \tag{6}$$

This provides a very intuitive result. To retain all modern human capital, the promotion rate must be higher if the current wage is lower, and must be higher if the value of the promoted position is lower. Thus firms bent on full workforce retention need to be cognizant of both current wages and benefits of promotion, and set promotion rates accordingly.

However, this approach will typically not be *optimal*. Optimality for the firm can be characterized by $[p_t^*, p_m^*]$, the pair of promotion rates that maximizes firm profits, and this will often involve some on-the-job search and exit by workers.

Suppose the firm endeavors to maximize current total product net of labor costs. Labor costs come in two forms — payment to those workers who are not promoted, and payment to those workers who are. Assuming that firms essentially pay promoted workers the value V_p,[11] firms have the objective to maximize the following with respect to p_t and p_m:

$$z\left[v\left(1-\delta_t s_t^{*^{\alpha}})h_t\right)^{\sigma} + (1-v)\left(1-\delta_m s_m^{*^{\alpha}} h_m\right)^{\sigma}\right]^{1/\sigma} - \left(1-\delta_t s_t^{*^{\alpha}}\right)(1-p_t)h_t w_t - \left(1-\delta_t s_t^{*^{\alpha}}\right)p_t h_t V_p - \tag{7}$$

$$\left(1-\delta_m s_m^{*^{\alpha}}\right)(1-p_m)h_m w_m - \left(1-\delta_m s_m^{*^{\alpha}}\right)p_m h_m V_p$$

The first term is production (one can consider the price of final output 1), the second and third terms are wages paid to non-promoted and promoted traditional workers, and the fourth and fifth terms are wages paid to non-promoted and promoted modern workers. Notice that worker exit lowers production since human capital is lost, while worker promotion raises labor costs. Notice also that these are for *optimized* search intensities, which are themselves

---

[11] This is equivalent to having the promoted position give a one-time payoff.

functions of promotion rates.

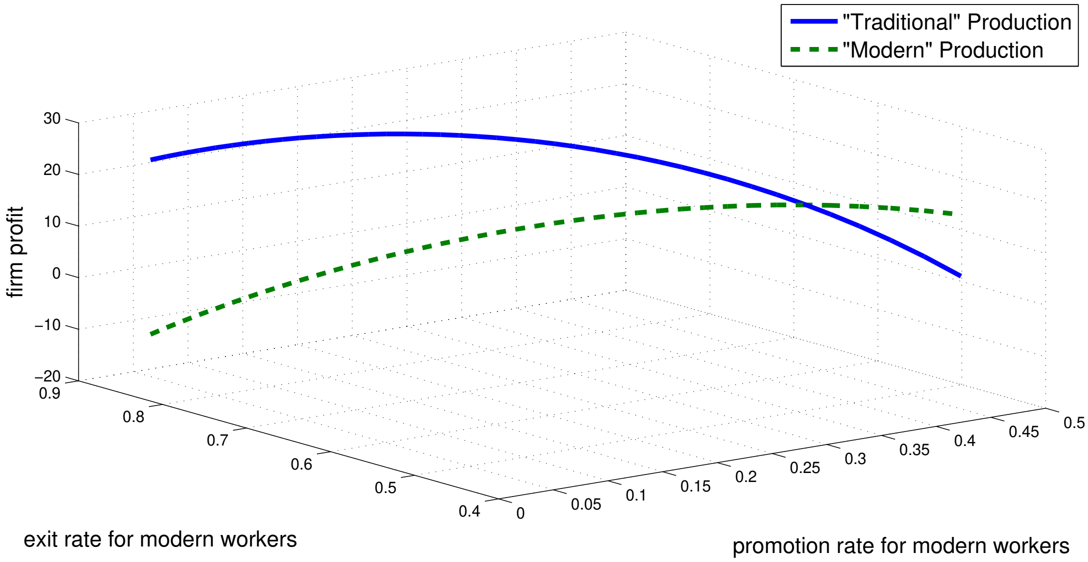
Given the complicated nature of maximizing (7), we can solve for $[p_t^*, p_m^*]$ by simply running a grid search. Depending on parameter values, this often yields an interior solution where the firm promotes a certain fraction of both workers and both worker types also optimally exit.

We can illustrate one particular case using the above-mentioned values (other cases available upon request). This is illustrated in Figure 2. Here we initially set $v = 0.5$, so that traditional and modern workers are evenly valued in production. Let us call this "traditional production." Even in this case, a corner solution exists for traditional workers — the best response for the firm is to not promote any traditional workers ($p_t = 0$). This creates the highest exit rate possible for these workers, although it is still not that high given their relative lack of human capital transferability. The firm also optimally promotes roughly a third of its modern workforce. This still induces high exit rates for modern workers since their human capital transferability is large, but this allows for a better alignment between marginal products and wages for the workers remaining.

An interesting scenario is when the firm "modernizes" — in this context this is where v is lowered, giving greater weight to modern workers in production and less weight to traditional workers. Here we observe that the optimal strategy is for the firm to raise promotion rates for modern workers (the no-promotion strategy for traditional workers remains). This induces a fall in exits for modern workers.

The model also suggests that without a rise in promotion rates, modern workers will start exiting *over time*. As a worker stagnates at a given rank, he accumulates human capital and so his reservation wage essentially lowers each period. Since modern workers are able to transfer more of this human capital, their reservation wages fall faster. The industry will then have to promote modern workers at a faster rate. Thus a firm continuously modernizing will raise the human capital of its modern workforce and so lower their reservation wages

Figure 2: Optimal Promotion Rates for Modern Workers



The figure shows the effects of promotion rates on worker retention and firm profits for modern workers. In this case p_t is set to zero. Here we see that for more "modern" production (where v is lower) it is optimal to promote modern workers more, and thereby retain more of their human capital, than for more "traditional" production.

for exit. To counteract they would need to raise promotion rates (if they could!), essentially lifting reservation wages back up.

3 Background

The model of the previous section demonstrates that industries face skilled-worker exit when internal wages are rigid and external economic modernization is robust. We use late-19th century skilled naval personnel to test these ideas. 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 industries, 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).

The model also suggests that internal modernization can lead to skilled worker exit when wages are rigidly set. We can test this idea as well by observing rates of return to technical experience in "pre-" and "post-" modern navies. Both navies suffered protracted technological uncertainly and backwardness during the 1870s and 80s. Marder (1961), the standard historical work on the Royal Navy, argues British naval strength deteriorated after 1868. The naval manoeuvers of 1888 demonstrated profound technological and strategic weaknesses. That demonstration, along with the frightening prospect of a Franco-Russian alliance, finally spurred the Naval Defense Act of 1889 and ushered in the era of the new technologically advanced navy.

