Development and Retention of Human Capital in Large Bureaucracies*

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Abstract

This paper examines the effects of technical experience on job mobility during an era of rapid technological advance. 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 late 19th-Century British and American naval officer- and engineer-careers, we show how different forms of technical experience and promotion rates influence job switching. Using our estimates we find rates of return to technical experience rising dramatically by the turn of the 20th Century. To our knowledge these are the earliest estimates of returns to any type of technical skill. These findings help us understand how modernizing organizations can become *more* vulnerable to loss of skilled personnel, and how organizations might optimally respond.

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

JEL Classifications: J6, J45, J62, N31.

1 Introduction

Why do large bureaucracies seem so inefficient? Perhaps one reason relates to wage rigidity — bureaucracies often have rigid wage schedules and few opportunities for promotion. In times of rapid innovation with economy wide skill-enhancing technological growth, large bureaucratic organizations may find it difficult to match the skills of their high-skilled workers to their earnings. If external opportunities for the highly-skilled grow and internal retention mechanisms do not keep pace, quality workers walk.

Yet there may be other factors related to job retention that exacerbate inefficiencies — bureaucracies may be forced to allocate resources in ways that limit production even further. Linking specific tasks and skills to job switching remains under-explored, and economic studies examining bureaucratic efficiency are nonexistent, at least to our knowledge.

An understanding of these links seems crucial to fully understand the long-term evolution of human capital development and use (Acemoglu and Autor 2012). Furthermore, 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 from large bureaucracies. 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.

This environment is particularly well suited for such an analysis, since navies in general were technical and engineer-oriented bureaucracies during the nineteenth century. Often, but not always, they required workers to master the most cutting-edge technologies of their day (Harley 1993). Both the Royal and American navies used and experimented with many new technologies, and many members of 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 pay scales were remarkably rigid and consistent, and officer exits were essentially one-sided decisions during this period.[1] 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 labor search model to demonstrate that certain kinds of technical experience can produce powerful incentives for job switching. Specifically, this shows how a modernizing organization creates opportunities for workers to accumulate human capital "marketable" for external offers — this leads to greater exits for both technically *and* non-technically oriented workers. We also show how firms can respond by eliminating task specialization among workers. This lessens job exits at the expense of lost efficiency.

We follow this with a unique empirical study that supports our theoretical findings — when navies modernized, personnel in more technical or bureaucratic office positions (conceivably involving skills employable in other industries) more likely switched careers out of naval service. 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.[2] 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.[3]

[1] 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.

[2] 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).

[3] More recently, Grogger (2009) looks at welfare recipients and estimates they receive the return of roughly

Further, we show that workers respond to internal wage changes with remarkable consistency, tending to remain on the job when they rise and exit when they stagnate. This suggests 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.

Finally, we delve deeper into naval history to suggest that both navies mainly eliminated task specialization among officer personnel, in part to combat such loss of human capital. We document a force within bureaucracies that moves against the typical notion of industrialization, that of the factory system and worker specialization. Such a system works very well when tasks are idiosyncratic to the organization and not of particular use in alternative businesses or industries. When some tasks are more readily employable elsewhere than others, however, things become more complicated, and a full embrace of Smithian specialization in fact appear sub-optimal to the firm.

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.

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.

First, as we alluded earlier, navies tend to be at the industrial 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."[4] But the navies of the late 19th century offer a unique opportunity to explore how technological *transition* interacts with human capital accumulation and job-exit decisions. Our data capture two fairly distinct naval periods a generation apart — one of technological backwardness and job insecurity, the other of technological leadership and robust job opportunity.

Naval officers during this time had a wide array of possible jobs, from the fairly mundane to the most technologically sophisticated. Naval officers served not only on ships, but also 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, more importantly, 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 in part from Jovanovic (1979b), which merges separation theories based on job-search with those based on the accumulation of firm-specific human capital. Our results focus on the heterogeneous effects on earnings from both firm-specific and more general, adaptable and transferable human 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).[5]

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

[4]from Tim Shutt's audio course "High seas, high stakes - naval battles that changed history."
[5]See also early century studies in Reynolds (1951), Ginzberg (1951) and Parnes (1954).

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.

2 A Model of Human Capital and Retention

Here we develop a simple on-the-job search theory in a bureaucratic organization. Presenting a formal model serves a number of purposes. First, we can demonstrate how those with different levels of human capital may exit at different rates in order to anticipate what to expect in an empirical setting. Second, while we apply the insights of the theory to naval personnel in the late 19th and early 20th centuries, one could find application here for any rigid bureaucracy employing different types of human capital. Finally, we can derive insights on relationships not directly measurable, such as how a bureaucracy might respond to worker exit. For simplicity, the analysis focuses on steady states.

The firm's objective is to *train and retain personnel*.[6] Specifically, they endeavor to

[6]Yes, firms may have many objectives, not least among these to maximize profits. We clearly abstract from this, as well as from considerations about short and long run tradeoffs. Here we suggest that human

maximize an aggregation of two types of human capital:

$$H = \left[h_f^\sigma + h_g^\sigma\right]^{1/\sigma}, \tag{1}$$

where h_f is the human capital of workers who we will call "firm specialists," h_g is the human capital of workers who we will call "generalists," and $\sigma < 1$ governs the degree of substitutability between the two in "production" of retained skills.

There are also two types of tasks — firm-specific tasks and general tasks. Firm specialists have a comparative advantage in doing firm-specific tasks. We capture this by assuming that firm specialists accumulate human capital from firm-specific tasks at a rate of $a_f > 1$, while they accumulate human capital from general tasks at a rate of only 1. In the same way, generalists have a comparative advantage in general tasks — they accumulate skills from these tasks at rate $a_g > 1$, but accumulate skills from firm-specific tasks at rate 1. Irrespective of worker type or tasks, all workers earn w.[7]

The firm chooses the degree of specialization of each worker for these tasks to take advantage of productivity differences (more on this below). However, the firm's choice is complicated by the fact that workers 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 assume these external opportunities tend to be "general," in that human capital for general skills are more transferable than for firm-specific skills. Specifically, a firm specialist who exits will retain $0 < \delta_{\alpha,f} < 1$ units of firm specific skills and $0 < \delta_{\alpha,g} < 1$ units of general skills in the new job. A generalist who exits will retain $0 < \delta_{\beta,f} < 1$ units of firm-specific skills and $0 < \delta_{\beta,g} < 1$ units of general skills in the new job. We assume $\delta_{\alpha,f} < \delta_{\alpha,g}$ and $\delta_{\beta,f} < \delta_{\beta,g}$. We also assume a known distribution of external

capital retention complements many of these other goals, and so our abstraction does not damage the generalizability of our findings. Furthermore, a single layer of an organization would conceivably be more concerned with retention at that level than with firm-level profits.

[7]For example, a widget factory may employ both widget makers (firm specialists) and administrators (generalists). An academic department may require both committee work and other departmental service (firm specialists) and academic research (generalists).

wage offers exogenously given.

In competitive and flexible-wage environments, workers are always paid their marginal products. All industries face some form of wage rigidity however, especially large bureaucratic ones. Often these come in the form of rigid salary schedules, including wages for administrative and managerial positions, health and education, and virtually all government and military positions. In these cases, worker pay follows a rigid schedule based on position and tenure. All workers earn w, so the only way personnel receive a wage increase is via promotion. Finally, p is the hazard of promotion for a worker, specialist or generalist.

We 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 their reservation wage. 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 their original industry.

Finally we can define some lifetime values. V_f and V_g are the values of being a firm-specialist and generalist for a given rank, respectively. V^p is the lifetime value of a job promotion for either worker-type within the industry, and p is the instantaneous probability of getting promoted. V_i^e is the lifetime value of an external job for worker of type i.

Note that because transitions among states are Poisson processes, V_f and V_g do not depend on how long the worker has been in the current state or the worker's prior history. And because we are focusing on steady states, V_i's are constant over time.

The Bellman equation for a firm specialist for period Δt will thus be given by:

$$V_f(\Delta t) = \int_{t=0}^{\Delta t} \left[e^{-\rho t} e^{-\pi(s_f)t} e^{-pt} \left(w - c(s_f)\right)\right] dt + e^{-\rho(\Delta t)} \left[e^{-(p+\pi_f(s_f))(\Delta t)} V_f\left(\Delta t\right) + \left(1 - e^{-\pi_f(s_f)(\Delta t)}\right) V_f^e(\Delta t) + e^{-\pi_f(s_f)(\Delta t)} \left(1 - e^{-p(\Delta t)}\right) V^p(\Delta t). \right. \tag{2}$$

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 firm specialist can continue working in their current position, or can exit for an external job, or can receive a promotion.[8] We abstract away from other possibilities such as death or exogenous firings. If we compute the integral in (2) and take the limit of $V_f(\Delta t)$ as Δt approaches zero, we can solve for the asset-price form of the value of the job for the firm-specialist as:

$$\rho V_f = w - c(s_f) + p\left(1 - \pi_f(s_f)\right)\left(V^p - V_f\right) + \pi_f(s_f)\left(V_f^e - V_f\right). \tag{3}$$

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

$$\rho V_g = w - c(s_g) + p\left(1 - \pi_g(s_g)\right)\left(V^p - V_g\right) + \pi_g(s_g)\left(V_g^e - V_g\right). \tag{4}$$

