Human Capital and Technological Transition - Insights from the U.S. Navy

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Abstract

This paper explores the effects of human capital on workers during the latter 19th century by examining the specific case of the U.S. Navy. During this time, naval officers belonged either to a regular or an engineer corps and had tasks assigned for their specialized training and experience. To test the effects of specialized skills on career performance, we compile educational data from original-source Naval Academy records for the graduating classes of 1858 to 1905. We merge these with career data extracted from official Navy registers for the years 1859 to 1907. This compilation comprises one of the longest and earliest longitudinal records of labor market earnings, education and experience of which we are aware. Our results suggest that wage premia for "engineer-skilled" officers rapidly deteriorated over their careers; more traditionally skilled officers were better compensated and promoted more frequently as their careers progressed. This compelled those with engineering skills to leave the service early, contributing to the Navy's failure to keep up with the technological frontier of the time.

- *Keywords*: human capital, Industrial Revolution, naval history, tournaments
- *JEL Codes*: J24, M5, N31, N41, N71, O33

1 Introduction

This paper explores the effects of human capital on individual workers during the second Industrial Revolution (roughly 1860-1910) by examining the specific case of the United States Navy during the latter 19th century. This period is a critical juncture in our economic history, for many modern skill-intensive technologies can trace their roots to the turn of the 20th century (see for example Mokyr 1990, 2002; O'Rourke et al 2008). Understanding the Industrial Revolution and economic growth in history requires us to understand the interactions between human capital and technological change. For example, theories on "unified growth"[1] and "appropriate" technological change[2] make precise, sometimes heroic assumptions on how technologies and skills interact in order to better understand why so many industries or economies fail to reap the rewards of industrialization. Without careful study of specific personnel and the firms in which they work, we can only speculate over these relationships, and theorize in a manner more ad hoc than we would like (Lazear and Oyer 2009).

Unfortunately our knowledge of this period is limited; individual-level data on human capital collected consistently over time are typically not available for any period prior to the second half of the *twentieth* century.[3] Arguably then, this is a great arena to explore the historic role of technical skill, for navies have been both excellent indicators and creators of a nation's economic and technological capabilities.[4]

In fact navies have typically led technological developments for the wider economy (O'Brien 2001). Instead the post-bellum Navy gives us an informative case study of an industry *struggling* with technological transition. Specifically, innovations in propulsion, hull construction and ordnance increasingly raised the importance of "engineer-oriented" skills among naval officers; at the same time disgruntled naval engineers felt undermined and marginalized by the profession (Bennett 1896, McBride 2000). At a time when engineering and mechanical training was rising in importance throughout the whole economy, can we learn from the Navy's ostensible schizophrenia concerning such training?

The analysis of the naval profession affords us a unique opportunity to understand the role of human capital in a specific labor market during a period of uncertain technological transition. During this time officers played in separate "promotion tournaments" - each officer belonged to either the regular corps or an engineer-specific corps, with different duties leading to separate career paths. Given these different tournaments, we ask a number of questions. What kinds of technical skill correlated with naval career success? Did officers with specialized engineering training and skill fare better than officers with more general or traditional training? And how did career success evolve over the length of one's career?

We answer these questions by first compiling data on naval officers documented in the

[1] See for example Galor and Weil 2000, Galor and Mountford 2008, Galor 2009

[2] See for example Basu and Weil 1998, Acemoglu and Zilibotti 2001

[3] The earliest example of a study linking individual schooling and experience data of which we are aware comes from the Iowa State Census of 1915, skillfully exploited by Goldin and Katz 2000. Aldrich 1970 has a very interesting study that tracks the earnings of West Point graduates during the ante-bellum period, but not their educational profiles.

[4] The person who mockingly named economics "the dismal science" would nevertheless have appreciated gleaming broader economic insights from military history: "For we are to bethink us that the Epic verily is not *Arms and the Man*, but *Tools and the Man* - an infinitely wider kind of Epic" (Carlyle 1843).

