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ABSTRACT

Between the Dockyard and the Deep Blue Sea: Retention and Personnel Economics in the Royal Navy

This paper tackles some issues in personnel economics using the career profiles of British naval officers during the late 19th and early 20th centuries. We ask how promotions, payouts, positions, and peers affect worker retention. Random variation in task assignments and job promotions allows us to explore factors that affect retention of personnel. We develop a number of key insights. Firm-specific human capital accumulation bolsters retention, while technological changes can undo some of this effect. Other challenges to worker retention include lack of promotion opportunities, and “exit contagion” from exits of former peers. Modernizing organizations may need to enhance promotion opportunities and reorganize certain tasks, or else face loss of skilled personnel.

JEL Classification: J6, J45, J62, N31

Keywords: personnel economics, human capital, job mobility, promotion tournaments, technological change, military personnel, naval history, peer effects

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1 Introduction

What factors induce workers to leave their current employer? What can firms do to retain their personnel? These questions have helped spur the rise of personnel economics (Lazaer and Gibbs 2014), the subfield in labour devoted to these and other topics which concern the human resources of hiring organizations.

Coming up with answers to such questions is challenging. In dealing with problems in personnel economics Laezer and Oyer (2007) urge for more studies of single organizations, which can provide more precise analysis of various human resource policies. Yet for most firms finding plausibly exogenous variation in factors regarding employee wages, promotion, and experiences can prove difficult.

One difficulty may relate to the empirical challenges of measuring the applicability and value of skills acquired while on the job. The canonical study estimating the returns to general training while working is Topel and Ward (1992), which uses the wage gains caused by job switches to estimate the return to accumulated on-the-job skills. Specifically the study uses Social Security earnings records to follow 10,000 men and their careers across many industries and firms.

Using this approach for specific firms, industries or historical contexts however poses some problems. One, firms can pay workers performing similar tasks different wages, due to discrimination or other strategic reasons. A worker may then exit due to perceived wage disparity within the firm, rather than factors related to experience.

Two, workers are often assigned different tasks based on inherent abilities. Topel (1991) suggests firm-specific human capital can be very important for internal wage growth. But the estimation of the rate of return to experience as executed in Topel (1991) and Topel and Ward (1992) is complicated by the presence of different tasks in a firm. According to Acemoglu and Autor (2019), “returns to experience may be non-constant, and they may be higher in jobs to which workers are a better match” (pp. 191–192). Worker ability may be correlated with both worker exit and certain assigned tasks. In the context of endogenous tasks assigned by the firm, estimated returns to experience may be biased. Furthermore, as stressed by Acemoglu and Pischke (1998), firms can possess better information regarding the skills of their workers than outsiders. With different tasks involving different degrees of firm-specific human capital accumulation, firms may allocate tasks in order in part to *limit* employee exits.

This paper endeavors to fill the gap in this literature by disentangling the longitudinal effects of different kinds of experiences with promotions, payouts, positions, and peers, on the probability of abandoning one's career. We focus on groups of highly skilled workers in an environment well-suited for this study during a time of rapid technological change — officers serving in the Royal Navy during the late 19th century. More specifically, in their extensive discussion on personnel economics, Lazear and Oyer (2012) explore five aspects of the employment relationship. In this paper we focus on three of these as they relate to worker retention in the Royal Navy — compensation, skill development, and the organization of work.

Why Naval History?

At first blush it might seem peculiar to look to Belle Époche naval history to glean insights into labour-market questions in advanced economies. In fact the Royal Navy during this time produces a great laboratory setting for us in a number of ways.

First, the Navy employed a very rigid payment system for its corp of officers. Compensation was determined in large part by rank, with other pay adjustments due to different job assignments, certifications or levels of experience. For a given rank, the firm could not lower or raise wages based on idiosyncratic reasons. This allows us to more cleanly measure the effects of work experiences separately from the effects of different pay.

Importantly for this study, we can decompose compensation into the portion attributable to rank, and the portion attributable to other factors. Further, given how promotions are structured in the Royal Navy during this time, we can observe promotions that are clearly unrelated to the officer's ability. In this way we are uniquely able to capture the promotion effects on retention from the effects of other forms of pecuniary rewards.

Second, naval officers had an array of possible jobs ranging widely in technological sophistication. During this time the full spectrum of naval vessels with all kinds of technological designs were in service. Officers would either be stationed on shore duty, or selected to serve on vessels of various vintages. This allows us to explore how differential exposures to different technologies influenced retention. Our framework follows from Jovanovic (1979) which merges separation theories based on job-search with those based on the accumulation of different forms of firm-specific human capital.

Third, and perhaps most importantly, job assignments were largely random. Given the nature and demands of naval operations, employee-task matching functioned mainly for immediate needs rather than human capital growth or other longer-term considerations related to worker retention. Specifically here, matching capital to particular individuals is rather challenging when this capital literally floats around the world! Of course, tasks could not be considered *strictly* random, as certain skilled individuals would surely have a propensity for some specific tasks. To address this concern more formally, we instrument for certain job assignments by exploiting the random nature of ship deployments from various stations. As we will see, our instrumental variable results support our overall findings.

Fourth, this was a period of naval technological transition, so we can also observe how modernization changes rates of returns to experiences, as suggested by Acemoglu and Autor (2019). Navies in general tend to be at the forefront, developing and using the latest technologies of the day (Harley 1993). 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."[1] The navies of the late 19th century however experienced wrenching changes emblematic of the second Industrial Revo-

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

lution transforming Western economies, while still employing workers trained in increasingly antiquated techniques.

Finally, this was also an era of relative peace — there were no serious international naval conflicts, no mass conscriptions, no overt acts of bellicosity by the major powers. The relative calm fostered by *Pax Britannica* may bore naval historians but should excite labour economists — technologies were advancing, but the naval environment was stable enough for one to study changes in human capital, technical experience, rates of return to experience and career exits. We suggest this is in fact an ideal time and place to study these questions.

What Do We Learn?

First, firm-specific training can help retain personnel even if workers have limited outside employment opportunities. Specifically, experiences of officers serving on blue-sea faring vessels help retain these officers, even though we see little evidence to suggest that workers who do *not* receive sea experience exit for alternative jobs. Rather we observe this latter group tends to exit naval service and remain idle, living on their own means with no pension. Thus it appears this form of firm-specific training can help raise labour participation.

Second, we show that workers respond to internal wage changes with remarkable consistency, tending to remain on the job when they rise and to 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. Specifically, we see that a 1 percent increase in wages lowers the likelihood of exit by between 1 and 2 percent. Young naval personnel in the late 1800s reacted to labour market incentives in similar ways to the young workers studied by Topel and Ward (1992) a century later.

However, exploiting the unique structure of naval pay, we are able to differentiate pay increases in two ways. First, we can separate pay raises due to promotions from raises due to other factors related to job tenure or certifications. Second, we can distinguish between promotion-based raises that are due to merit from promotion-based raises that are randomly granted. Our key takeaway is that promoting workers is the key driver of retention — salary boosts from other sources are not nearly as effective in retaining personnel.

Third, we show that changes in technologies used by personnel can threaten retention. The Royal Navy of this period serves as an informative case study of an organization attempting to industrialize its operations while maintaining a tradition-bound group of personnel trained in primeval techniques. We demonstrate that officer exposure to newer and more complicated ships exacerbates exits in ways consistent with this story.

Fourth, we demonstrate that exits can be contagious. Specially, officers who serve on vessels with others who exit service tend to themselves exit after a certain period of time. Interestingly this peer effect does not appear to occur among peers serving on land stations, suggesting that the close proximity of vessel service can generate strong peer ties that help to magnify exit rates among personnel.

Finally, we stress that we can identify many of these findings through random job assignments particular to naval operations. Specifically, we are able to instrument for a subset of experiences using ship deployments in various stations across England and Scotland. This makes our usage of naval personnel particularly valuable. Our findings mentioned above are robust to such IV approaches.