The U.S. Navy likewise faced immediate post-bellum stagnation and difficulties. Buhl (1978) describes technological uncertainties to have stabilized only by 1890.[12] Vlahos (1989) labels 1865–1885 for the U.S. Navy a period of "post-war parochialism," and 1885-1888 as a time of "ferment before transformation." The new battleship strategic philosophy, developed and championed by England, defined the American technological paradigm after 1890 (McBride 1990).

By most accounts then, both navies were transformed into industrialized workplaces only by the final decade of the 19th century. Navies historically have served as laboratories and vanguards of technological progress (O'Brien 2001) — here we can observe internal labor effects during a period of such transition. Technological advances changed nearly every aspect of naval operations, and these changes coincided with economy-wide technological advances in steel manufacturing, chemicals and electricity during the second industrial revolution (Mokyr 1990). The corps of officers in both navies had very different experiences in working

---

[12] "However linear and inexorable the technological progress of the period appears in hindsight, to the contemporaries everywhere, experts and amateurs alike, things were a terrible jumble — a confused jigsaw puzzle of many unknown pieces, being fitted together quite unsystematically." (Buhl 1978)

with these technologies. Accumulated technical human capital propitiously positioned many of them to take advantage of changes in the overall economy.

One often thinks of a naval officer as a master of seamanship, navigation and gunnery. Beyond this, latter 19th century naval officers had different 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. Their training also enabled some of them to develop skills in the art of diplomacy and negotiation, mathematics, chemistry, electricity, telecommunications and numerous other fundamental tools useful in private industry. Certain military jobs undoubtedly enhanced general human capital, and made certain personnel attractive candidates for jobs in other rapidly expanding private sectors. This is supported by words from the U.S. 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).[13] 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.

3.1 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 specific naval and engineering training. The officer/engineer distinction was more distinct for the U.S. Navy (as documented extensively in McBride 2000), and a greater source of internal debate. In England the Royal Naval College was established in 1873 to

---

[13] This is also supported by our cursory examination of U.S. census records for those few ex-officers we can match with near-certainty 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.

bolster engineering education for all officers. In the United States Secretary of the Navy Gideon Welles argued back in 1864 that all Naval Academy students should study engineering (McBride 2000). Much like 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, especially the American engineers.[14] On shore duty, each corps would perform a variety of managerial and bureaucratic functions in naval bureaus or dry-docked vessels. Only in the early 20th century was the officer/engineer distinction greatly diminished, through the 'Selborne Scheme' of 1903–05 in England and the Amalgamation Act in 1900 in the U.S.

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 mobility, as well as the implicit pecuniary rates of return for each experience.

3.2 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.

---

[14] 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.

For both navies, the primary way to get a wage raise was to get promoted. Thus if personnel responded to wage incentives (as we suggest in the model and 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. And as we suggested earlier, workers with more modern or technical experience would exit faster.

Tables 1*a* and 1*b* provide a glimpse of the structure of Royal and American navy officer ranks (the engineer breakdown is not shown here). Each column represents the conditional frequency of ranks by years of service within each Navy. For example, 5.5% of all American line officers with 15 years of tenure achieved the rank of O-4 (Lieutenant Commander), while around 9% attain the rank of Commander within the Royal Navy. Here we can see that after a 30-year career, most personnel do not reach their highest possible rank. We also observe only a few promotion opportunities through one's career, leaving the possibility for wages to stagnate for protracted periods of time.

British officers could languish even longer within the same rank, oftentimes serving at the same rank as lieutenants for more than 15 or 20 years. For example, 99% of all officers with ten years of service held the rank of lieutenant. After 15 years of service, this share only drops to 88.7%. Wage determination on an annual basis could be somewhat more involved than for American personnel, with pay often a function of ship assignments, seniority aboard a ship, and qualification of navigation or gunnery duties. Nonetheless, promotions constitute the bulk of internal wage increases.[15]

Table 1a: Royal 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
sub-lieutenant	0.52	1.93	0.48	-	-
lieutenant	99.13	88.66	38.13	20.76	-
commander	0.35	8.99	51.31	43.90	20.73
captain	-	0.43	9.93	35.12	75.19
admiral	-	-	0.60	0.21	4.07
# line officers	1720	1420	1259	968	516

Frequencies reported for line officers serving from 1879 to 1905.

---

[15] 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. Ranks for engineers ascend from assistant engineer, to engineer, chief engineer, staff engineer and fleet engineer.

Table 1b: 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 precise public or private sector jobs that separating naval personnel join 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. 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 observe a handful of erstwhile naval officers joining a myriad of different careers in fields like engineering, finance, law and shipping. 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.

4 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 and engineer for every year of their career, and also the deployment status of the ships on which they 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 3. 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 $2a$ and $2b$. 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 precise jobs when on shore duty.

For both navies we have further information regarding voluntary or involuntary retirement and sick leave. For the U.S. we also track whether an officer applied for or received a pension due to dis-ability or infirmity. These serve as important checks to our results, as we wish to focus on voluntary departures from naval service. Results from these checks are discussed in section 6.2.1.