U.S. Navy registries. These registry books, arranged in annual volumes, chart the rank, station and pay of every serving naval officer over time. We match this data with the scores these officers earned in different subjects as students at the Naval Academy (compiled in the Naval Academy registers) as well as data tracking the characteristics and stations of the fighting ships to which each officer was ultimately assigned each year. The final merged longitudinal dataset provides us one of the earliest examples of detailed individual measures of education, experience and work performance of which we are aware. Furthermore, while studied and discussed extensively by naval historians, this data has hitherto never been codified, and thus has never been systematically studied.

Using these data we conduct some empirical exercises; these uncover a number of results concerning the effects of skill on officer careers. First, those with engineering skill tend to leave the service earlier than those without. This is true whether we measure skill *extensively* (comparing engineer officers with regular line officers) or *intensively* (comparing line officers with varying engineering ability). On the other hand, those with more "traditional" naval skills tend to stay in the service longer. We suggest that a main cause for this was that the Navy did not adequately reward those with "modern" skills and instead rewarded those with traditional skills. Specifically, we see that those on engineer-oriented career paths earn relatively higher wages early on, but that these premia rapidly deteriorate due to fewer promotion opportunities. On the other hand, regular line officers appear to be on a more meritocratic career path; there are more opportunities for promotion, and those with higher orders of merit are promoted earlier and are "fast-tracked." Taken together, the Navy's promotion tournament set-up does not seem to be ideally suited to handle the forces modernization - its rigid payment structure undermined the relative earnings of those individuals whose skills were in high demand in other industries, while rewarding those with traditional skills likely to remain in the Navy anyway. This surely contributed to the Navy's inability to keep up technologically, not only relative to other modernizing industries in the U.S., but also relative to other major naval powers around the world.

The next section of the paper discusses the historic background in more detail. We then describe the data collected and some of the empirical tests, and present our econometric results.

2 Background

Depending on institutional arrangements or cultural beliefs, technological change can make certain groups chary or cheerful, and can entrench or dislodge interested parties (Grief 2005, North 2004). This can potentially threaten progress and lead to technological stagnation.[5] The recorded history of the U.S. Navy grants us a fascinating look at an industry undergoing technological upheaval. We can learn about the historic challenges of technological transition in general by studying the Navy's workforce, its job and promotion structure, and its response to the engineering-based changes occurring in the overall economy.

[5] After all, the promoters of the new technologies must first "dislodge the entrenched, persuade the skeptic, and reassure the fearful" before such technologies can be adopted (Mokyr 2005).

2.1 A Navy in Transition

The technological transition of the Navy was "engineering-biased"

The epilogue to the age of sail could be seen in the experiences of two burgeoning global powers - Russia's experience in the aftermath of the Crimean War and the United States' experience in its civil war (Smith 1937).[6] Even before the Civil War growing reliance on steam power was evident - in November 1860 Congress announced its plans to convert seven of the navy's sailing ships to steam power, at a cost of $3,064,000 (Sweetman 1984). In the meantime England, the paragon of all things naval, was rapidly transforming its navy into one propelled predominantly by steam (Bennett 1896).[7] In fact it appeared that all the other leading naval powers were abandoning the old guilds of ship constructors for the new engineering discipline of naval architecture (Barnaby 1960). A major reason for this was that the global naval renaissance beginning in the 1870s was a switch in overall strategy, from the *guerre de course* focus on commerce raiding and limited warfare to more ambitious *guerre d'escadre* approaches of global power projection (McBride 1992). This of course meant going up against the British, which required these naval powers to emulate their engineer-oriented naval technology.