The rest of the paper proceeds as follows. We first provide some historical background in section 2 and a description of the data in section 3. Section 4 presents the basic empirical model and section 5 discusses results and sensitivity checks. Section 6 provides a brief conclusion. An appendicized model demonstrating the potential of endogenous task assignments affecting worker exits is included at the end.

2 Background

The Royal Navy affords us a unique opportunity to test a number of key insights in personnel economics. During our period of study the Navy dramatically modernized its operations, as the composition of tasks among officers differed widely. This allows us to test the effects of different exposures to tasks and techniques on retention.

During the second Industrial Revolution of the latter 19th century, the premier navy of the world underwent its own fitful industrial development. There is in fact a rather clear break right around 1890, when naval technologies lurched towards the technological levels of modern industry due to the impetus for England to maintain naval superiority. Before this point the Royal Navy suffered protracted technological uncertainty and backwardness. Marder (1961), the gold standard of British naval history, argues that British naval strength deteriorated after 1868. The naval maneuvers of 1888 demonstrated profound technological and strategic weaknesses (Mullins 2016). 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 an era of naval technological advancement. We see this in figure 1, where British naval expansion truly launches only after 1890 to establish the "two-power" standard set forth by the Defense Act.[2]

Of course, naval officers that were trained in traditional naval techniques and maneuvers were rather suddenly thrust into an industrialized navy. Many officers were masters of seamanship, navigation and gunnery from the age of "wooden ships and iron men." Modernization eroded many of these hard-earned skills in favor of ability in more unfamiliar tasks. 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). Historically, navies have served as laboratories and vanguards of technological progress (O'Brien 2001). The corps of officers that our data captures had varying experiences in working with these technologies.

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[2] The Act called for the Royal Navy to maintain a number of battleships at least equal to the combined strength of the next two largest navies in the world.

Training and Human Capital

Prior to 1905 the overall officer corps in the Royal Navy were comprised of two fairly distinct groups — regular line-officers and engineering officers. Each group had different background skills, and performed different operations aboard vessels or on shore duty. Each group also had opportunities for task-specific naval or engineering training. The Royal Naval College was established in 1873 to bolster engineering education for all officers, but for decades still inculcated officers with a variety of more traditional forms of training (Dickinson 2016).

Each person in service accumulated a unique portfolio of experiences, serving on active or inactive ships, and on shore duty. As we mention in the introduction, task assignments may be endogenous as naval leaders embrace comparative advantages perceived among their employees. The exigencies of naval operations limit this possibility, as linking personnel to ships and tasks was often simply a matter of who was available. This fairly unique randomness of task assignments allow us to better understand the degree to which each type of task exposure helped or hindered job mobility, and the implicit pecuniary rates of return for each type of experience.

Aboard vessels, officers managed complements of sailors, developed strategy and performed navigational and technical operations. Engineers on the other hand performed more narrow and technical operations, typically below decks.[3] On shore duty officers would perform a variety of managerial and bureaucratic functions in naval bureaus or dry-docked vessels. The 'Selborne Scheme' of 1903–05 eliminated the officer/engineer distinction once and for all (Marder 1961).

Wages and Promotions

An important source of consistency in our study are the officer and engineer compensation schedules, which change only slightly during this period. Such stability in payment

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[3] 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.

structure meant personnel could confidently gage the internal pecuniary rewards of each task and position. It also suggests the ability for us to produce clean measures of the effect of pay on exit rates distinctly from the effects of experiences on exit rates.

Figure 2 shows a histogram of wages across all personnel and years. The primary way to get a permanent wage raise was promotion. Thus if personnel responded to wage incentives, promotions would seem crucial to retain employees. Yet there were other ways to get wage bumps unrelated to promotion. In this study we can explore if pecuniarly rewards alone can help keep exit rates low. If promotion opportunities are limited, as they are were the Royal Navy, other monetary rewards may be necessary to boost retention.

Table 1 provide a glimpse of the structure of 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, we see that around 9% of personnel attain the rank of Commander within the Royal Navy. After a 30-year career, most personnel still 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. 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%. Pay was also 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.[4]

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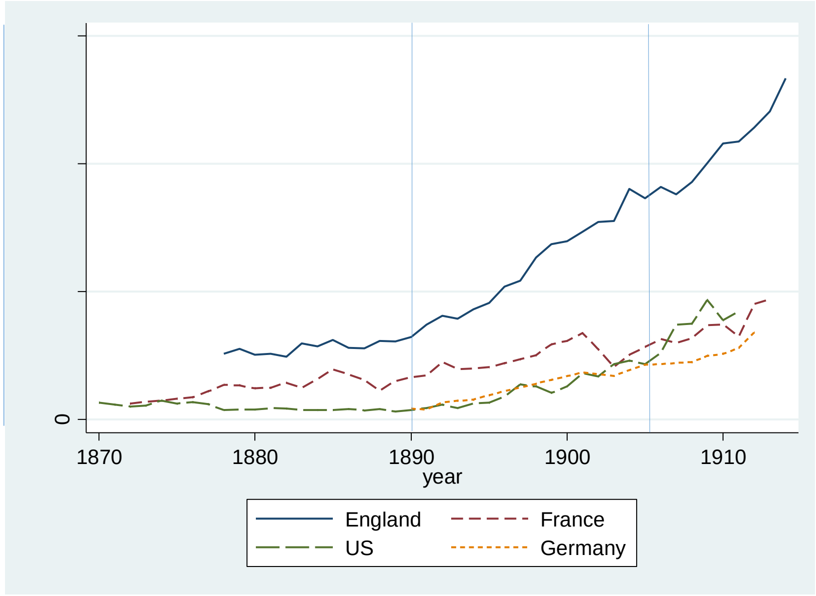
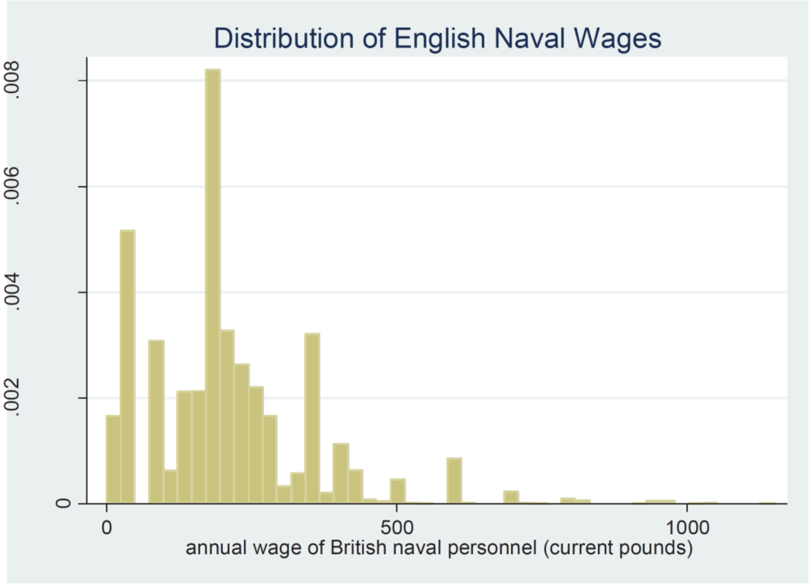
[4] The full digitized annual wage schedules for British naval personnel (from the Navy Lists) are available upon request. Ranks for engineers ascend from assistant engineer, to engineer, chief engineer, staff engineer and fleet engineer.

Figure 1: Total Displacement of Four Major Navies



Source: Authors' calculations.

Figure 2: Wages



Source: Authors' calculations.

Table 1: 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.

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. Further, officer exits were essentially one-sided decisions.[5] 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 of various experiences while in service.

3 Data

Data is compiled from publicly available naval officer career records stored in the U.S. Library of Congress and in the historical archives of the United States Naval Academy library. Published annually, the *Royal Naval Lists* 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 Royal naval personnel are available

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[5] 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.

in the *Navy List* (confusingly a distinct volume from the *Royal Navy List*). These data also enable the construction of measures for year-specific and cumulative experiences. These data have never before been codified, and so have never been used for systematic study. Wage profiles for personnel are displayed in figure 2. Data also exist for each officer's time in school (generally the Royal Naval College).