Figure 3: Wage Profiles for Naval Personnel

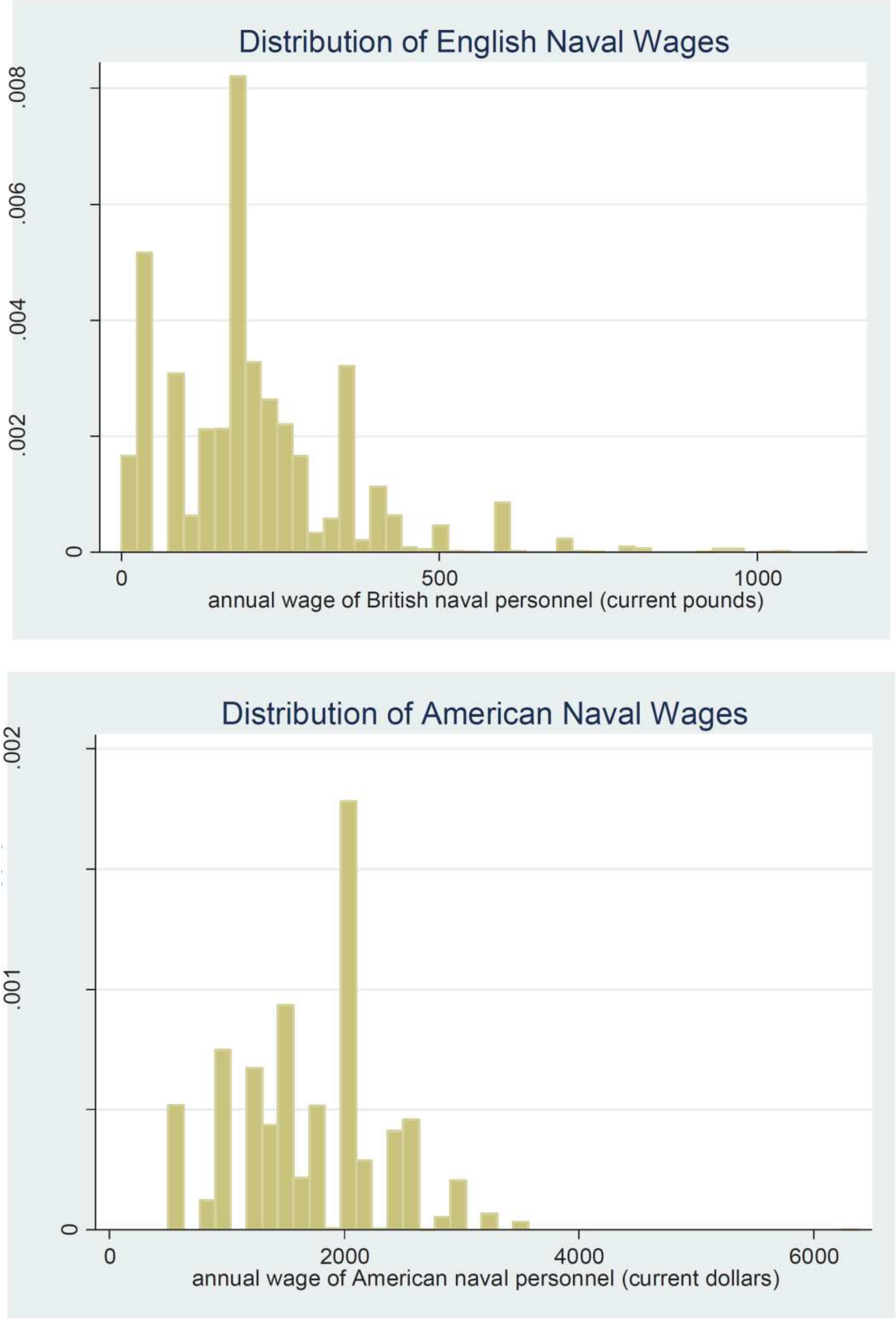


Table 2a: Royal Navy Descriptive Statistics (conditional on years of service)

	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	2376	1977	1793	1352	716

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

Also of interest are raw differences in the technical human capital of officers who leave relative to those who stay. 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 over 5500 men in the Royal Navy for which we have at least five years of naval history, over 2300 exit during the period 1879-1905. 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. We also observe more exits for those in technical shore jobs in the latter part of the sample (the "modern-era" navies).

During the later years of both samples, the average years of experience in technical shore jobs for those who leave is 25% higher than for those who stay.

Table 3a: Engineers and Separations in the Royal Navy

	1879-1890		1891-1905		1879-1905	
	stayers	leavers	stayers	leavers	stayers	leavers
experience in tech shore jobs						
mean years	0.314	0.390	0.801	1.06	0.600	0.710
(std. dev)	(0.834)	(0.985)	(1.65)	(2.01)	(1.39)	(1.60)
engineer share of sample						
fraction	0.324	0.446	0.302	0.268	0.311	0.360
(std. dev)	(0.468)	(0.487)	(0.459)	(0.443)	(0.463)	(0.480)
# year observations in group	24864	1195	35439	1114	60303	2309

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						
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)
# year observations in group	7266	214	9901	330	17167	544

5 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).[16] In general, this model best connects job switching decisions to the key factors highlighted in the model of section 2: the distributions of external and internal job offers, human capital acquired over time, internal wages and job tenure.

5.1 Topel and Ward job separations

The empirical 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

$$Prob(w^p < z; x) = G(z; x) \ . \tag{8}$$

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, promotions, though infrequent, allow for the largest jumps in wages. A deterministic mechanism for promotions does not exist on record, with only anecdotal discussions that relate it to seniority, merit and

---

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

availability of openings. Promotions were also likely related to the type and amount of fleet experience as demonstrated 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 — as highlighted in section 2, promotion was the key factor affecting wages for both organizations.

Without a promotion, officers faced smaller 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, officers and engineers could receive smaller wage increases if 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:

$$Prob(w^n < y; w, s, x, t) = F(y; w, s, x, t) \ . \tag{9}$$

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, then stochastically $F_t(\cdot) \geq 0$. 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 (8) and (9) 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 the t'th year of his career. Given a private-sector offer w^p, and human capital transferability of $0 < \delta < 1$, a job switch occurs when $v(w, s, x, t) < v(w^p, s, \delta x, 0)$. That is, an exit from the Navy occurs when the outside job (with experience set at $t = 0$ and retained human capital at δx) has greater expected wealth than the current naval job. On the margin, a reservation wage exists, $r(w, s, x, t)$, such that $v(r(w, s, x, t), s, \delta x, 0) = v(w, s, x, t)$. 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

$$h(w, s, t, x) \; = \; \pi Prob(w^p > r(w, s, t, x)) \; = \; \pi \left[1 - G(r(w, s, t, x))\right] \; . \tag{10}$$

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

$$h_w(w, s, t, x) = \; -\pi g(r; x) r_w(w, s, t, x) \; . \tag{11}$$

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

$$h_t(w,s,t,x) = -\pi g(r;x) r_t(w,s,t,x) \ . \tag{12}$$

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 greater experience. 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 both navies guaranteed wage increases for certain within-rank intervals (due to 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 human capital experience on the hazard is given by

$$h_x(w,s,t,x) \;=\; -\pi g(r;x) r_x(w,s,t,x) \;=\; -\pi G_x(r;x) \ . \tag{13}$$

We allow for the possibility that different types of jobs (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 (where δ is low), and $G_x(\cdot) \leq 0$ for more generally transferable forms of human capital (where δ is high). 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 (11) and (13) 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.[17]

---

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

5.2 Estimation

Estimation of (10) 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 latter 19th century (and unlike today), navies did *not* have a defined mechanism to force officers from service until they were of a certain age or physically unable to perform. In most cases, separation decisions were one-sided.[18] 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:

$$log\ L(\gamma,\beta) \ = \ \sum_{i=1}^{N}[\delta_i log\,[1 - exp\,\{-exp\,[\mathbf{x}_i(T_i)'\beta_x + \gamma(T_i)]\}] \ - \ \sum_{t=1}^{T_i-\delta_i} exp\,[\mathbf{x}_i(t)'\beta_x + \gamma(t)]]\ . \tag{14}$$

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[19]. Step-function intervals define the experience spline for years $[6, 10), [11, 15), ..., [31, 35)$. The job tenure spline generates from estimates of γ[20]. 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

---

(1992) for more detail on this method of imputation.

[18] Results are not sensitive to exclusion of the handful of cases that apparently were not one-sided. Forced retirements are controlled for in all specifications.

[19] 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.