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 $c(s_i) = s_i^{\phi}$ and $\pi_i(s_i) = 1 - e^{-s_i}$, where $\phi > 1$. Plugging these in and rearranging gives us the value of the job for worker type i as:

$$V_i = \frac{w - s_i^{\phi} + pe^{-s_i}V^p + \left(1 - e^{-s_i}\right)V_i^e}{\rho + pe^{-s_i} + \left(1 - e^{-s_i}\right)}. \tag{5}$$

We suggest that these workers maximize (5) with respect to search effort. Provided that $V^e > V^p$, we can propose the following:

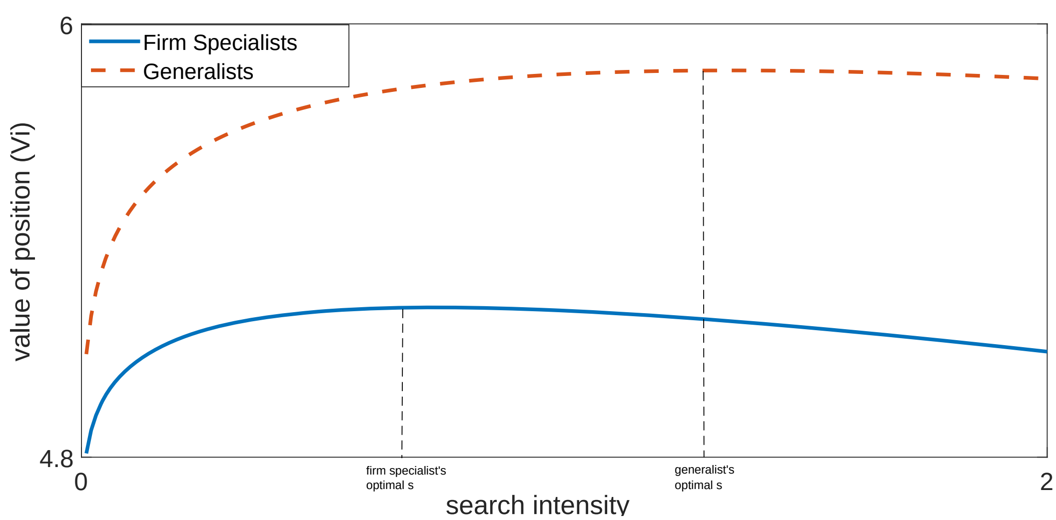
Proposition 1 *For a given V^e, $\frac{\partial s_i^*}{\partial p} < 0$ where s_i^* is the optimized search effort made by worker of type i.*

Proposition 2 $\frac{\partial s_t^*}{\partial V_i^e} > 0$ *where s_t^* is the optimized search effort made by worker of type i.*

[8] We do not allow the possibility for workers with an external option to renegotiate with their current employer. Such a possibility would have been virtually nil in the context of 19th century navy personnel, as well as many other governmental and private organizations.

In words, workers search less with higher rates of internal promotion. They also search more with higher external values of human capital. As we will demonstrate below, this will be a function of human capital transferability. Note that this is a result distinct from those in models such as Jovanovic (1979b). In the original Jovanovic model (admittedly a much different model with a different approach), accumulation of more general human capital does not affect job separations because such human capital produces the same wage increase everywhere. This is true only in the context where workers always earn their marginal product. In bureaucratic cases of internal wage rigidity, fully transferable human capital can influence exit decisions and rates.

Figure 1: Optimal Search Intensity for Given Value of External Job — $V_m^e > V_t^e$



The figure plots V_f and V_g as a function of each worker's search intensity. As we can see optimal search is higher for the generalist worker due to a higher value of the external job.

We see the implications of Proposition 2 in Figure 1, where we have $V_g^e > V_f^e$ (we formalize this in the next section). In this case firm-specialists and generalists only differ in this one respect.[9] Generalists 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

[9]Specific values for this exercise and what follows are the following: $w = 10$, $\rho = 1$, $\phi = 2$, and $p = 0.1$.

they exit with greater propensity than firm specialists.

2.2 Search and Degree of Specialization

However, firms need not suffer worker exits passively. They cannot influence wages or promotion rates (as many bureaucratic organizations often cannot). They can however affect search intensity by shifting around tasks among personnel — firms determine how specialized each worker will be, and this can affect how much human capital each worker can sell externally. Will firms endeavor to prevent workers from searching?

Let $x \subset [0.5, 1]$ be the degree to which personnel specialize in their comparative advantage. This is chosen by the firm. When $x = 1$ generalists only perform general tasks and firm-specific workers only perform firm-specific tasks. When $x = 0.5$ workers are equally distributed across both tasks, no matter their comparative advantage.

We normalize human capital, so that there is a mass of one unit of specialist labor and a mass of one unit of generalist labor. Given this, total human capital amounts that are *retained* by the firm are given by

$$h_f = (1 - \pi_f)\, a_f x + (1 - \pi_g)\,(1 - x), \tag{6}$$

$$h_g = (1 - \pi_g)\, a_g x + (1 - \pi_f)\,(1 - x), \tag{7}$$

where π_f and π_g are functions of search effort by firm-specialists and generalists respectively. Here we see that retained human capital is a function of both worker exit and worker specialization.

Given this, the firm chooses x (x^*) to maximize H:

$$\frac{\partial H}{\partial x} = \left[h_f^\sigma + h_g^\sigma\right]^{\frac{1-\sigma}{\sigma}} \left(h_f^{\sigma-1}\left(e^{s_f^*} a_f + (1 - e^{-s_g^*})\right) + h_g^{\sigma-1}\left(e^{s_g^*} a_g + (1 - e^{-s_f^*})\right)\right) = 0. \tag{8}$$

Workers on the other hand exert search effort. Traditional workers do this in order to maximize:

$$V_f = \frac{w - s_f^{\phi} + pe^{-s_f}V^p + (1 - e^{-s_f})\,\bar{w}\,(\delta_{\alpha,f}a_f x + \delta_{\alpha,g}(1-x))}{\rho + pe^{-s_f} + (1 - e^{-s_f})}, \tag{9}$$

where V_f^e from (5) is now equal to $\bar{w}\,(\delta_{\alpha,f}a_f x + \delta_{\alpha,g}(1-x))$. $\bar{w}$ is the external wage for either worker type, and $\delta_{\alpha,f}a_f x + \delta_{\alpha,g}(1-x)$ is the total amount of human capital that the specialist can use externally. This amount depends on how much exposure they have had in each task (which depends on x) and also the extent of transferability ($\delta_{\alpha,f}$ and $\delta_{\alpha,g}$). Generalists exert effort to maximize:

$$V_g = \frac{w - s_g^{\phi} + pe^{-s_g}V^p + (1 - e^{-s_g})\,\bar{w}\,(\delta_{\beta,f}a_g x + \delta_{\beta,g}(1-x))}{\rho + pe^{-s_g} + (1 - e^{-s_g})}. \tag{10}$$

Thus, each group chooses search effort (s_f^* and s_g^*, respectively) such that

$$\frac{\partial V_f}{\partial s_f} = 0, \tag{11}$$

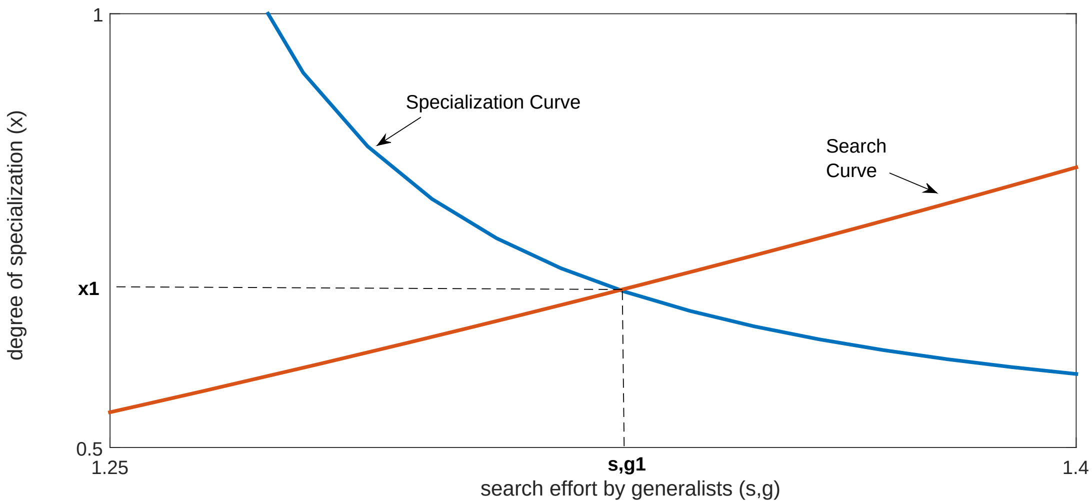
$$\frac{\partial V_g}{\partial s_g} = 0. \tag{12}$$

The steady-state equilibrium in this organization is given by solving (8), (11) and (12) for x^*, s_f^* and s_g^*. The firm chooses the degree of specialization given how workers respond through external job search, and workers exert search effort given how the firm shifts the degree of specialization.

This equilibrium can be characterized by the diagram in Figure 2. We can refer to (11) and (12) as "search curves" — these show how search effort changes as their specialization over tasks change. In Figure 2 we plot the search curve for generalists. As they specialize in more general tasks, their search efforts rise.

(8) on the other hand can be characterized as the "specialization curve" — it charts the firm's reaction to worker specialization in order to maximize human capital retention.