Summary statistics of measures of accumulated human capital appear in table 2. The data allows us to distinguish between personnel serving aboard ships on international tours versus those aboard docked vessels or on shore duty, and also has information regarding specific ship characteristics such as tonnage and horsepower. We have further information regarding voluntary or involuntary retirement and sick leave. These serve as important checks to our results, as we wish to focus on voluntary departures from naval service.

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

	years of service				
rank	10 yrs	15 yrs	20 yrs	25 yrs	30 yrs
annual log(earnings)					
mean (std. dev)	5.34 (0.19)	5.51 (0.22)	5.74 (0.25)	5.34 (0.19)	6.30 (0.26)
engineer share of sample					
percent of total (std. dev)	0.38 (0.49)	0.37 (0.48)	0.33 (0.47)	0.19 (0.39)	0.01 (0.10)
“modern” ship experience (local)					
mean years (std. dev)	0.23 (0.68)	0.19 (0.60)	0.37 (0.88)	0.43 (0.93)	0.54 (1.08)
% of years served	0.023	0.013	0.014	0.017	0.018
other ship experience (local)					
mean years (std. dev)	1.17 (1.34)	1.70 (1.69)	2.42 (2.00)	2.72 (2.21)	2.81 (2.01)
% of years served	0.117	0.113	0.121	0.109	0.093
“modern” ship experience (international)					
mean years (std. dev)	0.46 (1.08)	0.40 (1.11)	0.52 (1.20)	0.61 (1.34)	0.75 (1.28)
% of years served	0.046	0.027	0.026	0.024	0.025
other ship experience (international)					
mean years (std. dev)	3.53 (2.33)	4.58 (3.03)	5.71 (3.14)	5.99 (3.09)	7.14 (3.05)
% of years served	0.353	0.305	0.285	0.240	0.238
drydock experience					
mean years (std. dev)	0.51 (0.99)	0.86 (1.51)	1.38 (2.19)	0.96 (1.95)	0.20 (0.49)
% of years served	0.051	0.057	0.069	0.038	0.001
experience, senior ship officer/engineer					
mean years (std. dev)	0.58 (1.10)	1.85 (2.27)	3.84 (3.70)	5.02 (4.00)	7.05 (2.85)
% of years served	0.058	0.123	0.192	0.201	0.235
years of additional school/training					
mean years (std. dev)	0.61 (0.77)	0.46 (0.70)	0.42 (0.68)	0.43 (0.71)	0.71 (0.80)
% of years served	0.061	0.031	0.021	0.017	0.024
years in same rank					
mean years (std. dev)	6.27 (2.28)	6.74 (4.30)	5.95 (5.21)	7.32 (4.48)	8.26 (3.14)
average tonnage on ships served					
mean (std. dev)	3690 (2118)	3489 (1912)	3681 (1701)	3572 (1641)	3654 (1517)
average horsepower of ships served					
mean (std. dev)	3446 (2199)	3011 (1865)	3192 (1692)	3021 (1612)	3579 (1683)
# observations	2376	1977	1793	1352	716

Also of interest are raw differences in the shore experience of officers who leave relative to those who stay. These differences are highlighted in table 3. Out of over 5500 men in the Royal Navy for which we have at least five years of naval history, over 2300 exit on a voluntary basis during the period 1879–1905. We also observe more exits for those with a great deal of shore experience in the latter part of the sample (the "modern-era" navy).

Table 3: Separations in the Royal Navy

	1879-1890		1891-1905		1879-1905	
	stayers	leavers	stayers	leavers	stayers	leavers
experience in 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)
# observations in group	24864	1195	35439	1114	60303	2309

4 Econometric Model

The labour 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).[6] In general, this model connects job exit decisions to the distributions of external and internal job offers, experiences acquired over time, internal wages and job tenure.

4.1 Topel and Ward job separations

The empirical model begins with the primal assumption that naval officers base retention decisions on the maximization of the net present value of lifetime wealth. Wage "offers" from external opportunities ($\bar{w}$) generate from a known distribution and potentially vary as careers

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

progress.[7] Let x represent the human capital from experience on the job. Only $0 < \delta < 1$ of this capital can be transferred to an external job. The distribution of external offers depends of this observable experience and is defined by

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

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

Within the Royal Navy 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. Promotions relate to seniority, merit and availability of openings (more on this in the next section). Promotions were also likely related to the type and amount of fleet experience as demonstrated in table 2.[8]

Without a promotion, Royal naval 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, or awaiting further orders without a current assignment. Pay also depended on if an officer was licensed in navigation, gunnery or torpedoes. Officers in command often received a wage bump. For Royal 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. Wage increases from stagnation depended on the rank and to some extent the period (full details available upon request). In any case, these potential within-rank

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[7] Such "offers" can be viewed loosely, and may include the benefits of remaining out of work and living on one's own means.

[8] Glaser and Rahman (2011, 2014) 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.

interval wage bumps were well known to all officers in advance.

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

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

As Mortensen (1988) details, a higher current wage increases the entire distribution of internal offers such that stochastically $F_w(\cdot) < 0$. If internal wage growth is non-increasing (concave) with tenure, 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 (1) and (2) jointly capture the characteristics of the current career outcome of the officer, given his set of alternatives. With both sides of the labour 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 an external offer $\bar{w}$, and human capital transferability of $0 < \delta < 1$, an exit from service 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 position (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 $r(w, s, x, t)$ exists such that

$$v(r(w, s, x, t), s, \delta x, 0) = v(w, s, x, t). \tag{3}$$

Any external sector offer $\bar{w}$ exceeding the reservation wage leads to a job separation from the Navy.[9]

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[9] 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

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

$$h(w,s,t,x) \;=\; \pi Prob(\bar{w} > r(w,s,t,x)) \;=\; \pi\left[1 - G(r(w,s,t,x))\right] \; . \tag{4}$$

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

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

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

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

Given the assumption of concave wage-profiles over time from on-the-job general training, $r_t < 0$ for $t > 0$. All else equal, exiting service becomes optimal over time as external positions 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 the Navy 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.

$r_w(\cdot) > r_s(\cdot)$. We do not analyze this additional prediction here.

Finally, the effect of human capital accumulated from different experiences on the hazard is given by

$$h_x(w, s, t, x) \;=\; -\pi g(r; x) r_x(w, s, t, x) \;=\; -\pi G_x(r; x)\ . \tag{7}$$

We allow for the possibility that different types of jobs (shore service, ship service and command) all may have different effects on the hazard. Presumably $G_x > 0$ for experience with more firm-specific human capital (where δ is low), and $G_x(\cdot) \leq 0$ for more generally transferable forms of human capital (where δ is high). Note that because of severe wage rigidity (where wages do not equal marginal products), we can separately estimate h_x and h_w.

If accumulated experience has a linear effect on the mean of log wage offers, and the reservation wage follows from an officer's current wage, then (5) and (7) 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. In other words, it is the "bribe" the Navy would need to pay the offer to remain in service for being exposed to the experience.[10]

4.2 Estimation

We estimate (4) 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.[11] Assuming covariates remain constant on the intervals between time periods t

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[10] For discussion purposes later in the paper, the estimates for $h_w(\cdot)$ and $h_x(\cdot)$ are the partial derivatives of (8) with respect to internal wages, w, and years of experience, x. See Topel and Ward (1992) for more detail on this method of imputation.

[11] 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.

and $t+1$, the specification of the log-likelihood function used to estimate the model for N officers follows as:

$$log\ L(\gamma,\beta)\ =\ \sum_{i=1}^{N}[\phi_i log\left[1-exp\left\{-exp\left[\mathbf{x}_i(T_i)'\beta_x+\gamma(T_i)\right]\right\}\right]\ -\ \sum_{t=1}^{T_i-\phi_i} exp\left[\mathbf{x}_i(t)'\beta_x+\gamma(t)\right]]\ . \tag{8}$$

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[12]. Step-function intervals define the experience spline for years $[6, 10), [11, 15), ..., [31, 35)$. The job tenure spline generates from estimates of γ[13]. 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 shore positions, controls for physical constitution[14], and year fixed effects. Alternative specifications include controls for unobserved individual-specific heterogeneity.[15]

5 Results

5.1 Wealth does not influence job duration

First, before we estimate the full hazard model described in the previous section, we wish to explore other factors related to one's background that could potentially influence the

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[12] Due to the limited number of observations remaining in the data beyond the thirty-fifth year of service, we limit the career time-frame to thirty-five years.