All this suggests that naval technical progress was becoming *engineer-biased* - that is, it was raising the importance of engineers and constructors relative to their line-officer counterparts in the modernizing fleet.[8] This kind of modernization required a new corps of officers that would function as inspectors and constructors of machinery (Bennett 1896). The transition underway was a big one - it required thinking of warships as an amalgamation of machines (a "weapons system"), and this struck many in the U.S. as incompatible with the warrior-ethos and aristocracy dear to naval traditionalists (McBride 2000). Indeed developments in steam propulsion, metallurgy, and naval ordnance was transforming the very nature of naval professional life. Because of this many American line officers viewed technological advances as destructive rather than progressive (Coletta 1987).

The Navy marginalized and alienated these same engineers

An irony of U.S. naval history is that the Engineering Corps shared the privileges of rank and status with regular naval officers only in the *ante*-bellum Navy; as engineering skill increased in importance after the Civil War, their privileges deteriorated (Calvert 1967). This seems contrary to endogenous growth stories told in the "directed technical change" literature, where "engineering-biased" technological transition should *heighten* the status and privileges of engineers (Acemoglu 1998, 2002). Instead naval engineers continually protested that they enjoyed neither the rights nor the duties to which they were entitled. Complaints

[6] The maintenance of blockades during the Civil War seems to owe much of its effectiveness to naval engineers (Davis and Engerman 2006).

[7] Since the English shaped the naval technological frontier, the U.S. certainly took note in 1870 when junior Lord of Admiralty Geoffrey Hornby bid farewell "to wooden ships, to sails and yards, to the old Navy of Nelson's time...henceforth came the era of steam and iron, of torpedoes and electricity; of what is called Science *versus* the keen observation which gained every advantage possible to be taken from wind and weather, and which used to be called Seamanship" (Smith 1937).

[8] See for example Griliches 1956, Bartel and Lichtenberg 1987, and Goldin and Katz 1998 for estimated micro effects of skill-biased technological change.

ranged from alleged pecuniary imbalances between engineers and non-engineers, as well as non-pecuniary indignities such as lack of wardroom privileges, insufficient living and eating accommodations, and interference in engineering work by line officers (Calvert 1967).

Much of the difficulties for engineers stemmed from the anti-steam orthodoxy that erupted from the wake of technological change.[9] Many traditionally-minded officers believed that technological transition created a contamination within the "gentlemanly" officer corps with non-gentlemanly mechanics (Karsten 1972). Others feared the loss of control over weapons and the means of propulsion; technological changes would require officers to rely on mechanics, subordinating their role in core operations to a "non-aristocratic" engineer corps (McBride 2000). Consequently naval leadership rigidly controlled the activities of those best suited to lead the Navy through its technological transition, stressing instead their subservient role. This was designed to "prevent the engineering tail from wagging the sea dog" (McBride 2000).

Even Alfred Mahan, the celebrated champion of the big and technologically sophisticated navy, dismissed the engineer corps as "those who snored away below while line officers fought the ship" (McBride 2000). Others referred derisively to engineers as "wipers" and "greasers" (Coletta 1987). Perhaps in order to highlight the separate roles of engineer and line officers and to avoid further disharmony, a bill passed in 1871 which defined "relative ranks" for engineers; these relative ranks were in effect until the Amalgamation Act of 1899 (Calvert 1967). The result was in effect to create a separate career path for engineers, one (as we will see) with limited promotion potential relative to line officers.

2.2 Naval Education and The Pre-Amalgamated Line

The Navy was divided between line officers and staff (engineer) officers

During the latter half of the 19th century nearly every new officer in the navy was a graduate of the Naval Academy. Always striving to be a mirror of the navy itself, the academy sought to design a curriculum with the express technological and personnel needs of the naval profession. The challenge was calibrating the proper mix of technical engineering courses with traditional seamanship and navigation training. The primary debate was over the question of whether all officers needed to be engineers as well as sailors, or whether a certain amount of specialization could take place between engineer and line officers. Proponents of the former approach included Secretary of the Navy Gideon Wells, who back in 1863 rhetorically asked "whether every officer of the line ought not to be educated to and capable of performing the duties that devolve upon engineers."[10]

The Department of Steam Enginery was developed by Admiral Porter, Superintendent of the Academy, to attempt to make all future officers engineers as well. Blocks of academic time were set aside for engineering instruction, and during the summer cruise of 1866 the midshipmen alternated watches between the engine room and on deck. But this was an utter failure from the start. The midshipmen showed very little interest in the engineering courses, and their engineering performance on cruise was so abysmal that the approach was altogether abandoned. Steam stayed in the curriculum, but the academy made no subsequent attempts

[9] See for example Morrison 1966, Calvert 1967, Buhl 1974, Albion 1980, and McBride 2000.