[20] 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.

experience in various types of technical and bureaucratic jobs, controls for physical constitution[21], and year fixed effects. Alternative specifications include controls for unobserved individual-specific heterogeneity.[22]

6 Results

Hazard ratios estimated from (14) appear in tables 4*a*, 4*b*, and 6. Table 4*a* covers the sample of Royal Navy officers and engineers during the full sample of years 1879-1905. Table 4*b* includes estimates on U.S. officers and engineers during the full sample of years 1872-1905. We also provide results for sub-sample years to demonstrate differences in hazards between the "pre-modern" and "modern" navies (these results are provided in the Appendix).

First, as indicated in equation (11), higher wages in the current job should decrease the probability of an exit. 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 between 1 and 2 percent.

This provides us a consistent baseline to impute rates of return to different types 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. 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.

---

[21] 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.

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

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

To our knowledge, these are the earliest workers for which Topel and Ward's framework have been tested.

Table 4a: Hazard-Ratios for Separations from the Royal Navy
(sample years from 1879-1905)

	sample				
variable	**full**	**full**	**full**	**officers**	**engineers**
log(earnings)	0.981	0.982	0.982	0.983	0.989
	(<0.000)	(<0.000)	(<0.000)	(<0.000)	(<0.000)
engineer	0.842	0.790	0.771		
	(0.31)	(0.16)	(0.125)		
shore duty experience	1.066	1.161	1.141	1.130	1.019
	(0.02)	(0.00)	(0.00)	(0.00)	(0.481)
shore duty experience (engineers)	0.978	0.912	0.892		
	(0.45)	(0.02)	(0.004)		
ship experience		0.935	0.902	0.911	0.886
		(0.53)	(0.00)	(0.00)	(0.00)
ship experience (engineers)		1.026	0.997		
		(0.05)	(0.883)		
horsepower experience			1.005	1.006	1.011
			(0.002)	(0.001)	(0.000)
horsepower experience (engineers)			1.007		
			(0.001)		
command experience	0.931	0.961	0.975	0.981	0.984
	(0.00)	(0.001)	(0.031)	(0.231)	(0.376)
years in same rank	1.029	1.043	1.043	1.039	1.050
	(0.000)	(0.001)	(0.000)	(0.000)	(0.001)
years of additional school/training	0.864	0.925	0.911	0.921	0.832
	(0.00)	(0.039)	(0.013)	(0.052)	(0.035)
eligible for retirement	1.82	1.85	1.92	2.76	
	(0.00)	(0.00)	(0.00)	(0.00)	
sick/disability	2.72	2.19	3.00	3.41	1.92
	(0.00)	(0.00)	(0.00)	(0.00)	(0.001)
year effects	yes	yes	yes	yes	yes
baseline splines (4 years)	increasing	increasing	increasing	increasing	increasing
log likelihood	-2092	-2047	-2029	-1555	-437
individual events	61376	61376	61376	41770	19606
officers and engineers : separations	5566:2280	5566:2280	5566:2280	3973:1448	1804:832

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: Hazard-Ratios for Separations from the U.S. Navy

(sample years from 1872-1905)

	sample years				
variable	**full**	**full**	**full**	**officers**	**engineers**
log(earnings)	0.984	0.984	0.982	0.979	0.988
	(<0.000)	(<0.000)	(<0.000)	(<0.000)	(<0.000)
engineer	1.431	1.480	1.86		
	(0.001)	(0.001)	(0.009)		
shore duty experience (tech)	1.044	1.044	1.044	1.018	1.096
	(0.088)	(0.082)	(0.087)	(0.448)	(0.105)
shore duty experience (steam bureau)	0.926	0.923	0.948	0.916	1.014
	(0.099)	(0.088)	(0.224)	(0.102)	(0.823)
shore duty experience (other bureau)	0.992	0.997	0.981	0.973	0.930
	(0.875)	(0.962)	(0.730)	(0.676)	(0.489)
ship experience (sea)		0.980	1.009	1.035	0.947
		(0.460)	(0.739)	(0.248)	(0.456)
ship experience (brown sea)		1.021	1.044	1.060	0.939
		(0.327)	(0.104)	(0.028)	(0.427)
speed experience			0.996	0.995	1.0003
			(0.039)	(0.032)	(0.956)
speed experience (engineers)			0.996		
			(0.337)		
command experience	1.072	1.061	1.067	1.085	
	(0.081)	(0.191)	(0.176)	(0.088)	
in rank: 5, 10, 15, or 20 years	0.663	0.665	0.659	0.748	0.094
	(0.002)	(0.002)	(0.001)	(0.033)	(0.031)
USNA class percentile	0.973	0.977	0.984	0.884	1.49
	(0.877)	(0.892)	(0.927)	(0.528)	(0.367)
sick	1.37	1.37	1.36	1.34	0.993
	(0.00)	(0.00)	(0.00)	(0.00)	(0.984)
year effects	yes	yes	yes	yes	yes
baseline splines (5 years)	concave	concave	concave	concave	concave
log likelihood	-626.4	-624.9	-620.3	-510.6	-72.2
individual events	17383	17383	17383	15072	2311
officers and engineers : separations	1263 : 510	1263:510	1263:510	1053:430	210:80

Odds-ratios reported with p-values in parentheses.
Standard errors clustered by USNA graduating class.

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

	U.S. Navy 1872-1905	 1872-1890	 1891-1905	Royal Navy 1879-1900
engineer				
rate of return	0.248***	0.307*	0.155*	-
(p-value)	(0.007)	(0.083)	(0.065)	
all technical experience				
rate of return	0.027*	0.000	0.024***	0.085***
(p-value)	(0.043)	(0.995)	(0.036)	(0.000)

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 $p \leq 0.10$.

6.1 Engineers and technical job experience

In looking at our extensive measures of technical skill (engineers versus officers), we observe some differences between the two organizations. Over the entire sample British engineers appear to act no differently in terms of exit rates compared with their line-officer counterparts. But if we look at the early Royal Navy (table 8*a*), we see that engineers in fact exited at lower rates than line officers. After 1890 (table 8*b*), they appear *more* likely to separate, although these hazards are very imprecisely estimated. In any case Royal engineers working in the "modern" navy were no longer staying in service for longer durations.

American engineers appear to exit at much higher rates compared to American officers over the whole sample. But it is instructive to look at the pre- and post-1890 navy here as well. When looking at the full set of controls (third specification), we find that engineer hazards are estimated imprecisely for the early sample, while they are larger and more precisely estimated for the later sample.

Thus we see evidence that for both navies, technologically skilled workers were more prone to take their human capital and exit during the period of modernization. The U.S. in particular may serve as a cautionary tale — when the modern workforce differs much from the traditional workforce (using the notation of the model, one can capture this by suggesting δ_m is much larger than δ_t), the organization is susceptible to human capital loss when there is a rigid system of compensation.