[13] 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.

[14] 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.

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

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

duration of service in the Navy. To that end we link for a subset of officers the number of servants that the officer had as a child.[16] We can also link for some others the number of servants the officer had after leaving service. Number of servants in the household can serve as a convenient proxy for family wealth (Howe et al. 2011). Given Royal naval officers tend to originate from rather privileged backgrounds, one might wonder if those of greater privilege tend to have shorter naval careers.

Logit (where the dependent variable indicates in officer is an engineer) and OLS (where the dependent variable is the total years of naval service) regression results are displayed in Table 4. Here we observe that engineers tend to originate from poorer households. This makes sense, given the rather strong social class distinctions during this time in England, as well as the general disdain line officers felt for their engineer counterparts.

Table 4: Relationships between wealth and work

Dep. variable:	engineer	engineer	duration of service	duration of service	duration of service
servants in childhood home	-1.606*** (0.00)	–	-0.010 (0.95)	–	–
servants in any home		-0.911*** (0.00)		-0.030 (0.84)	-0.003 (0.98)
engineer	–	–	–	–	0.954 (0.61)
N	191	245	191	245	245
R^2	–	–	0.00	0.00	0.001
χ^2	95.42***	67.47***	–	–	–
F-stat	–	–	0.00	0.04	0.15

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Yet despite this class distinction, engineers do not appear to leave service any earlier or later than their more wealthy compatriots (this is echoed in our duration analysis, results not reported). Further, wealth as proxied by number of domestic servants does not predict duration of service either. In short it appears that wealth is not a big factor in deciding whether or not to stay in the Navy.

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[16] We first link the officer's name to the Royal Naval Officers' Service Records Index, 1756-1931, provided by ancestry.com. From here we can link to UK census records, 1841–1911. Match rates tend to be rather low, on average around 15 percent. We restrict our attention to all officers who exit before becoming eligible for a naval pension.

5.2 Experiences in the Navy tend to be firm-specific

Next, we look to see the effects of various experiences in the Navy on career retention. Part of our motivation stems from trying to understand the degree of firm-specificity in naval experiences. To that end we first run logistic regressions where the dependent variable indicates that the erstwhile officer had been externally employed.[17]

Results are displayed in Table 5. First, we see that the longer one serves in the navy, the less likely one will work after exiting service. When we control for the officer's age upon exit, this result essentially goes away, and age upon exit appears as the dominant factor.[18] In any case, lock-in appears to occur fairly early — the older you are when you leave service, the less likely you are to ever work again. By the time one reaches 30 years of age, it becomes very improbable one will do anything else. The skills one might have accumulated in naval service, if any, appear not to be used very often in external employment.

Table 5: Factors affecting work after service

	(1)	(2)	(3)	(4)
duration of service	**-0.215*****	**-0.035**	**0.134**	**0.266**
	(0.00)	**(0.83)**	**(0.55)**	**(0.31)**
age upon exit	–	**-0.298***	**-0.428***	**-0.568***
		(0.05)	**(0.04)**	**(0.03)**
age in 1901	–	0.021	0.021	0.033
		(0.39)	(0.51)	(0.33)
total shore experience	–	-0.537	-0.336	-0.345
		(0.27)	(0.49)	(0.48)
total sea experience	–	0.174	0.149	0.146
		(0.06)	(0.13)	(0.14)
total command experience	–	0.226	0.171	0.176
		(0.35)	(0.47)	(0.45)
servants in all homes	–	–	-0.042	-0.028
			(0.45)	(0.60)
engineer	–	–	–	0.966
				(0.24)
N	245	245	183	183
χ^2	87.263***	90.470***	61.676***	61.676***

Dependent variable is indicator on whether erstwhile officer worked after service. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Further, different activities done in the navy do not appear to predict labour participa-

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[17] Here we also use UK census records. Specifically, we observe the censuses of 1891, 1901 or 1911, depending on the officer's date of exit. We mark the person as not working if they list their occupation as a retired naval officer or if they are "living on own means" for all census records found.

[18] We measure age in months. For those entering the Navy in any particular year, age might vary by a couple of years at most.

tion after service. All told, experiences in the navy do not appear to be used for gainful employment elsewhere (that is, evidence suggests δ described in section 4.1 is low). This constitutes our first piece of evidence that skills accumulated in the Royal Navy during this time were quite firm-specific.

Note that this shows that retention can be important not just for the firm, but for macroeconomic efficiency, since exiting workers who have served for some time, conceivably accumulating valuable skills, fail to contribute to economic production afterwards.

Next, we estimate the hazard model described by (4) to observe more deeply the firm-specificity of specific experiences in the Navy. Results are displayed in Table 6. Note that here we focus in particular on sea and command experience — we discuss earnings effects in the next section.

Table 6: Hazard-ratios for separations for
Royal naval officers

	sample		
variable	**full**	**officers**	**engineers**
log(earnings)	**0.167*****	**0.188*****	**0.392*****
	(0.000)	**(0.000)**	**(0.000)**
shore experience	1.105***	1.151***	1.056*
	(0.000)	(0.000)	(0.032)
ship experience	**0.941*****	**0.936*****	**0.929*****
	(0.000)	**(0.000)**	**(0.000)**
command experience	**0.967****	**0.967***	**0.974**
	(0.003)	**(0.034)**	**(0.151)**
years in same rank	1.041***	1.038***	1.050***
	(0.000)	(0.000)	(0.001)
years of additional schol/training	0.916*	0.936	0.851
	(0.019)	(0.113)	(0.065)
eligible for retirement	1.846***	2.650***	–
	(0.000)	(0.000)	
sick/disability	2.229***	3.293***	1.920***
	(0.000)	(0.000)	(0.001)
χ^2	2556.0***	1577.5***	1042.4***
individual events	61376	41770	19606
personnel : separations	5566:2280	3973:1448	1804:832

Exponentiated coefficients; p-values in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Odds-ratios reported with p-values in parentheses.
Estimates over (under) 1 suggest higher (lower) likelihood of exit. Standard errors clustered by cohort of first year as a Sub-Lieutenant or Assistant Engineer.

First, let us note that stagnation within the same rank leads to a higher likelihood of exit. Controlling for such stagnation is important for interpreting our estimated effects from experience. Interestingly, we also see that years of additional schooling or training indicates a lower likelihood of exit. Of course schooling in this context was primarily the Royal Naval College, an institution explicitly designed to inculcate firm-specific skills.[19]

More importantly for our discussion here, the cumulative time served out at sea lowers the probability of exit. Each year of *past* sea experience lowers the likelihood of exit by roughly 6 percent. Serving time out on vessels, of obvious critical importance to the Navy involving a variety of naval-specific tasks, appears to lock-in officers to their naval careers.

Command experience likewise lowers the probability of exit. For officers this is mostly associated with command of a vessel. For engineers command was mainly confined to shore positions. Overall then it seems that experience aboard vessels help keep naval personnel in the service. The claim would be that this is a firm-specific type of human capital accumulation, one that officers indeed signed up for, and so we would expect higher retention to those who get more of it.

However, task assignments made by firms are almost always endogenous, with certain jobs going to certain people. The literature is rich with cases. Rosen (1978) develops a model of firms and workers matching based on the tasks firms need done and the comparative advantage of workers in performing each of these tasks. Rosen (1986) models firms and workers matching based on employee preferences. Gibbons, Katz, Lemieux and Parent (2005) highlights the importance of assigning workers to their most productive sector. And Gibbons and Waldman (2006) develop a model where workers accumulate task-specific human capital, so that a person's job assignment has important effects on the next assignment. These papers highlight the difficulty in estimating the impact of task assignment on retention. The current skills of the workers (Rosen 1978), the preferences of the workers (Rosen 1986) and the skills they will accumulate (Gibbons and Waldman 2006) are potential considerations for the firm

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[19] This would be a far cry from the service academies of the United States today, liberal arts and baccalaureate colleges teaching a wide variety of subject matter.

as it assigns tasks, and all can play important roles in the decision of workers to quit. Furthermore, Topel and Ward (1992) focuses on changing jobs, rather than tasks assigned within each job, and so does not address the potential endogeneity of task assignment.