[10] Annual Report of the Secretary of the Navy 1863.

at qualifying all the midshipmen as engineers (Sweetman 1979).

As a result of both this failed experiment and the tensions among traditional officers and engineers, a heterogenous officer core emerged, where line officers and engineer officers performed mostly separate functions and competed in their own promotion tournaments. In order to accommodate this specialization among personnel, the Naval Academy developed a separate corps of cadet engineers who were instructed separately from the other midshipmen during the last two years of their studies.

There were three phases during the 19th century when this was attempted. In 1868, sixteen cadets were appointed acting third assistant engineers and began a two-year engineer-oriented course of study. This program was discontinued after one year, but a new group of cadet engineers was subsequently admitted. From 1872 until 1882 the academy consistently graduated engineer officers along with line officers, offering them a "relative rank." The Personnel Act discontinued this separate line of training, but it was resumed with the act's repeal in 1889, and so from 1894 to 1899 the academy continued to graduate and commission engineer officers. Finally came the Amalgamation Act of 1899, whereby engineer officers were absorbed into a new "amalgamated" line, to be evaluated and promoted by the same criteria as for line officers. Thereafter all newly minted officers were allegedly skilled enough to perform any task aboard any vessel. This shift in organizational strategy was prompted by a study made under the auspices of Assistant Secretary of the Navy Theodore Roosevelt. The amalgamation ostensibly eliminated the independent corps of line and engineer officers, for according to Roosevelt "on the modern war vessel, every officer has to be an engineer whether he wants to or not" (McBride 2000).

Engineer officers had incentives to leave the Navy; line officers had incentives to stay

We argue that the U.S. interbellum period of the latter 19th century produced many incentives (both "carrots" and "sticks") for naval engineers to leave the corps for alternative pursuits compared with their line-officer counterparts.

Of course the ever-shrinking size of the fleet in the two decades after the Civil War limited promotional possibilities for *all* officers. By the early 1880s Annapolis graduates took as long as eight years to make ensign (Sweetman 1979).[11] Congress's rather blunt solution to this imbalance was the Personnel Act of 1882, which stipulated that the number of officers annually commissioned could be no greater than the number of vacancies that had opened up in the previous year. Those who were chosen to be commissioned were picked on the basis of class standing. Those who were not received a diploma, a severance package of $950, and an honorable discharge. Of the 305 Academy graduates from 1882 to 1887, only 136 remained past their second year of service. Although it is impossible to know exactly who among these were directly affected by the act and who merely "were driven out of the service by the discouraging outlook,"[12] it is clear that the fortunes of all officers in all classes were tied to technological developments and naval funding.

Were those with engineering skills disproportionately hurt? This remains an empirical question, but one could argue that while the Navy was treating engineering skill with hostility

[11]Ensign is the lowest rank for a naval line officer, ranking just ahead of midshipman.
[12]NY Times article, December 7, 1892

and relegating it to a mere trade, it was increasingly being viewed in other industries as an important profession (Calvert 1967). An "engineering culture" spread across the greater economy, marrying engineering skill with entrepreneurship, which paid well and attracted engineers of all stripes (Goldstone, forthcoming). And mechanical engineers, as opposed to their civil engineering brethren, were entrepreneurally inclined, and thus likely to join private industry if it was considered more remunerative (Calvert 1967).[13]

Thus compared to regular officers, engineers had greater incentives and opportunities to pursue employment in alternative industries. For example, dozens were given temporary assignments as professors at engineering schools - the great need for engineering education in civilian schools compelled many to resign their commissions and become permanent instructors (Calvert 1967). Others sought more profitable employment in private industry, such as a number of naval engineers who, after demonstrating their technical skill at the Midwinter Fair in San Francisco in 1894, were offered civilian machinist jobs (Bennett 1896). Further, these engineers and constructors could more effectively engage in "reputation pooling" by joining reputable firms and organizations with less hostility towards the engineer profession (Brennan and Pettit 2004).