What about more intensive measures of technical human capital? Again we observe some interesting differences between the two organizations. First consider the Royal Navy. For Royal officers, cumulative years in shore positions positively predicts separation. While we do not have details linking personnel with specific duties, we know that these positions were typically linked to a repairing vessel or to a technical bureau. Interestingly though, this positive affect only exists for the latter sample (table 8*b*). Again this makes sense — as the Royal Navy transitioned into a industrialized workplace, shore positions would involve a variety of technical and administrative tasks that conceivably would be applicable in other industries.

On the other hand, cumulative experience on deployed vessels appears in general to be *negatively* related to job separation. This is especially true for the pre-modern Navy. These findings are consistent with the idea that sea duty for officers involved a myriad of seamanship, navigation and ordnance tasks extremely important for naval operations but not easily transferable to other industries.[23]

There is however a caveat. The negative ship experience effect is attenuated the more "modern" is the ship. We proxy for experience on more modern vessels by the cumulative horsepower of each ship on which personnel served (other proxies for modern ships, such as total displacement or vintage of vessels, echo these results). Thus is appears that exposure to newer technologies embedded in vessels can be transferred to other industries, even though ship experience in general cannot.

We also observe some differences between officers and engineers when looking at effects from technical experience. Engineers tend not to exit with greater shore-duty experience the

---

[23] A perhaps facile parallel would be an academic position in a college that involves both research and service tasks. Research experience makes the candidate more attractive to other colleges, while institutional-specific service makes the candidate less attractive. Indeed every industry is likely to have tasks with different degrees of firm specificity and modernity that can influence job retention.

way their officer counterparts do, while they do exit more with greater exposure to modern ships. Thus while the bureaucratic structure of the Royal Navy blurred the distinctions between officers and engineers at the extensive margin, we still observe effects from differences in backgrounds interacting with experiences in ways that make sense.

The U.S. Navy provides an interesting case with which to contrast the English case. For the U.S. we can observe in more detail officers' and engineers' shore office positions (which bureau they work under). The first thing to note is that there are no measurable experiences we observe prior to 1890 that raise exit rates. Technical experience in shore jobs[24] has no affect at all on separation probabilities before 1890 (table 8*c*). In fact when looking at experience on more "modern" vessels (this time proxied by average cruising speed of each vessel), we observe the opposite — service on faster vessels prior to 1890 decreases the likelihood of exit.[25]

Like the Royal Navy, the traditional U.S. navy appears to be a model of job retention. But this changes dramatically post-1890 (table 8*d*). Technical shore jobs here positively predict job separation, while less technical shore jobs remain unrelated to separations. Prior to the 1890s for example, officers assigned to Navy yards had far more naval-specific (firm-specific) than technical (general) work. 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.[26]

We also see an increase in separation probabilities as workers accumulate experience on "brown sea" ships after 1890. These are either repairing or dry-docked vessels, or vessels patrolling local waters — conceivably service on these ships involved more bureaucratic and maintenance activities and fewer skills involving naval-specific activities dealing with navi-

---

[24] Specifically these include ship construction jobs, navy yard experience and lighthouse and other inspector jobs.

[25] Note that because the U.S. Navy was undergoing a combination of technological stasis and fitful attempts at ship-upgrading during this period, the average cruising speeds of newer vessels were in many cases lower than older vessels.

[26] *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.

gation and seamanship. In short, the modernizing U.S. Navy suddenly created opportunities for personnel to accumulate human capital for use in external industries.[27]

Another area of difference between the two organizations was the effects from command experience. While in the Royal Navy cumulative years at command were associated with lower rates of exit, in the U.S. they were associated with higher rates. It bears noting that there were far more command opportunities on *vessels* in the Royal Navy than in the American Navy, especially for the latter period. Command in the Royal Navy usually meant commanding a ship, which meant further human capital accumulation in naval-specific operations. Given the relative dearth of vessels in the U.S. Navy, command for American officers was more associated with office and shore-duty leadership positions. As we can see in tables 8c and 8d, these positions were in fact associated with higher retention during the pre-modern era, and with lower retention only during the modern era.

6.1.1 Rates of Return to Technical Experience

How valuable were these external opportunities for naval personnel? 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 the Royal Navy on the other hand, rates of return from shore duty (which as we suggested involved mostly technical and bureaucratic responsibilities) are roughly 8.5 percent per annum. Again, these returns were earned primarily after 1890. For both organizations, technically-oriented experiences

---

[27] We estimate no statistically significant effects from cross engineer-experience terms for the U.S. Differences in exit rates appear confined to the extensive margin. Results available upon request.

after 1890 earned rates of return comparable to those found today.

While there is no measurable difference in rates of return between officers and engineers in the Royal Navy, American engineers earn roughly a 24 percent premium relative to their officer counterparts. This supports the history of the U.S. naval bureaucracy, which struggled to retain personnel while maintaining a clear officer/engineer distinction under a rigid pay system (McBride 2000).

In summary, transferable job skills (general experience) 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).

6.2 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 blocks of time during officer or engineer careers. For example, we have no information on periodic reviews of performance within either navy.[28] If the Royal Navy reviews all officers during year 12 for example, 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.

Specific results of these splines are extensive and available upon request from the authors (including all figures). All specifications are estimated with splines that cover 4 year blocks

---

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

of time for the Royal navy and 5 year blocks for the U.S. Navy.[29] Results for Royal Navy splines demonstrate an increasing hazard over the entire career. Results for the U.S. Navy, on the other hand, suggest 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. 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 30*th* year in the U.S., tenure effects decline, perhaps as the remaining workers settle-down and wait for a forced retirement. Despite potential non-pecuniary benefits of military seniority (which we cannot observe), the wage stagnation that accompanies tenure appears to matter for most of a career.[30] 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 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.

6.2.1 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

---

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

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

pension income (we are able to control for retirement eligibility for the Royal Navy). The U.S. Navy Pension Fund was 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.*[31] 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.[32] 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[33] without sub-sets of pension applicants, and table 6 reports the sensitivity of key parameters to these sample exclusions. These sub-samples exclude: (1) officers who apply for a pension ($n = 28$), (2) officers or

---

[31] These are now available electronically through http://www.ancestry.com.

[32] These are respectively labeled as “Navy Widows’ Certificates,” “Navy Widows’ Originals,” “Navy Survivor’s Certificates,” and “Navy Survivor’s Originals.”

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

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.[34] 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 6: Sensitivity to possible pension-related exits

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

Same specifications as table 4*b*, 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.

6.2.2 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

---

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

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.[35] 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.

7 Conclusion

This paper models how naval personnel 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 during the "modern" era alter job-separation

---

[35] 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.

probabilities by substantial margins, suggesting large rates of return to such human capital. 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 aboard sea-faring vessels or holding other firm-specific skills did not similarly appear rewarded by the private sector. Industries facing technological transformation may face human capital depletion under rigid payment systems.