Figure 2: Equilibrium Levels of Search and Specialization



2.3 Comparative Statics

Here we demonstrate what insights the model can provide in anticipating factors that affect the rate of job exits for workers. These help to motivate our empirical analysis of naval personnel retention in subsequent sections.[10]

Proposition 3 $\forall \sigma < 1,\ \frac{\partial s_f^*}{\partial w} < 0$ *and* $\frac{\partial s_g^*}{\partial w} < 0.$

Proposition 4 *If* $\delta_{\alpha,f} = \delta_{\beta,f} < \delta_{\alpha,g} = \delta_{\beta,g},$ *then* $\forall \sigma < 1,\ s_g^* > s_f^*.$

Proposition 3 is straight-forward — higher wages will lower search effort, and thus the rate of exit, for both types of workers. Proposition 4 states that if general skills are more transferable to external markets than firm-specific skills, generalists search more than firm-specialists and so exit at faster rates.

Note that both of these are true for any degree of complementarity between human capital types. It is also true for any endogenously-determined level of specialization. That is, firms

[10] For all simulated solutions that follow, parameter values are set to the following: $a_f = 1.1$, $a_g = 1.1$, $\rho = 1$, $\phi = 2$, $w = 10$, $\bar{w} = 15$, $p = 0.1$, $V^p = 12$. All propositions below are robust to values where $a_f > 1$, $a_g > 1$, $\phi > 1$, $\bar{w} > w$, and $V^p > w$. A fuller set of simulation results with different ranges of parameters are available upon request.

are *optimally* choosing a certain degree of specialization ($x^* > 0.5$), and so are *optimally* allowing for generalists to exit at faster rates.

2.3.1 Greater transferability of all general skills

Now we turn to situations where the transferability of general skills are rising. This would correspond to scenarios where the firm is itself modernizing, adapting modern tasks to those resembling tasks in external and cutting-edge industries, and so allowing skills acquired in the firm to be more readily sold externally.

Proposition 5 *If* $\delta_{\alpha,g} = \delta_{\beta,g} = \delta_g$, *then* $\forall \sigma < 1$ $\frac{\partial s_g^*}{\partial \delta_g} > 0$.

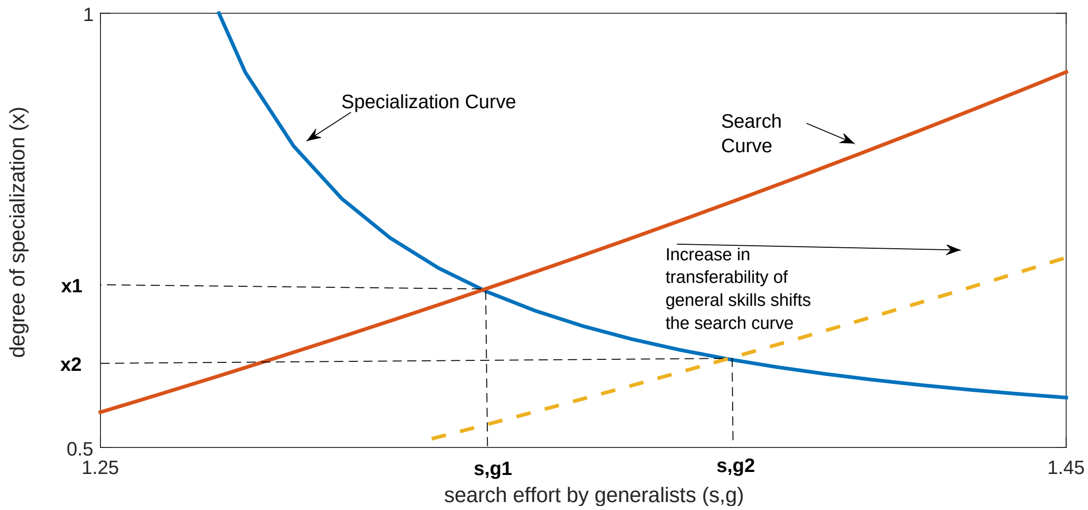
Proposition 6 *If* $\delta_{\alpha,g} = \delta_{\beta,g} = \delta_g$, *then* $\forall \sigma < 1$ $\frac{\partial s_f^*}{\partial \delta_g} > 0$.

Proposition 7 *If* $\delta_{\alpha,g} = \delta_{\beta,g} = \delta_g$, *then* $\forall \sigma < 1$ $\frac{\partial x^*}{\partial \delta_g} < 0$.

Proposition 5 says that generalists will exit at a faster rate as general skill transferability rises. Proposition 6 says that *specialists* will also exit at a faster rate as general skill transferability rises. The latter might appear counter-intuitive. However, recall that for all $x^* < 1$, traditional workers are also employed in general tasks to at least some degree, and so are also able to sell their general human capital more readily.

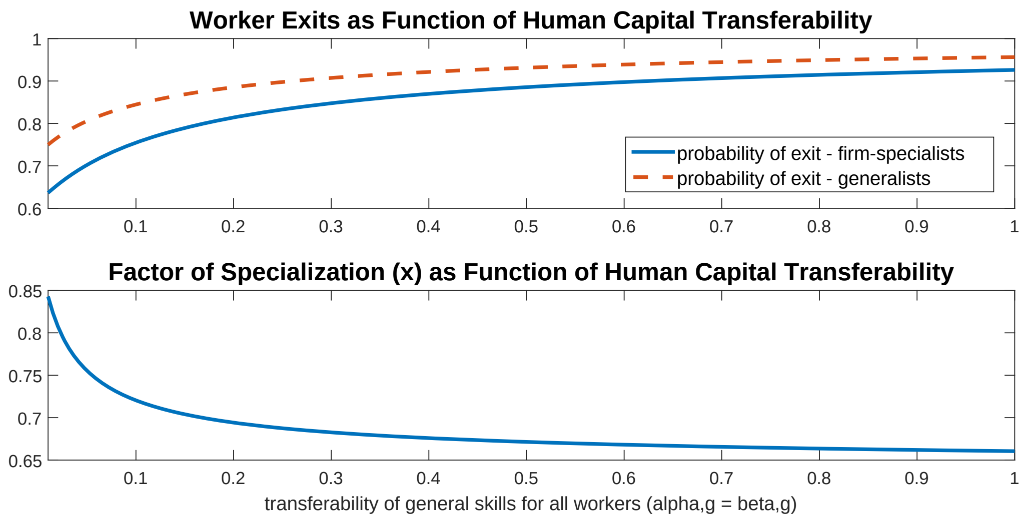
However, it is also true that the firm responds to this higher transferability by changing the mix of tasks performed by each worker. Proposition 7 says that as general skill transferability rises, the firm lessens the extent of specialization. That is, it optimally chooses to have generalists perform more firm-specific tasks, and firm specialists to perform more general tasks. This of course lessens efficiency in the sense of pulling workers away from their respective comparative advantages, but it also lessens the extent of worker exit. Yet it doesn't neutralize higher exits entirely. Thus higher rates of general skill transferability creates both worker loss *and* less efficiency — the firm lessens specialization, but still countenances greater exits.

Figure 3: Comparative Statics



The figure shows the change in equilibrium values of x and s_g for a given exogenous rise in δ_g.

Figure 4: Effects of Greater Skill Transferability of General Skills for All Workers



The figure shows the relationship between δ_g and π_f and π_g (top figure), and between δ_g and x (bottom figure).

Figure 3 demonstrates what happens to equilibrium search and specialization with greater transferability of general skills. For any given level of specialization generalists will search more. The firm will respond by lowering the degree of specialization.

Figure 4 shows equilibrium values when we *continuously* change the level of transferability of general skills for both worker-types. Here we observe that when transferability for general skills rise for *all* workers, exits rise, and rise even faster for firm-specialists (top diagram). We also see how this induces the firm to reduce specialization (bottom diagram).

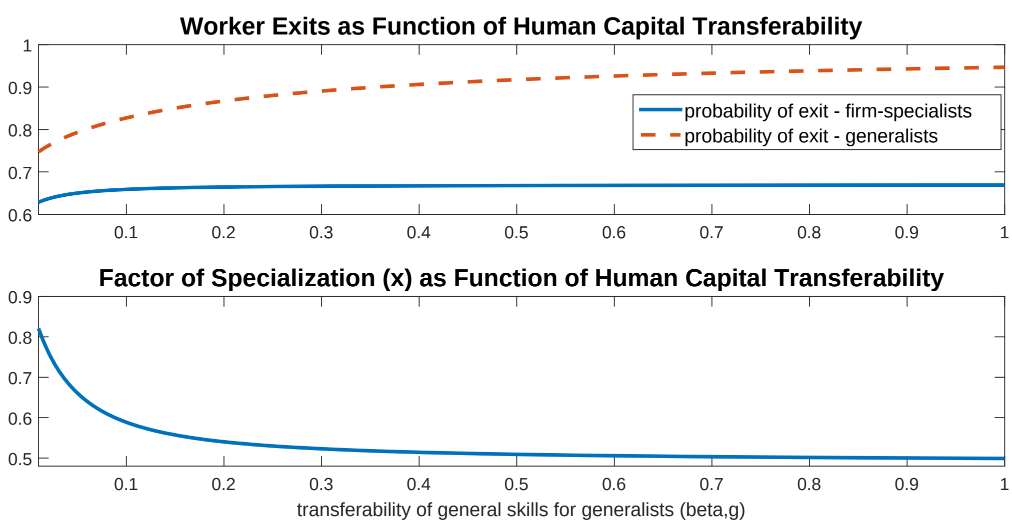
2.3.2 Greater transferability of general skills only for generalists

It is also possible that in certain cases general skill transferability will disproportionately affect generalists more. The final two propositions address this.