2.3 Delays in Technological Transition

The result of this technological wrangling coupled with separate officer promotion structures was a decline in the overall effectiveness of the service (Karsten 1972). The officer core (and by extension the Congress) was divided over virtually everything; questions over general naval strategy, proper building materials for ships, proper metals for gun construction, and the appropriate method of propulsion consumed naval dialectics for decades. These internecine battles between the different corps only delayed the inevitable transition to a mechanical-engineer oriented navy. The dilemma of course was that the construction and operation of first-rate ships would necessary privilege engineers and naval constructors; those who were loathe to do to so became technological reactionaries, and as the Navy increasingly filled with their ranks, progress stalled (McBride 2000).

Delays in naval technological progress are well documented. This delay was perhaps most clearly embodied in the Navy's reluctance to abandon sailing techniques. In 1869 the Navy Department directed the return of full sail power for all ships (Coletta 1987). After this an awkward compromise resulted in new war vessels being equipped with both sail and steam rigging, provoking Rear Admiral Thorton A. Jenkins to proclaim the fleet to be a "heterogenous mass of naval incongruity miscalled a navy" (Scott 1986). Shipbuilders were forced to design vessels that would accommodate two incompatible propulsion systems, and officers were forced to familiarize themselves with both.

Technological compromise continued up to the turn of the century. The "ABCD" ships of 1883 (the Atlanta, Boston, Chicago and Dolphin), trumpeted for their steel hulls and steam-powered propulsion systems as technological marvels and harbingers of a modernizing fleet, still incorporated traditional sail rigs. Even the USS Texas and USS Maine, commissioned in 1895 as the nation's first modern battleships, were designed to carry sails in order to

[13]In 1905 engineer Henry Towne went so far as to tell students at Purdue University that "the dollar is the final term in every engineering equation" (reported in *American Machinist*, July 20, 1905).

complement their steam engines and extend their cruising radii (McBride 1992). The navy continued to install both sail and steam technology on warships until 1904, when the USS *Intrepid* became the last sail-rigged ship to be decommissioned (Coletta 1987).

A related area of technological uncertainty was the advance in metallurgy that allowed the transition from wood to metal ships. Again, a smooth transition was thwarted by internal debate among top naval brass. Guided by the various factions in the Navy, Congress contributed to the delay, which was generally unwilling to spend money on guns and warships that would likely be obsoleted in a short period of time (Scott 1986). On the other hand, many other congressional leaders held the antithetical but equally misguided viewpoint that the fleet consisted of highly durable and long-lasting vessels. John Ericsson, himself a celebrated naval engineer, proclaimed that "vessels like the monitors are good for fifty years." Such "false but soothing" advice failed to acknowledge that technological change demanded constant military adjustments to military capital (Roberts 2002).

All this serves as a cautionary tale for industries on the cusp of modernization. The suspicion held by traditionalists over steam powered vessels and the engineers necessary to produce and operate them brought about the ebbing and outright decline of American naval power, ushering in the Navy's "Dark Ages" (Albion 1980). Bradley Fiske, a line officer and inventor, testified before the Senate Naval Affairs Committee in 1908 that technological advance was thwarted by the lack of appreciation for the engineer, and the failure of officers to "correlate the military and the engineering arts" and to understand that "relations ought to exist between the two" (McBride 1992). The separate promotion structures only deepened this divide. To glean further insight into this industry in relative decline, we look into the fortunes of these two groups of officers in the following sections.