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.[36]

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.

References

[1] Abowd, John and Francis Kramarz, 1999. “The Analysis of Labor Markets Using Matched Employer-Employee Data,” in Orley Ashenfelter and David Card (eds.), *Handbook of Labor Economics, Vol. 3B*, Amsterdam: Elsevier, 2629–2710.

[2] Acemoglu, Daron and David Autor, 2012. “What Does Human Capital Do? A Review of Goldin and Katz’s *The Race between Education and*

---

[36] 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.

Technology." *Journal of Economic Literature*, 50(2), 426–463.

[3] Altonji, Joseph G., 1993. "The Demand for and Return to Education When Education Outcomes are Uncertain." *Journal of Labor Economics*, 11(1), 48–83.

[4] Bartlett, Lawrence Wood, 2011. "Not Merely for Defense: The Creation of the New American Navy, 1865–1914." unpublished manuscript.

[5] Becker, Gary, 1964. *Human Capital.* New York: National Bureau of Economic Research.

[6] Bennett, Frank M., 1896. *The Steam Navy of the United States.* Pittsburgh: W.T. Nicholson Press.

[7] Bernhardt, Dan, 1995. "Strategic Promotion and Compensation." *Review of Economic Studies*, 62, 315-339.

[8] Bessen, James, 2012. "More Machines, Better Machines...Or Better Workers?" *Journal of Economic History* 72(1): 44–74.

[9] Blank, David M. and George J. Stigler, 1957. *The Demand and Supply of Scientific Personnel.* No. 62, General Series. National Bureau of Economic Research. New York: National Bureau of Economic Research.

[10] Buhl, Lance C. 1978. "Maintaining An American Navy,, 1865-1889," pp 145–173 in Kenneth J. Hagan (ed.) *In Peace and War: Interpretations of American Naval History, 1775–1978*, Westport, CT: Greenwood.

[11] Burdett, K., 1978. "A theory of employee job search and quit rates." *American Economic Review*, 68, 212–220.

[12] Calvert, Monte, 1967. *The Mechanical Engineer in America, 1830–1910: Professional Cultures in Conflict*. Baltimore, MD: Johns Hopkins University Press.

[13] Card, David and Dean R. Hyslop, 2005. "Estimating The Effects Of A Time-Limited Earnings Subsidy For Welfare-Leavers," *Econometrica*, 73(6), 1723–1770.

[14] Card, David, Charles Michalopoulos, and Philip K. Robins, 2001. "The Limits to Wage Growth: Measuring the Growth Rate of Wages For Recent Welfare Leavers." NBER Working Paper 8444.

[15] Clark, Robert L., Lee A. Craig, and Jack W. Wilson, 2003. *A History of Public Sector Pensions in the United States*. Philadelphia: University of Pennsylvania Press.

[16] Coletta, Paolo E., 1987. *A Survey of U.S. Naval Affairs*. London: University Press of America.

[17] Douglas, Paul H., 1930. *Real Wages in the United States, 1890–1926*. New York: Houghton-Mifflin Co..

[18] Edelstein, Michael, 2009. "The Production of Engineers in New York Colleges and Universities, Some New Data." In David Eltis, Frank D. Lewis and Kenneth L. Sokoloff (eds.), *Human Capital and Institutions: A Long-Run View*, (New York: Cambridge University Press) pp. 179–219.

[19] Farber, Henry S., 1999. "Mobility and Stability: The Dynamics of Job Change in Labor Markets," in Orley Ashenfelter and David Card (eds.), *Handbook of Labor Economics, Vol. 3B*, Amsterdam: Elsevier, 2439–2483.

[20] Farber, Henry S., 2007. "Is the Company Man an Anachronism? Trends in Long-Term Employment in the United States, 1973–2006." In Shelden Danziger and Cecilia Elena Rouse (eds.), *The Price of Independence: The Economics of Early Adulthood*, New York: Russell Sage Foundation, pp.56–83.

[21] Ferber, Marianne A. and Jane Waldfogel, 1998. "The Long-Term Consequences of Nontraditional Employment." *Monthly Labor Review*, May, 3–12.

[22] Friedman, Norman, 1984. *U.S. Cruisers: An Illustrated Design History.* Annapolis, MD: Naval Institute Press.

[23] Galor, Oded, 2011. *Unified Growth Theory.* Princeton, NJ: Princeton University Press.

[24] Gibbons, Robert and Michael Waldman, 1999. "Careers in Organizations: Theory and Evidence," in: O. Ashenfelter and D. Card, eds., *Handbook of Labor Economics, Vol. 3B*, (North-Holland, Amsterdam) pp. 2373-2437.

[25] Ginzberg, Eli, et al., 1951. *Occupational Choice: An Approach to a General Theory.* New York: Columbia University Press.

[26] Gladden, Tricia, and Christopher Taber, 2000. "Wage Progression Among Less Killed Workers," In David E. Card and Rebecca M. Blank, eds., *Finding Jobs: Work and Welfare Reform.* New York: Russell Sage.

[27] Glaser, Darrell J., 2011. "Time-Varying Effects of Human Capital on Military Retention." *Contemporary Economic Policy*, 29(2), 231–249.

[28] Glaser, Darrell J. and Ahmed S. Rahman, 2011. “Human Capital and Technological Transition: Insights from the U.S. Navy.” *Journal of Economic History*, 71(3), 704–729.

[29] Glaser, Darrell J. and Ahmed S. Rahman, 2014. “Engineering and Labor Specialization during the Industrial Revolution.” *Cliometrica*, 8, 173–200.

[30] Goldin, Claudia and Lawrence F. Katz, 2010. *The Race Between Education and Technology.* Cambridge, MA and London, UK: Harvard University Press.

[31] Gotz, Glenn A. and John J. McCall, 1984. *A Dynamic Retention Model for Air Force Officers: Theory and Estimates*, Santa Monica, Calif.: RAND Corporation, R-3028-AF.

[32] Grogger, Jeff, 2009. “Welfare Reform, Returns to Experience, and Wages: Using Reservation Wages to Account for Sample Selection Bias,” *The Review of Economics and Statistics*, 91(3), 490–502.

[33] Harley, C.K. 1993. “Reassessing the Industrial Revolution: a Macro View,” in Joel Mokyr ed. *The British Industrial Revolution: An Economic Perspective* Westview Press, pp.171–226.

[34] Hartley, Keith, and Todd Sandler, eds., 2007. *Handbook of Defense Economics, vol 2.* Oxford: North-Holland.

[35] Heckman, James and B., 1984. “A method for minimizing the impact of distribution assumptions in econometric models for duration data.” *Econometrica*, 52(2), 271–320.