Proposition 8 $\forall \sigma < 1$, $\frac{\partial s_g^*}{\partial \delta_{\beta,g}} > \frac{\partial s_f^*}{\partial \delta_{\beta,g}}$.

Proposition 9 $\forall \sigma < 1$, $\frac{\partial x^*}{\partial \delta_{\beta,g}} < 0$.

Figure 5: Effects of Greater Skill Transferability of General Skills for Generalists



The figure shows the relationship between $\delta_{\beta,g}$ and π_f and π_g (top figure), and between $\delta_{\beta,g}$ and x (bottom figure).

Proposition 8 is straight-forward — when transferability of general skills is greater for generalists, they exit at greater rates than firm-specialists. This happens despite what is suggested in Proposition 9 — this increase in transferability induces the firm to reduce specialization, which counters this higher exit. Indeed, because exit rates diverge between the two types of workers in this case, the firm optimally limits specialization even more to counter this divergence. This can be seen in Figure 5. Here we can see that with a high enough rate of general-skill transferability, the firm abolishes specialization altogether. x hits its floor of 0.5, and the firm abandons comparative advantages entirely.

These propositions seem plausible for contemporary economies. Individuals move to occupations with similar task requirements, and task-specific human capital is an important source of wage growth for workers moving across firms or organizations (Gathmann and Schoenberg 2010). Having workers evenly distribute themselves across *all* tasks would then limit movement to new occupations. In the context of navies officers were made to become omni-competent. Everyone does some of everything, "whether he wants to or not."[11]

3 Background

The model of the previous section demonstrates that industries always face skilled-worker exit when internal wages are rigid. It also shows that modernization will foster even *greater* skill-worker exit despite moves by the firm to limit specialized human capital accumulation. 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

[11] A fuller quote from Assistant Secretary of the Navy Theodore Roosevelt: "....every officer in a modern war vessel has in reality to be an engineer, whether he wants to or not....There is no longer any reason for having a separate body of engineers, responsible for only a part of the machinery; what we need is one homogenous body, all of whose members are trained for the efficient performance of the duties of the modern line officer."

(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).

We can test the model's predictions by observing rates of return to technical experience in "pre-" and "post-" modern navies. There is a very clear break for both organizations right around 1890, when naval technologies suddenly converged to the technological levels of modern industry. The model suggests a clearly testable implication — empirically we should see greater exit rates for those exposed to more general and modern tasks and experiences during the latter period.

Both navies suffered protracted technological uncertainty 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, committing the British to a path of naval expansion and ushering in the era of the new technologically advanced navy.

The U.S. Navy likewise faced immediate stagnation and difficulties in its post-bellum period. 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

[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)

effects during a period of such transition. Technological advances implemented after 1890 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 varying experiences in working 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

Prior to the early 1890s the overall officer corps of these modern navies were comprised of two fairly distinct groups — regular line-officers (the "firm-specialists" of our model) and engineering officers (the "generalists" of our model). Each group had different background

[13]This is also supported by our cursory examination of U.S. census records for those 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.

skills, and performed different operations aboard vessels or on shore duty. Each group also had opportunities for task-specific naval or engineering training. In Britain the Royal Naval College was established in 1873 to bolster engineering education for all officers. But it took over two decades to fully transform the human capital composition of the Royal Navy. 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 provide all new officers with more highly technical education. Indeed the process evolved over time and involved everything from executive orders, to acts of Congress and even rulings by the United States Supreme Court (Glaser and Rahman 2011).

Each person in service accumulated a unique portfolio of experiences based on comparative advantages — serving 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, implicit pecuniary rates of return for each experience, and organizational responses to greater transferability of some experiences.

Through technological upheavals, officers and engineers followed different career paths and accumulated different kinds of human capital. Aboard vessels, officers managed complements of sailors, developed strategy and performed navigational and technical operations. Engineers on the other hand performed vastly more technical operations, typically below decks.[14] This was especially true of the American engineers. 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. These acts essentially wiped away specialization of tasks and training, and set the table for many inefficiencies in subsequent naval operations.

[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.

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.

For both navies, the primary way to get a permanent wage raise was promotion. 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. during the 1870s and 80s — a glut of officers in the "pre-modern" Navy competed for limited positions on a declining number of ships. This influenced earnings not just through promotions but also through limited opportunities for sea service. 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 prior to 1890, exiting the Navy for the private sector would become many officers' best means to increase earnings. But as we suggested earlier, this would depend in part on human capital transferability.

Tables 1*a* and 1*b* provide a glimpse of the structure of Royal and American navy officer ranks (the engineer ranks, not shown here, fluctuate across certain time periods). 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 for British officers as well.[15]

Table 1a: Royal Navy Distribution of Line 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)

rank	years of service 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). Of the handful of erstwhile officers we do observe after service, they appear to join a myriad of different careers in fields like engineering, finance, law and shipping.

4 Data

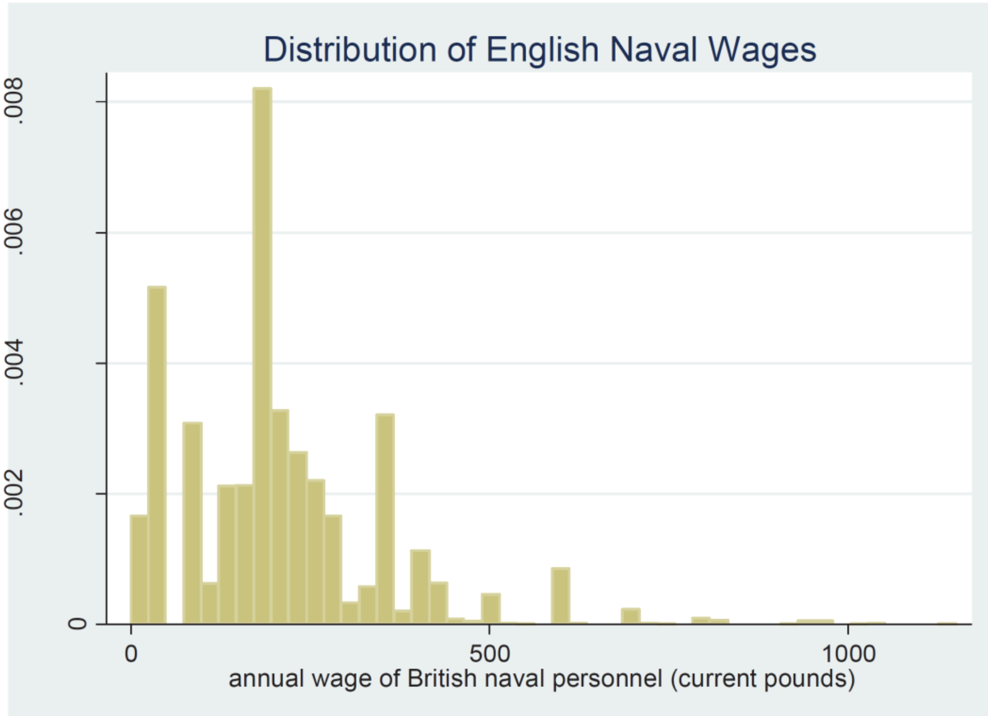
Data is compiled from publicly available naval officer career records stored in the National Archives and in the historical archives of the United States Naval Academy library.

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 6. 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 the U.S. Navy we are able to distinguish between personnel serving aboard ships on international tours versus those aboard docked vessels or in domestic waters. For the Royal Navy we 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 6: Wage Profiles for Naval Personnel



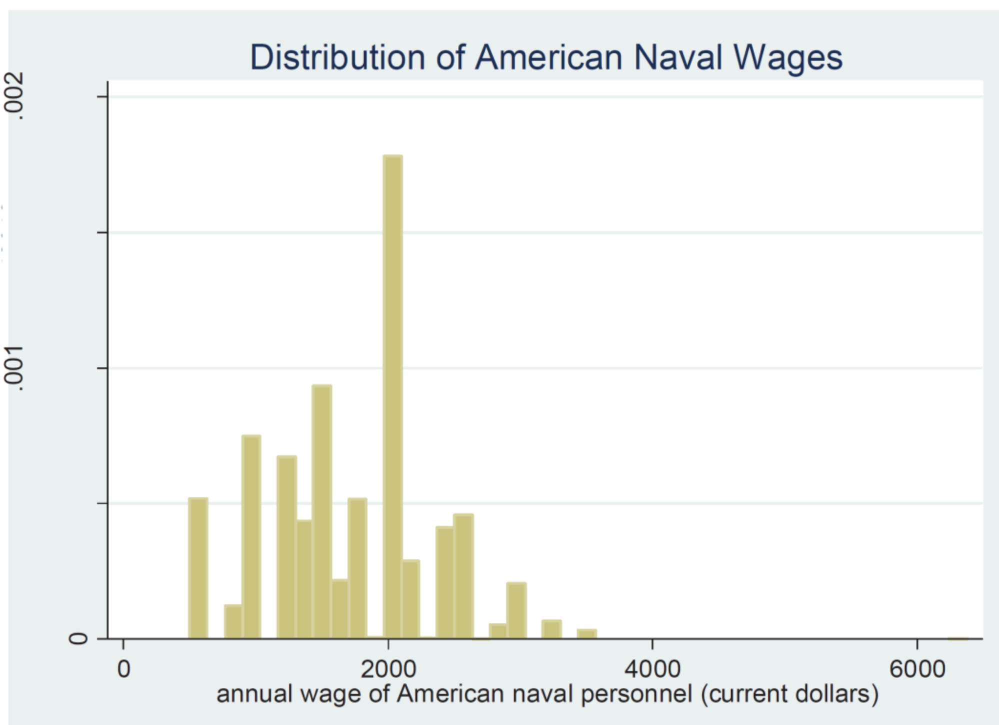


Table 2a: Royal Navy Descriptive Statistics (conditional on years of service)

	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					
% of total (std. dev)	0.38 (0.49)	0.37 (0.48)	0.33 (0.47)	0.19 (0.39)	0.01 (0.10)
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
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

Note: As years of service rises, mean years of specific types of experience can rise (as same individual accumulates more experience) or fall (as those with more experience exit the service).