3 Human Capital and Technological Transition in the Navy

3.1 Framework

Given the history outlined above, we can consider the Navy as an industry with workers embodied with two general types of skills - traditional skill and modern (engineering) skill. Workers can embody both types of human capital, and technological changes can potentially be biased towards either.

The workers we consider in our study are U.S. naval officers. During the latter 19th century, line officers had more traditional skills and were engaged in a promotions tournament, while engineers and naval constructors had more engineering skills and were involved in separate tournaments. As detailed in section 2.1, technological changes during this time were clearly *engineering-biased*. Such changes would suggest that engineers and naval constructors became more valuable to the Navy.[14] At the same time, one could imagine that

[14]The idea that certain skills can help in coping with technological change dates back to at least Nelson and Phelps (1966) and Welch (1970), who suggest that education can yield higher returns in an environment with more rapid technological growth. More recent studies such as Krueger and Kumar (2004) suggest that only workers with "general" education can operate new, risky technologies, whereas workers with "vocational" education are relatively more effective in operating old, established technologies.

the traditional skills embodied in line officers eroded in relative importance.[15]

This general framework however does not take into account the bureaucratic structure of the industry, or the various struggles between the labor-types. Given the institutional context, which kinds of skills actually thrived in this environment is the question to which we now turn.

3.2 Empirical Strategy

Our basic empirical strategy is to test the effects of education and experience on various measures of career performance. These include the length of service an officer has in the Navy (*duration*), the wages an officer earns over a certain period of time (*earnings*), and the probability that an officer gets promoted (p).[16]

To get some idea of how education influenced the length of officer careers, we run the following specification:

$$duration_i \ = \ A \ + \ \gamma' x_{1i} \ + \ \mu_i \ , \tag{1}$$

where $duration_i$ is the number of years officer i is in the service, γ' represents a vector of parameters, μ_i is a random disturbance term, and x_{1i} gives a subset of officer i's human capital characteristics. These can include an *extensive* measure of skill (engineer officer versus not), or *intensive* measures of skill (overall or subject-specific percentile scores earned at the Academy, in subjects such as steam engineering, seamanship, ordnance and gunnery, and navigation). x_{1i} also includes the variable $sick_i$, an indicator variable equalling one if officer i is on sick leave at any time during his service, and the variable $leave_i$, an indicator variable equalling one if officer i is on leave at any time during his service. Finally, we include dummies for each graduating class of the Naval Academy. Because the fortunes of each graduation class varied dramatically (due to appropriation differences year to year, number of vessels year to year, and so forth), this is potentially an important control to include.[17]

For our wage analysis, our basic empirical strategy is to test the effects of education and experience on an aggregation of wages within a stylized Mincerian framework. We run the following:

$$ln \ (earnings)_{i,rs} \ = \ B \ + \ \delta' x_{2i} \ + \ \varepsilon_i \ , \tag{2}$$

where *earnings* is given by the expression

[15]See for example Galor and Weil (2000) and Galor and Moav (2000), who suggest that at least a portion of human capital dissolves away with technical progress.

[16]Unfortunately we are unable to track workers once they leave the Navy except for the handful of former officers we have been able to track down from census records.

[17]Glaser and Rahman (2010) develop a fully-specified survivor framework to estimate the job separation probabilities of these officers. This requires a more extensive analysis using both experience and external wage measures. Here we aim merely to establish some "stylized facts" concerning the relationships between Academy education and career lengths. Nonetheless, our survivor analysis fully confirm the results of the more simple model presented here.

$$earnings_{i,rs} = \sum_{t=r}^{s} wage_{it}$$

Here r is the chosen *starting* year and s is the chosen *final* year of officer i's wage history. The dependent variable is thus simply a summation of annual wages for a pre-chosen period of time. Because wages are documented only once a year in our data, we use a summation of wages to get a more accurate estimate of what each officer truly earned. Further, pay differences among officers were primarily a function of different occupations and ranks. The "schedule" of pay among the different ranks, however, remained remarkably consistent through the period we are analyzing. Table 1 provides a portion of the schedule of the annual wages paid to line officers and engineer officers during the late-19th century.[18]

[18]Other positions not reported in the table include the various ranks for marines, paymasters, naval constructors, and even professors (these were typically instructors at the Naval Academy). These positions also had specific pay schedules that varied according to rank and length of tenure.