5.2.1 Instrumenting for Ship Assignment and Experience

We have argued that job assignments in the Navy involve much randomness that lends itself nicely to studying the effects of job experience on worker exit. The randomness stems from the need of officers to man vessels when they become operationable and available. This is particularly true with regards to shore and sea duties. The exigencies of naval operations compel leadership to use what labour resources happen to be available with respect to the manning of vessels and the filling of billets.[20] Naval capital quite literally comes and goes; the labour that must accompany it must be immediately available upon departure. This creates a great deal of noise that thwarts any effort at purely specializing in any one set of tasks. We exploit this randomness more formally by instrumenting for ship assignments using the number of launching ships in the port to which the officer is stationed.

First, we instrument for cumulative ship service. Specifically, we estimate in a first stage an officer's cumulative ship service as predicted by the cumulative number of ships prepared to launch to sea in the station where the officer himself is stationed.[21] This approach captures the variation of officer "exposure" to launching vessels. If the officer is not stationed at a port, a value of zero is assigned.[22] Officers dropped off at one port will have a greater likelihood of more sea service if that port has many ships about to embark. This exploits the extent to which naval operations and global strategy exogenously impact each officer's career trajectory.

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[20] Given capital-skill complementarities, the numbers of officers needed for each deploying vessel were quite rigidly defined (Glaser and Rahman 2014).

[21] Stations are Aberdeen, Chatham, Devonport, Glasgow, Greenock, Portsmouth, Pembroke, and Sheerness. These are ports spread widely over England and Scotland. Chatham and Sheerness are close enough to be considered a single station, which we do in alternate specifications.

[22] Because our data come from annual registers, we cannot capture brief stays at naval stations for certain officers. In these cases officers may appear to transfer vessels without the intermediate step of docking at shore.

Table 7 demonstrates some of these first stage estimates (first two columns — the final two columns instrument for ship technology, which we describe more fully in section 5.4. We use as an instrument either the cumulative number of launched ships from a station, or the total displacement of launched ships from a station.

Table 7: Relationships for first-stage estimates

Instrument	Dependent variable Cumulative ship service	 Cumulative ship service	 Cumulative displacement	 Cumulative horsepower
Cumulative no. of launched ships	0.672*** (0.008)	–	–	–
Cumulative disp. of launched ships	–	0.00016*** (<0.000)	–	–
Average cum. disp. of docked ships	–	–	0.752*** (0.004)	–
Average cum. hp of docked ships	–	–	–	0.825*** (0.004)
number of observations	62612	62612	62612	62612
R-squared	0.126	0.095	0.427	0.508
F-stat	7761.8***	5700.5***	30011.7***	39929.6***

Robust standard errors. p-values in parentheses.

There are no pre-packaged instrumental variable procedures specifically designed to take survival time into account. There are however a number of possible approaches. We demonstrate two of these here. First, we perform a two-stage predictor substitution procedure (Greene and Zhang 2003). In the first stage the relationship between officer exposure to launching vessels on the likelihood of sea service is estimated via Probit. The resulting fitted exposure status replaces the actual increases in ship service in the survival model.[23] Results are displayed in Table 8, where the first stage alternatively uses the cumulative number of launched ships and the cumulative displacement of launched ships. Estimates are fairly consistent between the instrumented and un-instrumented versions.

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[23] Alternatively we perform the two stage residual inclusion model proposed by Hausman (1978), where the residuals from the first stage are included in the second. Results are very similar (not reported).

Table 8: Hazard-ratios for separations —
instrumenting for ship experience using two-stage model

variable	Regression-type **Survival model**	**2SPS model** **Cum. no. launched ships**	**2SPS model** **Cum. disp. launched ships**
ship experience	**0.941***** **(<0.000)**	**0.986** **(0.202)**	**0.968***** **(0.003)**
log(earnings)	0.982*** (<0.000)	0.981*** (<0.000)	0.981*** (<0.000)
engineer (dummy)	0.826 (0.135)	0.838 (0.408)	0.834 (0.367)
shore experience	1.105** (0.014)	1.046*** (0.004)	1.045*** (0.001)
command experience	0.966*** (0.008)	0.931*** (<0.000)	0.932*** (<0.000)
years in same rank	1.04*** (<0.000)	1.029*** (<0.000)	1.030*** (<0.000)
years of additional school/training	0.916* (0.019)	0.865** (0.006)	0.865*** (<0.000)
sick/disability	2.241*** (<0.000)	2.067*** (<0.000)	2.055*** (<0.000)
eligible for retirement	1.844*** (<0.000)	1.817*** (<0.000)	1.810*** (<0.000)
year effects	yes	yes	yes
baseline splines (4 years)	increasing	increasing	increasing
individual events	61376	61376	61376
personnel : separations	5566:2280	5566:2280	5566:2280

Incidence rate ratios reported with p-values in parentheses. Estimates over (under) 1 suggest higher (lower) likelihood of exit. Standard errors clustered by cohort of first year as a Sub-Lieutenant or Assistant Engineer.

Alternatively, we can estimate the model as a Poisson regression when time is discrete.[24] We demonstrate results in Table 9.[25] In the first column we demonstrate that the Poisson regression in fact produces the same estimates as the standard survival model. We then use IV Poisson GMM to perform the two-stage instrumental procedure. Once again, estimates are quite similar.[26]

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[24] See the following posted forum discussion: https://www.statalist.org/forums/forum/general-stata-discussion/general/1375220-instrumental-variable-in-cox-regression.

[25] Standard errors are either clustered or bootstrapped, with little change.

[26] We also run all specifications using a standard two-stage least squares approach. Estimates remain quite similar. This also allows us to explicitly run weak identification and under identification tests; we reject the null in all cases (all results available upon request).

Table 9: Hazard-ratios for separations —
instrumenting for ship experience using IV Poisson

	Regression-type		
variable	**Poisson**	**IV Poisson GMM**	**IV Poisson GMM**
ship experience	**0.941*** **	**0.968**	**0.931** **
	(<0.000)	**(0.168)**	**(0.011)**
log(earnings)	0.982***	0.982***	0.983***
	(<0.000)	(<0.000)	(<0.000)
shore experience	1.105***	1.1079***	1.115***
	(<0.000)	(0.004)	(<0.000)
command experience	0.967**	0.950**	0.973
	(0.003)	(0.004)	(0.178)
years in same rank	1.04***	1.036***	1.044***
	(<0.000)	(<0.000)	(<0.000)
years of additional school/training	0.916*	0.893**	0.925
	(0.019)	(0.006)	(0.06)
sick/disability	2.241***	2.161***	2.271***
	(<0.000)	(<0.000)	(<0.000)
eligible for retirement	1.844***	1.839***	1.845***
	(<0.000)	(<0.000)	(<0.000)
year effects	yes	yes	yes
baseline splines (4 years)	increasing	increasing	increasing
individual events	61376	61376	61376
personnel : separations	5566:2280	5566:2280	5566:2280

Incidence rate ratios reported with p-values in parentheses.
Estimates over (under) 1 suggest higher (lower) likelihood
of exit. Standard errors clustered by cohort of first year
as a Sub-Lieutenant or Assistant Engineer.

5.3 Increases in earnings help with retention, but promotions help more

Recall that Table 6 presents estimates from the basic hazard model. From this we can observe that increases in earnings always lowers the probability of exit. This is consistent for both officers and engineers, as well as different sub-periods (not shown). Specifically, a one percent increase in internal earnings decreases the likelihood of exit by one to two percent.[27] *Homo economicus* appears to have been alive and well in the Royal Navy, a comforting thought to at least some of us.