[36] Jovanovic, Boyan, 1979. “Job matching and the theory of turnover.” *Journal of Political Economy*, 87(5), 972–990.

[37] Jovanovic, Boyan, 1979. "Firm specific capital and turnover." *Journal of Political Economy*, 87(6), 1246–1260.

[38] Kalbfleisch, J.D. and R.L. Prentice, 1980. *The Statistical Analysis of Failure Time Data*. New York: John Wiley and Sons.

[39] Kiefer, Nicholas M., 1988. "Economic Duration Data and Hazard Functions." *Journal of Economic Literature*, 26(2), 646–679.

[40] Klein, John P. and Melvin L. Moeschberger, 2003. *Survival Analysis: Techniques for Censored and Truncated Data. 2d. ed.*. New York: Springer.

[41] Lagakos, David, Benjamin Moll, Tommaso Porzio and Nancy Qian, 2012. "Experience Matters: Human Capital and Development Accounting," NBER working paper no. 18602.

[42] Light, Audrey and Manuelita Ureta, 1995. "Early-Career Work Experience and Gender Wage Differentials." *Journal of Labor Economics* 13, 121–154.

[43] Loeb, Susanna and Mary Corcoran, 2001. "Welfare, Work Experience, and Economic Self- Sufficiency." *Journal of Policy Analysis and Management* 20, 1–20.

[44] Long, Clarence D., 1960. *Wages and Earnings in the United States: 1860–1890*. Princeton: Princeton University Press.

[45] Lynch, Lisa M., 1993. "Entry-Level Jobs: First Rung on the Employment Ladder or Economic Dead End?" *Journal of Labor Research* 14, 249–263.

[46] Marder, Arthur J., 1961. *From the Deadnought to Scapa Flow: The Royal Navy in the Fisher Era 1904–1919*. Annapolis: Naval Institute Press.

[47] Mattock, Michael and Jeremy Arkes, 2007. *The Dynamic Retention Model for Air Force Officers: New Estimates and Policy Simulations of the Aviator Continuation Pay Program*. Santa Monica:, CA.: RAND Corporation.

[48] McCall, B.P., 1994. "Testing the Proportional Hazards Assumption in the Presence of Unmeasured Heterogeneity." *Journal of Applied Econometrics*, 9, 321–334.

[49] McBride, William M., 2000. *Technological Change and the United States Navy, 1865–1945*. Baltimore and London: Johns Hopkins University Press.

[50] McCue, Kristin, 1996. "Promotions and Wage Growth." *Journal of Labor Economics*, 14(2), 175–209.

[51] Melese, Francois, James Blandin and Phillip Fanchon, 1992. "Benefits and Pay: The Economics of Military Compensation." *Defense and Peace Economics*, 3(3), 243–253

[52] Meyer, Bruce, 1990. "Unemployment Insurance and Employment Spells." *Econometrica*, 58(4), 757–782.

[53] Mincer, Jacob, 1974. *Schooling, Experience and Earnings*, New York: Columbia University Press.

[54] Mitch, David, 2004. "Technology-Skill Complementarity in British Merchant Shipping in the last half of the Nineteenth century." Department of Economics Working Paper, University of Maryland—Baltimore County.

[55] Mokyr, Joel, 1990. *The Lever of Riches: Technological Creativity and Economic Progress*. New York and Oxford: Oxford University Press.

[56] Mortensen, Dale T., 1988. “Wages, Separations and Job Tenure: On-the-Job Specific Training or Matching?” *Journal of Labor Economics*, 6(4), 445–471.

[57] O’Brien, Phillips Payson, 2001. Introduction to *Technology and Naval Combat in the Twentieth Century and Beyond*. London and Portland, OR: Frank Cass Publishers.

[58] Parnes, Herbert S., 1954. *Research on Labor Mobility*. New York: Social Science Research Council.

[59] Prentice, Robert L. and L.A. Gloeckler, 1978. “Regression Analysis of Grouped Survival Data with Application to Breast Cancer Data.” *Biometrics*, 34, 57–67.

[60] Rees, Albert, 1961. *Real Wages in Manufacturing: 1890-1914*. Princeton: Princeton University Press.

[61] Reynolds, Lloyd G., 1951. *The Structure of Labor Markets*. New York: Harper & Brothers.

[62] Topel, Robert H. and Michael P. Ward, 1992. “Job Mobility and the Careers of Young Men.” *The Quarterly Journal of Economics*. 107, 439–479.

[63] Usselman, Steven W., 1999. “Patents, engineering professionals, and the pipelines of innovation: the internalization of technical discovery by nineteenth century American railroads.” In Naomi R. Lamorweaux, Daniel M. Raff and Peter Temin (eds.), *Learning by Doing in Markets, Firms and Countries*. Chicago: University of Chicago Press, pp. 61–91.

[64] Vlahos, Michael E. 1989. “The Making of an American Style.” in *Naval Engineering and American Sea Power*, R.W. King, ed. Baltimore: The Nautical and Aviation Publishing Company of America, Inc.

[65] Zabel, Jeffrey, Saul Schwartz, and Stephen Donald, 2004. “An Analysis of the Impact of SSP on Wages and Employment Behavior.” Mimeo.

8 Appendix

Table 8a: Hazard-Ratios for Separations from the Royal Navy
(sample years from 1879-1890)

	sample				
variable	**full**	**full**	**full**	**officers**	**engineers**
log(earnings)	0.979 (<0.000)	0.983 (<0.000)	0.983 (<0.000)	0.987 (<0.000)	0.976 (<0.000)
engineer	0.523 (0.023)	0.413 (0.002)	0.414 (0.002)		
shore duty experience	0.752 (0.064)	0.816 (0.181)	0.824 (0.205)	0.793 (0.132)	0.977 (0.594)
shore duty experience (engineers)	1.36 (0.050)	1.309 (0.087)	1.171 (0.319)		
ship experience		0.840 (0.000)	0.788 (0.000)	0.761 (0.000)	0.833 (0.000)
ship experience (engineers)		1.055 (0.044)	1.023 (0.495)		
horsepower experience			1.024 (0.000)	1.027 (0.000)	1.030 (0.000)
horsepower experience (engineers)			1.009 (0.265)		
command experience	0.901 (0.000)	0.968 (0.129)	1.004 (0.850)	1.057 (0.142)	0.983 (0.529)
years in same rank	1.010 (0.402)	1.059 (0.000)	1.053 (0.000)	1.092 (0.000)	1.026 (0.194)
years of additional school/training	0.957 (0.568)	1.059 (0.000)	0.977 (0.760)	1.024 (0.775)	0.706 (0.063)
eligible for retirement	2.18 (0.000)	2.15 (0.000)	2.332 (0.000)	3.279 (0.000)	
sick/disability	1.50 (0.013)	1.67 (0.002)	1.804 (0.000)	3.420 (0.000)	1.612 (0.033)
year effects	yes	yes	yes	yes	yes
baseline splines (4 years)	increasing	increasing	increasing	increasing	increasing
log likelihood	-947	-905	-879	-833	-26
individual events	25787	25787	25787	17208	8579
officers and engineers : separations	3356:1187	3356:1187	3356:1187	2126:654	1230:533