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

rank	years of service 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					
% 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

Note: As years of service rises, mean years of specific types of experience can rise (as same individual accumulates more experience) or fall (as those with more experience exit the service).

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 $3a$ and $3b$. 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 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 ($\bar{w}$) generate from a known distribution and vary as careers progress due to the nature of work experience. Recall from section 2 that we had x be a worker's experience in their task of comparative advantage. Now let x represent experience more generally. The distribution of external private-sector offers depends of this observable experience and is defined by

$$Prob(\bar{w} < z; x) = G(z; x) \ . \tag{13}$$

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, *internal* 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

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

does not exist on record, with only anecdotal discussions that relate it to seniority, merit and availability of openings. Promotions were also likely related to the type and amount of fleet experience as demonstrated in tables 2*a* and 2*b*. Glaser and Rahman (2011) highlight the factors that most affected American officer promotions during this period, noting especially how the U.S. Navy was plagued with an overall dearth of promotions during the 1870s and 80s. 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. All these possibilities are accounted for in our measures of w.

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:

$$Prob(w^n < y; w, s, x, t) = F(y; w, s, x, t) \ . \tag{14}$$

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 $F_s(\cdot) < 0$. 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 (13) and (14) 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 $\bar{w}$, and human capital transferability of $0 < \delta < 1$, a job switch occurs when $v(w, s, x, t) < v(\bar{w}, s, \delta x, 0)$. 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 value than the current naval job. On the margin, a reservation wage exists, $r(w, s, x, t)$, such that

$$v(r(w, s, x, t), s, \delta x, 0) = v(w, s, x, t). \tag{15}$$

Any private sector offer $\bar{w}$ exceeding the reservation wage leads to a job separation from the Navy.[17]

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

[17]Not observed of course are any non-pecuniary benefits earned from promotions. With such benefits any wage increase stemming from promotions should bump up the reservation wage even more, such that $r_w(\cdot) > r_s(\cdot)$. We do not analyze this additional prediction here.

$$h(w,s,t,x) \;=\; \pi Prob(\bar{w} > r(w,s,t,x)) \;=\; \pi\left[1 - G(r(w,s,t,x))\right] \;. \tag{16}$$

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

$$h_w(w,s,t,x) = \; -\pi g(r;x) r_w(w,s,t,x) \;. \tag{17}$$

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

$$h_t(w,s,t,x) = \; -\pi g(r;x) r_t(w,s,t,x) \;. \tag{18}$$

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

$$h_x(w,s,t,x) \;=\; -\pi g(r;x) r_x(w,s,t,x) \;=\; -\pi G_x(r;x) \;. \tag{19}$$

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 — in section 2 this was δ_t), and $G_x(\cdot) \leq 0$ for more generally transferable forms of human capital (where δ is high — in section 2 this was δ_m). 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 (17) and (19) 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.[18]

5.2 Estimation

We estimate (16) by semi-parametric likelihood estimation. The likelihood function, which follows from Meyer (1990), 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.[19] 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:

$$log\ L(\gamma, \beta) \ = \ \sum_{i=1}^{N} [\phi_i log\,[1 - exp\,\{-exp\,[\mathbf{x}_i(T_i)'\beta_x + \gamma(T_i)]\}] \ - \ \sum_{t=1}^{T_i - \phi_i} exp\,[\mathbf{x}_i(t)'\beta_x + \gamma(t)]]\ . \tag{20}$$

This log-likelihood is a discrete time model with incompletely observed continuous hazards for censored ($\phi_i = 0$) and uncensored ($\phi_i = 1$) careers. Our estimates track careers from the beginning of year 6 until the beginning of year 36[20]. Step-function intervals define the

[18]For discussion purposes later in the paper, the estimates for $h_w(\cdot)$ and $h_x(\cdot)$ are the partial derivatives of (20) with respect to internal wages, w, and years of general (technical) experience, x. See Topel and Ward (1992) for more detail on this method of imputation.

[19]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.

[20]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.

experience spline for years $[6, 10), [11, 15), ..., [31, 35)$. The job tenure spline generates from estimates of γ[21]. Control variables at time period t are defined by the vector $\mathbf{x}(t)$ and include: the officer's wage, cumulative experience at sea or in command, a dummy variable to designate stagnation within rank, a dummy variable capturing status as an engineer, cumulative experience in various types of technical and bureaucratic jobs, controls for physical constitution[22], and year fixed effects. Alternative specifications include controls for unobserved individual-specific heterogeneity.[23]

6 Results

Hazard ratios estimated from (20) appear in tables $4a$–$4b$, 6 and $A1$–$A4$. Table $4a$ covers the sample of Royal Navy officers and engineers during the full sample of years 1879-1905. Table $4b$ includes estimates on U.S. officers and engineers during the full sample of years 1872-1905. Tables $A1$–$A4$, posted in the Appendix, provide results for sub-sample years for each organization to demonstrate differences in hazards between the "pre-modern" and "modern" navies. We first discuss analysis using the full sample, then discuss some implications from the sub-samples.

[21] 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.

[22] 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.

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

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

6.1 Analysis of Full Sample

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

variable	sample: full	full	full	officers	engineers
earnings	0.982*** (<0.000)	0.981*** (<0.000)	0.982*** (<0.000)	0.985*** (<0.000)	0.982*** (<0.000)
time	–	1.02*** (<0.000)	0.99 (0.59)	0.99* (0.07)	1.04*** (0.001)
engineer	0.83 (0.14)	0.62 (0.12)	0.68* (0.06)	–	–
engineer*time	–	1.02*** (0.001)	1.01** (0.02)	–	–
tech shore duty experience	1.11*** (<0.000)	1.09*** (0.021)	1.21 (0.36)	5.92*** (<0.000)	0.90 (0.71)
tech shore duty exp*time	–	–	1.00 (0.54)	1.02*** (<0.000)	0.99 (0.59)
ship experience	0.94*** (<0.000)	0.92*** (<0.000)	1.36*** (<0.000)	1.41*** (<0.000)	0.89 (0.50)
ship exp*time	–	–	1.01*** (<0.000)	1.005*** (<0.000)	1.0004 (0.84)
command experience	0.97*** (0.003)	0.97*** (0.003)	1.28** (0.03)	1.33* (0.10)	2.03*** (<0.000)
command exp*time	–	–	1.003** (0.02)	1.004* (0.07)	1.008*** (<0.000)
years in same rank	1.04*** (<0.000)	1.03*** (<0.000)	1.05*** (<0.000)	1.05*** (<0.000)	1.05*** (0.001)
years of additional school/training	0.92** (0.01)	0.88*** (0.001)	0.86*** (<0.000)	0.89** (0.001)	0.77*** (0.003)
eligible for retirement	1.84*** (<0.000)	1.89*** (<0.000)	1.90*** (<0.000)	2.77*** (<0.000)	–
sick/disability	2.24*** (<0.000)	2.12*** (<0.000)	2.06*** (<0.000)	3.28*** (<0.000)	1.38* (0.10)
year effects	yes	yes	yes	yes	yes
baseline splines (4 years)	increasing	increasing	increasing	increasing	increasing
log likelihood	-2051.1	-2023.9	-1973.1	-1512.6	-412.7
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. Estimates over (under) 1 suggest higher (lower) liklihood of exit. 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)