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[27] Note that the odds ratio for wages is calculated by taking the exponential of the estimated hazard divided by 100.

But how much of the wage effect on retention is due to promotions, as opposed to monetary incentives? The question of how firms should structure pay for the optimal retention of workers is explored in Lazear and Shaw (2007). To explore this further we strip away the wage component that relates to one's rank, and keep the portion that relates to everything else (sea pay, rank stagnation pay, license bonuses, etc.). We call this "after-rank earnings." Results are presented in Table 10.

Table 10: Hazard-ratios for separations with "after-rank" earnings

variable	sample **full**	 **full**	 **officers**	 **engineers**
log(after-rank earnings)	**0.854***** **(0.000)**	**0.856***** **(0.000)**	**0.863***** **(0.000)**	**1.271***** **(0.000)**
current rank		0.745*** (0.000)	0.772*** (0.000)	0.718*** (0.000)
shore experience	1.103*** (0.000)	1.107*** (0.000)	1.173*** (0.000)	1.043 (0.099)
ship experience	0.936*** (0.000)	0.941*** (0.000)	0.937*** (0.000)	0.924*** (0.000)
command experience	0.937*** (0.000)	0.951*** (0.000)	0.951** (0.002)	0.980 (0.272)
years in same rank	1.065*** (0.000)	1.044*** (0.000)	1.048*** (0.000)	0.982 (0.243)
years of additional school/training	0.896** (0.003)	0.906** (0.008)	0.931 (0.090)	0.803* (0.012)
eligible for retirement	1.943*** (0.000)	1.679*** (0.000)	2.847*** (0.000)	–
sick/disability	3.783*** (0.000)	2.702*** (0.000)	4.518*** (0.000)	1.606* (0.012)
χ^2	2326.1***	2417.3***	1509.8***	1093.9***
individual events	61678	61678	42072	19606
personnel : separations	5566:2280	5566:2280	3973:1448	1804:832

Exponentiated coefficients; p-values in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Odds-ratios reported with p-values in parentheses.
Estimates over (under) 1 suggest higher (lower) likelihood of exit. Standard errors clustered by cohort of first year as a Sub-Lieutenant or Assistant Engineer.

Here we see that the pecuniary rewards of work that are unrelated to promotion do not have nearly the same impact as pay raises related to an increase in rank. To appreciate how important promotion is for retention, we calculate compensating variations for various rewards.

First, note from Table 6 that a cumulation of shore duty experiences raises the probability of exit. The effects appear to be stronger for officers than for engineers. These duties include for example serving in lighthouse inspection, or within a naval bureau or department. While we cannot observe specific jobs, we can distinguish between those performing shore tasks from those merely on shore leave. These shore positions may leave officers feeling less valuable or appreciated, or may be viewed as hindering their naval careers (see discussion in Lazear and Gibbs 2014, pp. 73). When it comes to retaining personnel, the deep blue sea to which our title refers is preferable to the dockyard.

Thus despite their relatively aristocratic backgrounds, it appears line officers were not content with sinecure positions away from naval action. Our exercises here measure the pay raise that would be necessary to undue the negative retention effects of shore duty on officers. Results are presented in Table 11.

Table 11: Compensating variation calculations of shore duty

	h_w full wage	h_x/h_w full wage	h_w after-rank wage	h_x/h_w after-rank wage	h_s/h_w after-rank wage
all personnel					
estimate	0.0177***	-0.055***	0.0015***	-0.656***	-0.280***
(p-value)	(<0.000)	(<0.000)	(<0.000)	(<0.000)	(<0.000)
officers					
estimate	0.0165***	-0.084***	.0014***	-1.081***	-0.315***
(p-value)	(<0.000)	(<0.000)	(<0.000)	(<0.000)	(<0.000)
engineers					
estimate	0.009***	-0.058	–	–	–
(p-value)	(<0.000)	(0.063)			

Use of coefficients from tables 6 and 8.
One-sided significance indicated as *** if $p \leq 0.001$, ** if $p \leq 0.01$ and * if $p \leq 0.05$.

If we take the baseline hazard model for officers shown in Table 6 and look at the effect of $log(wages)$ (first column), we see that a one percentage point increase in wages translates into a 1.7 percent decrease in the likelihood of exit. Note that this is remarkably similar to Topel and Ward (1992), who find that a 10 percent within-career increase in the wage reduces the probability of changing jobs by about 20 percent.

If we perform a "rate of return" calculation similarly done in Topel and Ward (1992) (second column), we show that the navy would need to pay personnel around 5.5 percent more when they are on shore duty to offset the risk of exit (this is 8.4 percent for line officers only). Note however that Topel and Ward's analysis can not observe the *form* of the wage increase — wage bumps due to promotion, or bonuses, or automatic wage bumps due to tenure.

However, if you strip away the increase in rank and just look at the money, a one percent increase in the wage produces only a 0.15 percent decrease in the likelihood of exit for officers, and for engineers more money essentially does nothing to the likelihood of exit. You would have to pay officers over 100 percent more wages to retain them when they are on shore duty.

The primary lesson here is that promotions are very important for keeping personnel. We feel this is a useful exercise; after all, "money isn't everything, but everything can be expressed in terms of its monetary equivalent" (Lazear and Oyer 2012). This also echoes findings of the tournament theory produced by Lazear and Rosen (1981), where prizes are fixed in advance and depend on relative rather than absolute performance. Much like here, they demonstrate that the prize from the tournament is far more valuable than the monetary rewards outside of the tournament. Finally this demonstrates an alternative approach to understanding salary/benefit trade-offs.[28]

Further, note (also from Table 6) that staying at the same rank also boosts the change of exit. Based on our calculation in Table 11, the navy would need to pay officers an additional 32 percent to compensate them for not getting promoted each year.

One issue which can arise is that promotions may be endogenous. To address this we exploit a feature of officer data —personnel are arranged by order of when they join the service. The initial order is not a function of officer merit in any way. So we can characterize

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[28] See for example Olson (2002), which estimates that married women will accept a 20 percent salary reduction in return for health insurance. Stern (2004) shows that scientists are willing to accept substantial wage decreases to engage in on-the-job research.

promotions as either "meritocratic" (where the order has been disrupted and an officer who is lower in the order gets picked for promotion) or "mechanical" (where the officer gets promoted simply because it is his "turn."). We do this and show results in Table 12.

Table 12: Hazard-ratios for separations with different types of promotion

	sample				
variable	**full**	**full**	**full**	**full**	**full**
change in rank	0.669** (0.001)	–	–	–	–
merit based promotion	–	0.701** (0.006)	–	0.564*** (0.000)	0.696** (0.005)
mechanical promotion	–	–	**0.419*** **(0.048)**	**0.292*** **(0.014)**	**0.404*** **(0.045)**
current rank	0.737*** (0.000)	0.733*** (0.000)	0.724*** (0.000)		0.737*** (0.000)
shore experience	1.125*** (0.000)	1.126*** (0.000)	1.125*** (0.000)	1.117*** (0.000)	1.125*** (0.000)
ship experience	0.932*** (0.000)	0.932*** (0.000)	0.930*** (0.000)	0.929*** (0.000)	0.932*** (0.000)
command experience	0.952*** (0.000)	0.952*** (0.000)	0.952*** (0.000)	0.936*** (0.000)	0.952*** (0.000)
years in same rank	1.039*** (0.000)	1.039*** (0.000)	1.042*** (0.000)	1.058*** (0.000)	1.039*** (0.000)
years of additional school/training	0.899** (0.004)	0.899** (0.004)	0.897** (0.003)	0.888** (0.001)	0.899** (0.004)
eligible for retirement	1.752*** (0.000)	1.768*** (0.000)	1.739*** (0.000)	2.068*** (0.000)	1.739*** (0.000)
sick/disability	3.186*** (0.000)	3.173*** (0.000)	3.086*** (0.000)	4.539*** (0.000)	3.179*** (0.000)
χ^2	2317.2***	2314.1***	2309.7***	2231.8***	2318.5***
individual events	62612	62612	62612	62612	62612
personnel : separations	5566:2280	5566:2280	5566:2280	5566:2280	5566:2280

Exponentiated coefficients; p-values in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Odds-ratios reported with p-values in parentheses. Estimates over (under) 1 suggest higher (lower) likelihood of exit. Standard errors clustered by cohort of first year as a Sub-Lieutenant or Assistant Engineer.