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

Table 8b: Hazard-Ratios for Separations from the Royal Navy

(sample years from 1891-1905)

	sample				
variable	**full**	**full**	**full**	**officers**	**engineers**
log(earnings)	0.984 (<0.000)	0.984 (<0.000)	0.985 (<0.000)	0.983 (<0.000)	0.994 (<0.000)
engineer	1.062 (0.774)	1.027 (0.903)	1.019 (0.929)		
shore duty experience	1.112 (0.000)	1.168 (0.000)	1.161 (0.000)	1.151 (0.000)	1.025 (0.472)
shore duty experience (engineers)	0.926 (0.038)	0.889 (0.008)	0.886 (0.007)		
ship experience		0.942 (0.000)	0.934 (0.000)	0.935 (0.000)	0.922 (0.005)
ship experience (engineers)		1.032 (0.144)	1.024 (0.377)		
horsepower experience			1.002 (0.300)	1.003 (0.137)	1.002 (0.555)
horsepower experience (engineers)			1.001 (0.669)		
command experience	0.943 (0.000)	0.959 (0.005)	0.963 (0.014)	0.960 (0.031)	1.013 (0.628)
years in same rank	1.051 (0.000)	1.046 (0.000)	1.046 (0.000)	1.032 (0.001)	1.091 (0.001)
years of additional school/training	0.881 (0.006)	0.884 (0.008)	0.881 (0.006)	0.872 (0.007)	0.840 (0.121)
eligible for retirement	1.907 (0.000)	1.881 (0.000)	1.915 (0.000)	2.392 (0.000)	
sick/disability	2.631 (0.000)	2.748 (0.000)	2.768 (0.000)	3.076 (0.000)	1.568 (0.280)
year effects	yes	yes	yes	yes	yes
baseline splines (4 years)	increasing	increasing	increasing	increasing	increasing
log likelihood	-1098	-1083	-1081	-675	-379
individual events	35589	35589	35589	24562	11027
officers and engineers : separations	4231:1093	4231:1093	4231:1093	3193:794	1249:299

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

Table 8c: Hazard-Ratios for Separations from the U.S. Navy

(sample years from 1872-1890)

	sample years				
variable	**full**	**full**	**full**	**officers**	**engineers**
log(earnings)	0.987	0.987	0.987	0.986	0.987
	(<0.000)	(<0.000)	(<0.000)	(<0.000)	(<0.000)
engineer	1.569	1.475	1.515		
	(0.006)	(0.028)	(0.126)		
shore duty experience (tech)	1.006	0.999	0.999	0.981	1.082
	(0.903)	(0.993)	(0.996)	(0.727)	(0.550)
shore duty experience (steam bureau)	1.015	1.027	1.063		1.245
	(0.810)	(0.696)	(0.355)		(0.060)
shore duty experience (other bureau)	0.963	0.946	0.921	0.961	
	(0.772)	(0.703)	(0.562)	(0.751)	
ship experience (sea)		0.999	1.046	1.055	1.028
		(0.973)	(0.283)	(0.261)	(0.864)
ship experience (brown sea)		0.953	0.994	1.012	0.882
		(0.324)	(0.911)	(0.814)	(0.385)
speed experience			0.989	0.988	0.994
			(0.014)	(0.009)	(0.563)
speed experience (engineers)			(0.998)		
			(0.743)		
command experience	0.726	0.733	0.770	0.764	
	(0.012)	(0.014)	(0.061)	(0.069)	
in rank: 5, 10, 15, or 20 years	0.752	0.755	0.751	0.874	0.141
	(0.072)	(0.073)	(0.071)	(0.501)	(0.118)
USNA class percentile	0.718	0.700	0.694	0.642	1.420
	(0.217)	(0.169)	(0.163)	(0.129)	(0.645)
sick	1.365	1.355	1.355	1.355	0.448
	(0.004)	(0.006)	(0.002)	(0.003)	(0.157)
year effects	yes	yes	yes	yes	yes
baseline splines (5 years)	concave	concave	concave	concave	concave
log likelihood	-336	-355	-332	-276	-37
individual events	7353	7353	7353	6602	751
officers and engineers : separations	764:209	764:209	764:209	648:179	116:30

Odds-ratios reported with p-values in parentheses.
Standard errors clustered by USNA graduating class.

Table 8d: Hazard-Ratios for Separations from the U.S. Navy
(sample years from 1891-1905)

	sample years				
variable	**full**	**full**	**full**	**officers**	**engineers**
log(earnings)	0.976 (<0.000)	0.975 (<0.000)	0.973 (<0.000)	0.965 (<0.000)	0.985 (<0.000)
engineer	1.346 (0.092)	1.448 (0.037)	2.079 (0.047)		
shore duty experience (tech)	1.060 (0.030)	1.062 (0.020)	1.061 (0.026)	1.035 (0.020)	1.077 (0.153)
shore duty experience (steam bureau)	0.920 (0.143)	0.916 (0.102)	0.927 (0.105)		0.975 (0.645)
shore duty experience (other bureau)	0.995 (0.930)	1.008 (0.881)	0.991 (0.863)	0.983 (0.784)	0.956 (0.689)
ship experience (sea)		0.960 (0.182)	0.984 (0.585)	1.014 (0.681)	0.935 (0.346)
ship experience (brown sea)		1.041 (0.104)	1.056 (0.044)	1.072 (0.010)	0.974 (0.817)
speed experience			0.997 (0.196)	0.997 (0.182)	1.000 (0.926)
speed experience (engineers)			0.995 (0.325)		
command experience	1.124 (0.003)	1.102 (0.031)	1.110 (0.027)	1.139 (0.006)	
in rank: 5, 10, 15, or 20 years	0.549 (0.003)	0.552 (0.002)	0.539 (0.002)	0.586 (0.009)	0.550 (0.005)
USNA class percentile	1.226 (0.370)	1.242 (0.342)	1.253 (0.337)	1.081 (0.775)	1.909 (0.179)
sick	1.464 (0.002)	1.452 (0.002)	1.431 (0.002)	1.410 (0.010)	1.407 (0.403)
year effects	yes	yes	yes	yes	yes
baseline splines (5 years)	concave	concave	concave	concave	concave
log likelihood	-280	-276	-273	-220	-30
individual events	9412	9412	9412	7964	1448
officers and engineers : separations	994:301	994:301	994:301	820:251	174:50

Odds-ratios reported with p-values in parentheses.
Standard errors clustered by USNA graduating class.