variable	sample **full**	**full**	**full**	**officers**	**engineers**
earnings	0.988*** (<0.000)	0.987*** (<0.000)	0.987*** (<0.000)	0.984*** (<0.000)	0.992 (0.27)
time	–	0.99 (0.26)	0.99 (0.42)	0.98 (0.22)	0.98 (0.41)
engineer	1.49*** (<0.000)	1.05 (0.92)	1.26 (0.63)	–	–
engineer*time	–	1.02 (0.73)	1.01 (0.74)	–	–
tech shore duty experience	1.04 (0.17)	1.04 (0.14)	0.83** (0.01)	0.85** (0.02)	0.88 (0.66)
tech shore duty exp*time	–	–	1.01*** (0.002)	1.01*** (0.01)	1.01 (0.48)
steam bureau experience	0.61 (0.25)	0.92 (0.11)	0.60 (0.20)	0.62*** (<0.000)	0.72 (0.36)
steam bureau exp*time	–	–	1.01 (0.27)	1.15 (0.32)	1.01 (0.33)
non-tech shore duty experience	0.99 (0.86)	0.99 (0.99)	0.87 (0.56)	1.00 (0.97)	0.28** (0.04)
non-tech shore duty exp*time	–	–	1.00 (0.61)	0.99 (0.86)	1.04** (0.05)
ship experience (sea)	0.98 (0.48)	0.98 (0.28)	1.00 (0.88)	1.00 (0.74)	0.89 (0.54)
ship experience*time	–	–	0.99 (0.38)	1.00 (0.99)	1.00 (0.56)
command experience	1.05 (0.30)	1.05 (0.27)	0.73 (0.13)	0.70* (0.08)	0.85** (0.02)
command exp*time	–	–	1.01* (0.08)	1.02** (0.04)	1.03 (0.89)
in rank: 5, 10, 15, or 20 years	0.70** (0.02)	0.69** (0.02)	0.70** (0.02)	0.81 (0.22)	0.11** (0.04)
USNA class percentile	0.94 (0.76)	0.93 (0.69)	0.92 (0.63)	0.79 (0.19)	1.76 (0.26)
sick	1.43*** (<0.000)	1.41*** (<0.000)	1.39*** (<0.000)	1.38*** (<0.000)	6.83***
year effects	yes	yes	yes	yes	yes
baseline splines (5 years)	concave	concave	concave	concave	concave
log likelihood	-716.3	-716.2	-711.1	-585.8	-105.0
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. Estimates over (under) 1 suggest higher (lower) liklihood of exit. Standard errors clustered by USNA graduating class.

First, as indicated by equation (17), 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 (see first line of coefficient estimates in tables 4a, 4b, and A1-A4). 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 (discussed in the next section). This also supports Propositions 1 and 3 in section 2.1, which suggest workers search for external jobs *less* when receiving large wage hikes. It 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.[24] This strongly demonstrates the validity of Topel and Ward's argument for those working a century prior to their having made it — a key element leading to job durability is the wage. To our knowledge, these are the earliest workers for which Topel and Ward's framework have been tested and validated.

In testing the other propositions of the model, let us focus on the full samples for the Royal Navy (table 4a) and the U.S. Navy (table 4b).[25] First, proposition 4 suggests that the generalist will have higher rates of exit than the firm-specialist. As related in our historical discussion of section 3, we consider engineer officers to be those with skills having greater value to alternative industries. Hence, consider engineers as proxies for generalist workers from the theory. For the Royal Navy we see evidence that supports this conclusion from the theoretical model using the full sample. For the U.S. Navy, engineers also appear to exit at higher rates than traditional line officers, although when time trends are included estimated

[24]This also challenges Keegan (1994), who suggests that "soldiers are not as other men." In any case, perhaps even Keegan would agree that soldiers are *most* like other men when they can acquire technocratic and bureaucratic skills during times of peace.

[25]Note that for the U.S. we can observe in more detail officers' and engineers' shore office positions (which bureau they work under).

effects fall to insignificance. Overall the evidence suggests that generalists exit at higher rates than firm-specialists.

Further, when we include a time trend interaction, we see that the exit rates for engineers increases *over time*. This is particularly true for the British (in the U.S. case estimates are positive but insignificant). This is consistent with our model for modernizing bureaucracies, where engineers would be exposed to more modern (and thereby more sellable) techniques and approaches.

6.2 Transition to modernity

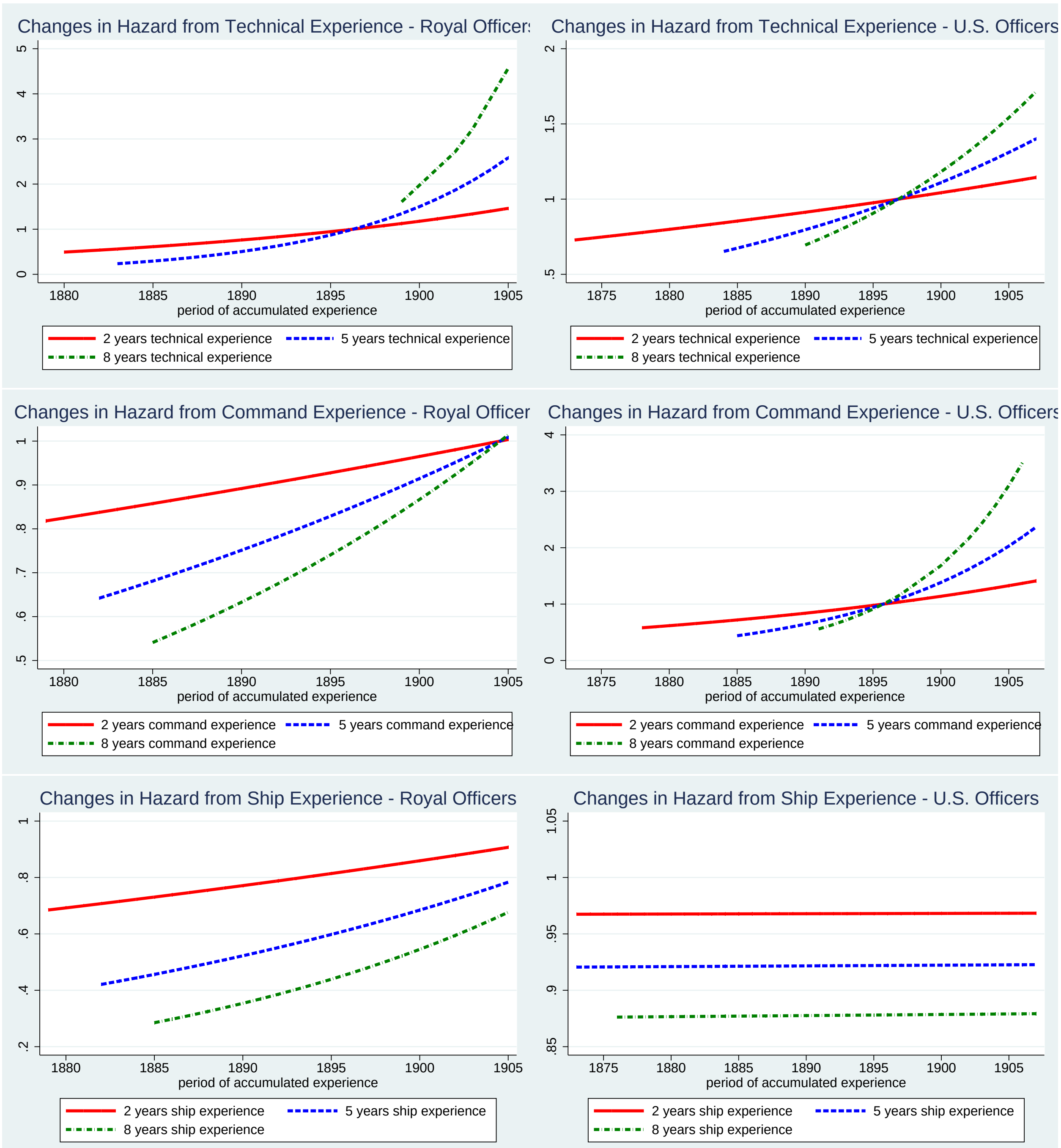
We have suggested that before the 1890s, skills accumulated by naval personnel tended to be of the "traditional" variety, meaning they were important for naval operations but not particularly employable in the greater economy. Once these two naval powers launched ambitious modernization programs, they exposed personnel to more marketable skills. The naval histories of British and America clearly mark the 1890s as a definitive break from tradition. Do the data support these histories?

They do in two basic ways. First, we split our sample between pre-1890 and post-1890, which we presume to label as the "pre-modern" and "modern" periods. For the pre-modern period (Tables A1 and A3), we observe no experience for officers of either navy that raises their likelihood of exit (whether they experience by land, or by sea, or by command). This supports Propositions 5 and 6 — low transferability of skills keeps exits low. This changes dramatically after 1890. In tables A2 and A4, we see that technical shore tasks raise the rates of exit for both Royal and American officers, and command positions raise rates of exit for American officers even more. Again, this supports the propositions of the model — exposure to generalizable tasks allows for higher exits.

The other way we can observe this transformation is to look at the estimated coefficients on experience interacted with estimated time trend effects. By doing this we can ask questions such as: what happens to an officer's likelihood of exit when he gets two years of

Figure 7: Changes in Hazard Rates for Different Types and Durations of Experiences

(a) Royal Navy **(b) U.S. Navy**



Note: Depending on the type of experience, changes in hazard either become positive after around 1895, or always remain negative. Estimates used are from the 4th columns of Tables 4a and 4b.

experience doing x in the 1880s? And what happens to this likelihood when he gets two years of x at the turn of the 20th century?

Answers to these types of questions can be displayed visually. This is done in Figure 7. Here we look at three basic types of experience — technical shore duty, command experience, and sea duty. We chart the estimated marginal effect on hazard ratios from human capital (vertical axes), as it was accumulated during specific periods of time (horizontal axes). We can immediately see one of the manifestations of modernization — experiences of all kinds become increasingly sellable to external industries. That is, all schedules are positively sloped, albeit at different rates.

Perhaps more tellingly, technical shore experience for both Royal and American officers are predicted to positively contribute to exits only starting in the 1890s, our period of earnest modernity. This is also true for American officers with command experience. For British officers command experience turns positive only at the end of our sampled period. This difference however is likely due to the fact that we only measure British officers commanding vessels, not shore positions, whereas we observe American officers commanding both ships and office positions.