Certainly we might consider merit-based promotions to be endogenous. Individuals who receive such promotions have been deemed by naval leadership as those with high potential, and indeed it may very well be this potential that keeps them in service. Mechanical promotions however occur with no regard to officer-quality — they occur based on where the officer is in the rank order, and the number of available slots positioned for promotion, neither of which are influenced by individual officer-quality. Indeed it appears that this form of promotion tends to matter more for retention. Thus we have a fairly unique way of capturing the effects of promotion on retention that are distinct from worker skill or quality considerations. In short promotions are a critical element in retaining personnel.

5.4 Modernization can threaten retention

Another benefit of studying this era and organization is it provides an opportunity to study an organization undergoing technological change and upheaval. Nearly every aspect of naval operations changed during the 19th century. From sail to steam, wood to metal, ropes to chains, cannonballs to explosive shells, what officers experienced in service to the Royal Navy evolved slowly, then all at once. We can thus explore how the changing nature of tasks through modernization can influence job exits.

For modern firms turnover is typically higher in industries where technology advances more rapidly (Lazaer and Gibbs 2014). Turing to our case, a common concern among naval leaders of the time was that the officer corps was *increasingly* ill-equipped and ill-prepared to take control of the changing modernizing navy (Marder 1961). One possible test then would be to interact each cumulative experience measure with the year of service. Results for this are presented in Table 13.

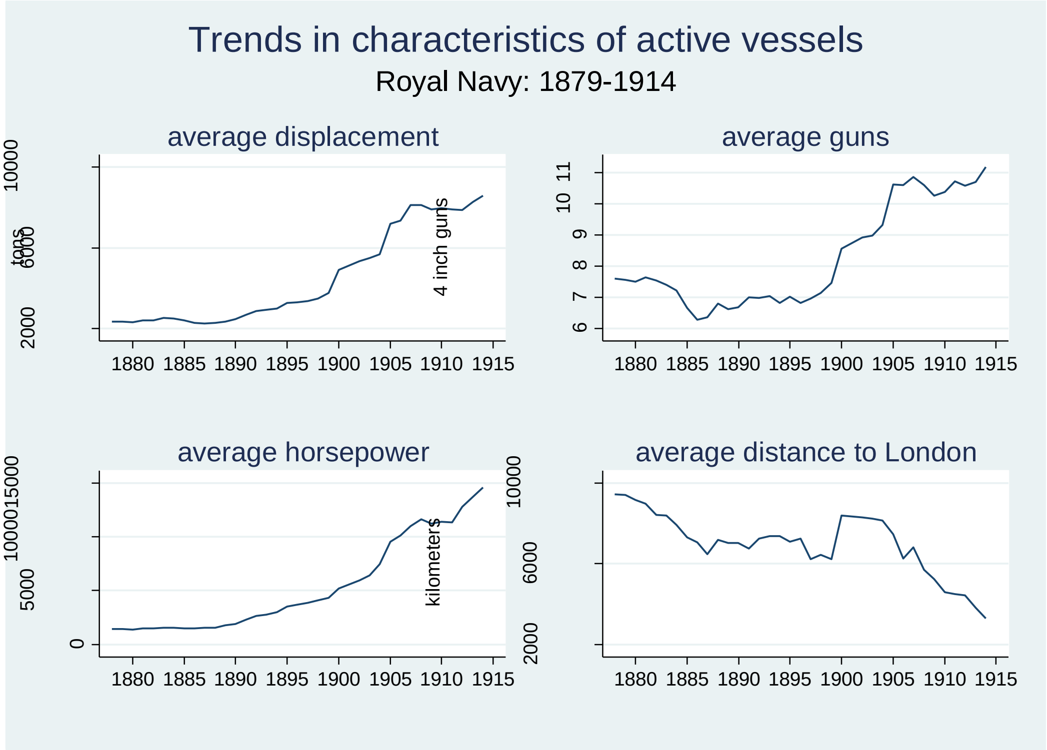
Table 13: Hazard-ratios for separations with time trend and time interactions

	sample		
variable	**full**	**officers**	**engineers**
log(earnings)	0.164*** (0.000)	0.215*** (0.000)	0.157*** (0.000)
time	1.002 (0.750)	0.987 (0.067)	1.040*** (0.001)
shore experience	1.026 (0.624)	0.672** (0.008)	1.083 (0.191)
shore experience*time	1.003 (0.320)	1.022*** (0.000)	0.998 (0.592)
ship experience	0.833*** (0.000)	0.823*** (0.000)	0.860*** (0.000)
ship experience*time	**1.005***** **(0.000)**	**1.005***** **(0.000)**	**1.000** **(0.843)**
command experience	0.915** (0.001)	0.901* (0.023)	0.882*** (0.001)
command experience*time	**1.004**** **(0.006)**	**1.004** **(0.073)**	**1.008***** **(0.000)**
years in same rank	1.046*** (0.000)	1.049*** (0.000)	1.052*** (0.001)
years of additional school/training	0.859*** (0.000)	0.890** (0.007)	0.774** (0.003)
eligible for retirement	1.888*** (0.000)	2.771*** (0.000)	–
sick/disability	2.084*** (0.000)	3.279*** (0.000)	1.380 (0.101)
χ^2	2707.6***	1674.0***	1113.8***
individual events	61376	41770	19606
personnel : separations	5566:2280	3973:1448	1804:832

Exponentiated coefficients; p-values in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Odds-ratios reported with p-values in parentheses. Estimates over (under) 1 suggest higher (lower) likelihood of exit. Standard errors clustered by cohort of first year as a Sub-Lieutenant or Assistant Engineer.

Notice that the year itself doesn't matter for retention, it is the year interacted with what the officer does that matters. Both service on ships and command experiences have weaker effects on retention over time. Could this have to do with the modernizing Navy? Newer ships built by the Royal Navy grew larger and faster, especially after 1890 (see figure 4), and larger vessels inevitably meant more sophisticated engineering systems in place (McBride 2000). Indeed displacement and horsepower are the most reliable proxies for ship technology during this period (Modelski and Thompson 1988).

Figure 3: Trends in Average Vessels



Source: Authors' calculations.

Thus we see that for later periods the positive effect on ship service on retention dissipates, likely due to the modernization that the Navy is undergoing. To explore this further we look at the technologies that are embedded in the ships, by looking at the displacement and horsepower of the vessels assigned to officers. We can also instrument for this. Particularly during the latter 19th century, bigger vessels meant more complex vessels, as the engineering systems needed to manage all parts of ship operations grew exponentially intricate (Modelski and Thompson 1988).

Our instrument for exposure to ship technology is the average technology (displacement or horsepower) of all ships stationed in the port where the officer himself is stationed. If the officer is not stationed at a port, a value of zero is assigned. First stage estimates are reported in Table 7. Once again we execute the instrumentation using both the 2SPS model (Table 14) and the IV Poisson GMM (Table 15). Instrumented or not, we see that cumulative exposure to superior ship technologies enhances the likelihood of exit. In alternative specifications we also control for the cumulative distance traveled on ships — this does not seem to affect hazards, nor does it affect our key findings. Once again, experiences with technically-oriented tasks appear to be a key driver in raising exit rates.