Ship experience accumulated by British officers becomes increasingly more marketable over time, while for American officers these profiles are virtually flat. This makes sense, since British vessels were certainly more technologically advanced than American vessels, despite the U.S.'s attempt at technological catch-up. But more critically for either navy, ship experience always decreases exit rates (marginal exit rates are always less than one). This also makes sense — we can conceive of vessel experience as more "firm-specific" (navy-specific) human capital, while shore or managerial experiences as more generalizable. And as these organizations modernized, these skills became increasingly sell-able, such that eventually they helped officer personnel leave for external opportunities elsewhere.

All this lends support to Propositions 5 and 6 of the theory. Propositions 5 and 6 address *changes* in skill transferability — as a firm or organization modernizes, more generalizable accumulated skills should be more marketable externally. This should be true for both firm-specialists *and* generalists. Indeed, when modern and technical tasks are performed by both types of workers, the model suggests that the effect on transferability from skills affect firm-specialists workers to a *greater* extent than generalists. By observing estimates from the experience-time interaction terms for the Royal Navy, we see that technical shore experience, ship experience, and command experience are increasingly sell-able by traditional line officers. For Royal engineers, only command experience appears to have increasing effects on exits. The U.S. case shows similar though not identical patterns. Here, similar to U.K. officers, technical shore experience and command experience appears to increasingly foster exits. Ship experience here does not.

6.3 Analysis of Subsets

Tables A1–A4 in the Appendix display empirical results when we separate periods before 1890 and periods after 1890. From these we make a number of observations consistent with our analysis using full samples.

First, in looking at our extensive measures of technical skill, exit rates for engineers are predicted to have risen for modern Royal Navy, while exits appear to remain high for the modern American Navy. Specifically, English engineers are predicted to actually stay with more likelihood than regular officers during the early period, while they are predicted to *leave* with more likelihood during the modern period (though estimates for the modern period are not statistically different from zero). American engineers on the other hand are predicted to have a roughly 50 percent higher likelihood of exiting compared with line officers during either period. The U.S. in particular may serve as a cautionary tale — when the generalist workforce differs much from the firm-specialist workforce, the organization is susceptible to human capital loss when there is a rigid system of compensation (see Proposition 4). What is remarkable is that much anecdotal evidence suggests that the technically skilled were more disgruntled during the *pre*-modern Navy (Marder 1961, McBride 2000). The technically oriented were in fact exiting even when their internal prospects were improving. This gives us *a fortiori* evidence that technical skills from naval service had become more marketable.

Next, we look at more intensive measures of technical skill. When it comes to traditional officers, both navies were models of retention during the early period. For both organizations, we observe not a single task performed by officers before 1890 where we would predict higher exit rates. This changes dramatically after 1890. Compared to the earlier period, estimated hazard rates rise for technical shore experience, command experience, and ship experience (brown water ships for the U.S.). And as is made clear from Figure 7, estimated exits are now positive for technical shore experience for both organizations.

For Royal officers, cumulative years in technical shore positions positively predicts separation only for the modern period. 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. As the Royal Navy transitioned into a industrialized workplace, shore positions would involve a variety of technical and administrative tasks that would be increasingly 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 Royal Navy — exit probabilities are statistically significantly *lower* for the pre-modern period. 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.[26]

The U.S. Navy provides an interesting case with which to compare and contrast the British case. The first similarity to note is that no measurable job experiences observed

[26] 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.

prior to 1890 raise exit rates. In particular, technical experience in shore jobs[27] does not affect separation probabilities before 1890 (table $A3$).

Like the Royal Navy, the traditional technically stagnant U.S. navy appears to be a model of job retention prior to 1890, but this changes dramatically with modernization (table $A4$). Technical shore jobs after 1890 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 involved more duties related to engineering, steel manufacturing and the maintenance of yard-wide electrical systems.[28]

We also see an increase in separation probabilities as workers accumulate experience on "brown sea" ships after 1890 (we cannot make a comparable separation between ship types for the Royal Navy). 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 navigation and seamanship.

An interesting 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 even after 1890, in the U.S. they were associated with higher rates during the modern period. We believe this is because 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 the tables, these positions were in fact

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

[28] *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.

associated with higher retention during the pre-modern era, and with lower retention only during the modern era.[29] Again, this empirical evidence lends support to the propositions of the theory.

6.3.1 Rates of Return to Technical Experience

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

	1878-1905	1878-1890	1891-1905
engineer			
rate of return	–	–	0.018
(p-value)			(0.903)
all technical experience			
rate of return	0.056***	–	0.107***
(p-value)	(0.000)		(0.000)

Use of coefficients from tables A1 and A2.
One-sided significance indicated as *** if $p \leq 0.01$, ** if $p \leq 0.05$ and * if $p \leq 0.10$.

Table 5b: Rates of Return to Technical Skills in U.S.: $\frac{h_x}{h_w}$

	1872-1905	1872-1890	1891-1905
engineer			
rate of return	0.17	0.304*	0.150*
(p-value)	(0.628)	(0.080)	(0.073)
all technical experience			
rate of return	0.029	–	0.024**
(p-value)	(0.194)		(0.036)

Use of coefficients from tables A3 and A4.
One-sided significance indicated as *** if $p \leq 0.01$, ** if $p \leq 0.05$ and * if $p \leq 0.10$.

How valuable were these external opportunities for naval personnel? With our broad specifications that include extensive control variables, we believe these hazard regressions

[29]Separating ship command versus shore command for U.S. officers bears this out. Results not shown but available upon request.

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. Indeed, within rigid bureaucracies we cannot look to internal earnings to measure such rates of return, as these are distorted. Measuring rates of exit for accumulated experiences is the *only* way to measures rates of human capital return in these cases.

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 5.6 percent per annum, with a larger 10 percent per annum for the latter period.

While there is no measurable difference in rates of return between officers and engineers in the Royal Navy, American engineers earn roughly a 17 percent premium relative to their officer counterparts for the whole period. 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 via 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 findings produce 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).

6.4 Organizational Response — Amalgamation

Finally, Propositions 7 and 9 suggest that greater technical skill transferability (either for all workers or for specialized technical workers) fosters an endogenous response from the firm — they lessen task specialization. Here we argue that the histories of both naval organizations fully support this suggestion.

6.4.1 Historical Evidence

The evolving strategy among the leadership of the Royal Navy is well documented in the Brassey's Annuals, the official periodic publication of that organization. Much is made about making sure traditional skills are acquired and maintained by all. This was particularly true for experience at sea, the one experience that we consistently predict to be associated with greater retention. "...the naval officer cannot be made without constant experience of the sea....The sea itself is the one element of a seaman's experience that cannot be reduced to book knowledge, and must be assimilated on the quarterdeck" (Brassey 1899). And as the Navy modernized, leadership stressed the need to maintain all forms of traditional skills, useful or not. "The particular system may be useless or even mischievous, but the necessity of its abolition....must be established...for other reasons" besides the fact that they are no longer applicable for naval readiness (Brassey 1900).

The abolition of specialization for the Royal Navy manifested itself in the so-called Selborne-Fisher Scheme, announced in 1903 but taking a few years thereafter to implement fully. In extensive discussion, leaders argued for the need to sacrifice lower-level task efficiency for a greater objective related to human capital retention. Essentially the goal was to "employ [officers] in relation to their individual efficiency, while tending to a *higher* specialization [emphasis ours].....This arrangement is in consonance with the general principle of the new educational scheme that, while it is necessary to have officers fitted for the highest positions, it is even more essential that there should be a large body of officers experienced in *all* duties" [emphasis ours] (Brassey 1904). The Brassey publication of the prior year discusses some of the motivation in more detail: "Efficiency of the ship should never be sacrificed to the efficiency of a department. Unity is therefore desireable. The Board of Admiralty hope to bring greater unity to the profession by a common system of entry and training for the four great branches hitherto known as the Executive, Royal Marine Light Infantry, Roayl Marine Artillery and Engineering branches" (Brassey 1903). Specialization in all areas was being wiped out, not just for engineers. For example, "the training of navigating officers has been revised, it having been recognized that a higher degree of efficiency is desirable and that the navigating officer must be available for general duties" (ibid).

For the U.S., the abolition of specialization was accomplished, at least in part, through the Amalgamation Act of 1899. Similar to its English counterpart, the act mandated all technical specialists to acquire traditional naval skills. For example engineers were given two years to become properly certified in seamanship to serve as deck watch officers; failure meant losing their commissions (McBride 2000). And similar to the Royal Navy, many naval leaders resisted the move to omni-competence for all naval personnel. For example in 1906 Real Admiral G.W. Baird condemned amalgamation for "working a great harm to the naval service," lamenting the profession's apparent abdication of specialization so crucial for modernizing industry. In his mind and others, officers were becoming jack of all trades and masters of none. "The amalgamated officer of today must 'qualify' in so many sciences, arts, professions and trades that he is not likely to be a specialist in any. While everyone else is specializing, the Navy alone is generalizing" (ibid). Due in part to this resistance, transition to a fully *de facto* amalgamated corps took many years to complete after the 1899 act.