Table 14: Hazard-ratios for separations — instrumenting for ship technology using two-stage model

	sample			
variable	**Survival model**	**Two-stage survival model**	**Survival model**	**Two-stage survival model**
cumulative displacement	**1.008***** **(<0.000)**	**1.021***** **(<0.000)**	–	–
cumulative horsepower	–	–	**1.008***** **(<0.000)**	**1.013***** **(<0.000)**
earnings	0.982*** (<0.000)	0.981*** (<0.000)	0.982*** (<0.000)	0.982*** (<0.000)
engineer (dummy)	0.810 (0.278)	1.119 (0.586)	0.813 (0.266)	1.029 (0.861)
tech shore duty experience	1.087*** (<0.000)	1.162*** (<0.000)	1.079*** (<0.000)	1.141** (<0.000)
ship experience	0.908*** (<0.000)	0.875*** (<0.000)	0.909*** (<0.000)	0.895*** (<0.000)
command experience	0.984 (0.17)	0.978*** (0.025)	0.980** (0.026)	.976*** (0.006)
years in same rank	1.041*** (<0.000)	1.040*** (<0.000)	1.042*** (<0.000)	1.041*** (<0.000)
years of additional school/training	0.907** (0.009)	0.882*** (<0.000)	0.899** (0.004)	0.889*** (<0.000)
sick/disability	2.34*** (<0.000)	2.242*** (<0.000)	2.31*** (<0.000)	2.23*** (<0.000)
eligible for retirement	1.91*** (<0.000)	1.837*** (<0.000)	1.92*** (<0.000)	1.836*** (<0.000)
year effects	yes	yes	yes	yes
baseline splines (4 years)	increasing	increasing	increasing	increasing
log likelihood	-2037	-2020	-2036	-2031
individual events	61376	61376	61376	61376
personnel : separations	5566:2280	5566:2280	5566:2280	5566:2280

Incidence rate 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 15: Hazard-ratios for separations —
instrumenting for ship technology using IV Poisson

	sample			
variable	**Poisson**	**IV Poisson GMM**	**Poisson**	**IV Poisson GMM**
cumulative displacement	**1.008***** **(<0.000)**	**1.041***** **(<0.000)**	–	–
cumulative horsepower	–	–	**1.007***** **(<0.000)**	**1.018***** **(<0.000)**
earnings	0.982*** (<0.000)	0.979*** (<0.000)	0.982*** (<0.000)	0.981*** (<0.000)
tech shore duty experience	1.087*** (<0.000)	0.998 (0.944)	1.079*** (<0.000)	1.044** (0.026)
ship experience	0.908*** (<0.000)	0.756*** (<0.000)	0.909*** (<0.000)	0.862*** (<0.000)
command experience	0.984 (0.17)	1.076*** (<0.000)	0.980 (0.085)	1.000 (0.97)
years in same rank	1.041*** (<0.000)	1.037*** (<0.000)	1.042*** (<0.000)	1.043*** (<0.000)
years of additional school/training	0.907** (0.009)	0.870*** (<0.000)	0.899** (0.004)	0.875*** (<0.000)
sick/disability	2.34*** (<0.000)	2.96*** (<0.000)	2.31*** (<0.000)	2.42*** (<0.000)
eligible for retirement	1.91*** (<0.000)	2.40*** (<0.000)	1.92*** (<0.000)	2.06*** (<0.000)
year effects	yes	yes	yes	yes
baseline splines (4 years)	increasing	increasing	increasing	increasing
log likelihood	-8495	–	-8494	
individual events	61376	61376	61376	61376
personnel : separations	5566:2280	5566:2280	5566:2280	5566:2280

Incidence rate 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.

Note that estimates are stronger for IV specifications, perhaps indicating that naval leadership assigned certain personnel to vessels to raise retention. Concerns over retention were widely discussed among naval brass. 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.[29] 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

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[29] See Brasseys 1893, 1895, 1899, 1900, 1903, 1904.

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). We echo this sentiment in our hazard model estimates with one caveat — experience with new ships equipped with unfamiliar designs and techniques may have first required a bit more book knowledge in advance.

5.5 Peers can induce others to exit

Finally, we look to see if officer exits could be contagious. Naval operations involve a great deal of group interactions. Peers can positively impact the productivity of others. This has been demonstrated for example with workers in the steel industry (Gant, Ichniowski and Shaw 2003) and among supermarket clerks (Mas and Moretti 2006). They can also produce "bad" behavior, as documented in Ichino and Maggi (2000) for Italian bank workers. The effect of peers on worker retention however has to our knowledge not been explored.

For this exercise we construct the variable *peers-exiting-1-yr-ago*, which is the number of officers with whom this officer had served in the past on the same active vessel (or land station) who exited naval service a year ago. *Peers-exiting-2-yr-ago* is the number of officers that this officer served with on the same active vessel (or land station) who exited two years ago, and so on. Results of this exercise are given in Table 16.

Table 16: Hazard-ratios for separations with different peer effects

	peers at sea	**peers at sea**	**peers at sea**	**peers on land**	**peers on land**	**peers on land**
peers exiting 1 year ago	1.002 (0.888)	0.996 (0.784)	0.989 (0.411)	1.005 (0.286)	1.006 (0.432)	1.008 (0.320)
peers exiting 2 year ago	–	1.013 (0.314)	1.004 (0.746)	–	0.993 (0.431)	0.994 (0.497)
peers exiting 3 year ago	–	1.027 (0.056)	1.018 (0.220)	–	1.006 (0.500)	1.003 (0.795)
peers exiting 4 year ago	–	–	**1.033*** **(0.023)**	–	–	**0.976*** **(0.029)**
peers exiting 5 year ago	–	–	**1.035*** **(0.026)**	–	–	**1.020** **(0.056)**
peers exiting 6 year ago	–	–	1.014 (0.419)	–	–	1.009 (0.407)
shore experience	1.119*** (0.000)	1.124*** (0.000)	1.128*** (0.000)	1.122*** (0.000)	1.122*** (0.000)	1.124*** (0.000)
ship experience	0.926*** (0.000)	0.920*** (0.000)	0.910*** (0.000)	0.925*** (0.000)	0.925*** (0.000)	0.925*** (0.000)
command experience	0.936*** (0.000)	0.939*** (0.000)	0.943*** (0.000)	0.936*** (0.000)	0.936*** (0.000)	0.936*** (0.000)
years in same rank	1.065*** (0.000)	1.064*** (0.000)	1.064*** (0.000)	1.065*** (0.000)	1.065*** (0.000)	1.065*** (0.000)
years of additional school/training	0.885*** (0.001)	0.884*** (0.001)	0.880*** (0.001)	0.886** (0.001)	0.886** (0.001)	0.885*** (0.001)
eligible for retirement	2.158*** (0.000)	2.167*** (0.000)	2.180*** (0.000)	2.162*** (0.000)	2.162*** (0.000)	2.166*** (0.000)
sick/disability	4.496*** (0.000)	4.510*** (0.000)	4.492*** (0.000)	4.511*** (0.000)	4.514*** (0.000)	4.520*** (0.000)
χ^2	2198.6	2203.7	2216.8	2199.7	2200.4	2208.6
individual events	62612	62612	62612	62612	62612	62612
personnel : separations	5566:2280	5566:2280	5566:2280	5566:2280	5566:2280	5566:2280

Exponentiated coefficients; p-values in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Odds-ratios reported with p-values in parentheses. Estimates over (under) 1 suggest higher (lower) likelihood of exit. Standard errors clustered by cohort of first year as a Sub-Lieutenant or Assistant Engineer.

In short, peers who exit can indeed induce others to exit. Interestingly, we see this for peers having served on the same ship, but not on the same land station. This may reasonably suggest that ship jobs involve more interactions among the crew. Results are not large and they occur with a notable delay — an officer has a roughly 3.5 percent higher likelihood of exiting service if they had a shipmate exit 4–5 years ago. Nevertheless, these results give some evidence that a cascade of exits can occur when workers interact closely with one another.

6 Conclusion

This paper attempts to update our knowledge of personnel economics by delving into an organization in many ways ideally suited for such a study. Given random assignments of tasks and random opportunities for promotion, we ask how promotions, payouts, positions, and peers influence retention. We produce a number of unique findings contributing to this important literature.

Analyzing royal naval officers, we can focus on a single organization with cleaner identification than most firms. Yet we think results are generalizable for us to glean important lessons for those concerned with human resource retention in any firm. The navy recounts for us a cautionary tale — where promotion opportunities are few, where technological changes alter many aspects of traditional work, where workers are assigned tasks that are not related to the primary mission of the organization, and where personnel work tightly with each other and form strong peer-to-peer bonds, retention problems may abound.

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