Was generalization of tasks a reaction to worker exits? We have suggestions of this as well. Grumblings over the loss of specialized human capital began in earnest for both organizations in the 1890s. Expansion of naval capital required more personnel: "...while we are constantly adding machinery of many thousands of horse-power to our Navy, we are taking no steps whatever to provide officers and men to look after it" (Brassey 1893). Loss of human capital became more and more costly: "...it is admitted that the lieutenants' list is far below our requirements, and the deficiency must be measured not by tens but by hundreds. To make an efficient naval officer is the work of years" (Brassey 1895). Because amalgamation in the U.S. was particularly protracted, exits continued. For example, four senior members of the Construction Corps resigned in 1912, prompting the chief conductor to blame this loss of expertise to the private sector, and to the incomplete state of amalgamation in naval organization (McBride 2000).

6.4.2 Empirical Evidence

Despite the historical evidence presented above, one could envision an alternative hypothesis — navies may have embraced omni-competence due to increased complementarities across different skills. Indeed, as vessels and naval organizations grew more sophisticated, well rounded officers may have had the most important mix of skills for success. In this case less specialization would lead to greater efficiencies, not less.

If this were true however officers with a greater balance of skills would earn the highest returns and exit at faster rates during the modern naval period. To test for this possibility we re-estimate (20) but include interaction terms between traditional and modern skills, and highlight these estimates. Specifically, we interact ship experience with a measure of more technical training, either technical shore experience or an engineer indicator, and we perform separate analyses for the traditional and modern naval periods.

Table 6 demonstrates the estimated coefficients from these interactions. Complementarities appear to drop for both navies for both interaction measures. For the Royal Navy, a mix of technical and sea experience appears valuable only for the traditional navy — during the modern period a greater balance of technical and ship experience appears to negatively impact exits, while the retention effect on engineers acquiring sea experience is not statistically distinguishable from zero. For the United States the effects of well-roundedness on retention are even stronger — the estimated exit rates from the balance between traditional and modern skills are statistically no different from zero for the traditional navy, but definitively turn negative for the modern navy.

Finally, wages paid to those with a greater balance between the two types of experiences tend to be lower than otherwise (results not displayed here). The cumulative picture suggests that the insistence for omni-competence among naval personnel was driven at least in part to retain human capital.

Table 6: Complementarity of Skills? Interaction between Technical and Sea Experience

	1878-1890	1891-1905
tech shore exp. * ship exp.		
Royal Navy	1.03***	0.99***
(p-value)	(0.00)	(0.009)
U.S. Navy	0.99	0.98**
(p-value)	(0.15)	(0.006)
engineer * ship exp.		
Royal Navy	1.055**	1.03
(p-value)	(0.03)	(0.15)
U.S. Navy	0.95	0.90**
(p-value)	(0.33)	(0.04)

Odds-ratios reported. All other estimates from (20) not displayed.
One-sided significance indicated as *** if $p \leq 0.01$, ** if $p \leq 0.05$ and * if $p \leq 0.10$.

6.5 Robustness

6.5.1 Robustness — Pensions

One possibility for the U.S. Navy is that our measures of wages used to estimate the specifications reported in tables $4b$, $A3$ and $A4$ are mis-measured by not accounting for the possibility of 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 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*.[30] 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.[31] 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[32] without sub-sets of pension applicants, and table 7 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 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

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

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

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

tenure (the "years experience" splines), remain robust to various sub-sample estimations.[33] The effect of cumulative technical experience increases slightly in the two re-estimations restricted to officers who never apply for pensions. These results appear to bolster the argument that more technical experience ultimately led officers to a faster exit.

Table 7: Sensitivity to possible pension-
-related exits: U.S. case

	(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	9129	8223	8414
officers : separations	970 : 291	886 : 256	904 : 263

Same specifications as table 4*b*, column (2) (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.

6.5.2 Robustness — Career malaise

In the United States, officers received pay increases through two basic avenues: promotion to a higher rank, or by stagnating within the same rank for too long. That is in the

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

absence of a promotion, a 10 percent pay-step increase occurs each time an officer achieves within-rank milestones of 5, 10, 15 or 20 years of service. Therefore we expect that 5 year bumps in earnings should influence decisions similarly to increases in w, in that officers pentennially increase their reservation wage in the absence of a promotion. This indicates a shift in the distribution of offers such that $h_s < 0$. When not in a pentennial year, officers expect zero growth from internal wage offers and thus $h_s \geq 0$. We control for this stagnation effect with a dummy variable for whether the officer/engineer is serving in his pentennial year within rank. Impending pay increases bump-up the reservation wage and decrease separations.[34] 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 accumulation of very specific types of technical human capital during the era of the "modern Navy" era alters job-separation probabilities by substantial margins, suggesting large rates

[34]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.

of return to such human capital. Experience aboard sea-faring vessels or holding other firm-specific skills did not similarly appear rewarded by the private sector. We also show that firms can respond by limiting task specialization. An implication here is that the focus on omni-competence *within* a firm can foster less mobility of workers *across* firms.

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.[35]

Our findings, both theoretical and empirical, suggest that industries in decline can be models of job retention, while modernizing industries can face severe skill shortages. We perhaps see something similar today in certain manufacturing industries, where workers cling to antiquated positions less because they are well paying and more because their skills are not as valuable elsewhere. Modernizing firms may need to sacrifice efficiencies from task specialization for, in the parlance of the Royal Navy, a "higher level" of organizational efficiency. Industries currently undergoing modernization should take note.

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A Estimates with split samples — before and after start of modernization

Table A1: Hazard-Ratios for Separations from the Royal Navy
(sample years from 1879-1890 — "pre-modern")

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

Odds-ratios reported with p-values in parentheses. Estimates over (under) 1 suggest higher (lower) liklihood of exit. Standard errors clustered by Cohort of First Year as a Sub-Lieutenant or Assistant Engineer.

Table A2: Hazard-Ratios for Separations from the Royal Navy
(sample years from 1891-1905 — "modern")

variable	sample: **full**	**full**	**officers**	**engineers**
log(earnings)	0.984 (<0.000)	0.984 (<0.000)	0.983 (<0.000)	0.994 (<0.000)
engineer	1.062 (0.774)	1.027 (0.903)	–	–
shore duty experience	1.112 (0.000)	1.168 (0.000)	1.151 (0.000)	1.025 (0.472)
shore duty experience (engineers)	0.926 (0.038)	0.889 (0.008)	–	–
ship experience	–	0.942 (0.000)	0.935 (0.000)	0.922 (0.005)
ship experience (engineers)	–	1.032 (0.144)	–	–
command experience	0.943 (0.000)	0.959 (0.005)	0.960 (0.031)	1.013 (0.628)
years in same rank	1.051 (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)	0.872 (0.007)	0.840 (0.121)
eligible for retirement	1.907 (0.000)	1.881 (0.000)	2.392 (0.000)	–
sick/disability	2.631 (0.000)	2.748 (0.000)	3.076 (0.000)	1.568 (0.280)
year effects	yes	yes	yes	yes
baseline splines (4 years)	increasing	increasing	increasing	increasing
log likelihood	-1098	-1083	-675	-379
individual events	35589	35589	24562	11027
officers and engineers : separations	4231:1093	4231:1093	3193:794	1249:299

Odds-ratios reported with p-values in parentheses. Estimates over (under) 1 suggest higher (lower) liklihood of exit. Standard errors clustered by Cohort of First Year as a Sub-Lieutenant or Assistant Engineer.

Table A3: Hazard-Ratios for Separations from the U.S. Navy
(sample years from 1872-1890 — "pre-modern")

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

Odds-ratios reported with p-values in parentheses. Estimates over (under) 1 suggest higher (lower) liklihood of exit. Standard errors clustered by USNA graduating class.

Table A4: Hazard-Ratios for Separations from the U.S. Navy
(sample years from 1891-1905 — "modern")

variable	sample years full	full	officers	engineers
log(earnings)	0.976 (<0.000)	0.975 (<0.000)	0.965 (<0.000)	0.985 (<0.000)
engineer	1.448 (0.037)	1.45 (0.037)	–	–
shore duty experience (tech)	1.060 (0.030)	1.062 (0.020)	1.035 (0.020)	1.077 (0.153)
shore duty experience (steam bureau)	0.920 (0.143)	0.916 (0.102)	–	0.975 (0.645)
shore duty experience (other bureau)	0.995 (0.930)	1.008 (0.881)	0.983 (0.784)	0.956 (0.689)
ship experience (sea)	–	0.960 (0.182)	1.014 (0.681)	0.935 (0.346)
ship experience (brown sea)	–	1.041 (0.104)	1.072 (0.010)	0.974 (0.817)
command experience	1.124 (0.003)	1.102 (0.031)	1.139 (0.006)	–
in rank: 5, 10, 15, or 20 years	0.549 (0.003)	0.552 (0.002)	0.586 (0.009)	0.550 (0.005)
USNA class percentile	1.226 (0.370)	1.242 (0.342)	1.081 (0.775)	1.909 (0.179)
sick	1.464 (0.002)	1.452 (0.002)	1.410 (0.010)	1.407 (0.403)
year effects	yes	yes	yes	yes
baseline splines (5 years)	concave	concave	concave	concave
log likelihood	-280	-276	-220	-30
individual events	9412	9412	7964	1448
officers and engineers : separations	994:301	994:301	820:251	174:50

Odds-ratios reported with p-values in parentheses. Estimates over (under) 1 suggest higher (lower) liklihood of exit. Standard errors clustered by USNA graduating class.