Table 1: Annual wages for selected naval officers and personnel in 1899 (contemporary dollars)

	at sea	on shore duty	on leave or waiting orders
Rear Admiral	6000	5000	4000
Captain	4500	3500	2800
Commander	3500	3000	2300
Lieutenant Commander			
first 4 years	2800	2400	2000
after 4 years	3000	2600	2200
Lieutenant			
first 5 years	2400	2000	1600
after 5 years	2600	2200	1800
Lieutenant junior grade (master)			
first 5 years	1800	1500	1200
after 5 years	2000	1700	1400
Ensign			
first 5 years	1200	1000	800
after 5 years	1400	1200	1000
Midshipman (cadet)	500	500	500
Chief Engineer			
first 5 years	2800	2400	2000
second 5 years	3200	2800	2400
third 5 years	3500	3200	2600
fourth 5 years	3700	3600	2800
Passed Assistant Engineer			
first 5 years	2000	1800	1500
second 5 years	2200	2000	1700
third 5 years	2450	2250	1900
fourth 5 years	2700	2350	1950
Assistant Engineer			
first 5 years	1700	1400	1000
after 5 years	1900	1600	1200

This pay depended on the type and rank of the officer, the length of time he has been at that rank, and his duty (broadly classified as "at sea," "on shore duty" and "on leave or waiting orders"). In order to construct earnings profiles, we match each officer's type, rank and duty station to the appropriate wage, constructing a time series of annual wages particular to each officer. To create a career earnings measure that varies among the officers, we aggregate these wages across time, ultimately capturing year to year variation in jobs, ranks, experience, and responsibilities (e.g. command). If the officer serves on a vessel during a particular year, we cross reference information on the ship to which he was assigned - if the ship is dry-docked, in ordnance, or otherwise incapable of being launched for sea service, we allocate shore duty pay for the officer.

δ' represents a vector of parameters, ε_i is a random disturbance term, and x_{2i} gives a subset of officer i's education and experience characteristics. Again, these can include either extensive or intensive measures of education. To capture some measure of past work experience, we also include the number of years (out of a total of r years) officer i spends assigned to a naval vessel assigned to *national* waters (which we call "brown sea experience"), the number of years out of r years officer i spends assigned to a naval vessel assigned to *international* waters (which we call "blue sea experience"), and the number of years out of r years officer i is in some command position (either of a vessel or a bureau). Here we also include graduating-class dummies.[19]

One thing to point out is that for this exercise we can only count those officers who actually serve up to year s. If many officers leave the service before that point, a selection issue arises that biases results. To check for the robustness of results to selection issues, we alternatively produce *Heckit* estimates (Heckman 1976). The sample selection mechanism is:

$$z^*_{i,s} \;=\; C \;+\; \phi' x_{3i} \;+\; \nu_i \;, \qquad x_{3i} \supset x_{2i} \tag{3}$$

where $z_{i,s}$ is an indicator variable equalling one if officer i remains in service for at least s years, ν_i is a random disturbance term, ϕ' is a vector of parameters, and x_{3i} is a superset of x_{2i}. Beyond what is in x_{2i}, we also include in x_{3i} an indicator variable equalling one if officer i had ever been sick or received naval hospital treatment any time up to year r of his career, an indicator variable equalling one if officer i had ever been on a leave of absence any time up to year r of his career, and a measure of past external wages provided by Brown and Brown (1968). These measures serve as potential predictors of early separation. The sample rule is that $earnings_{i,rs}$ is observed only when $z^*_{i,s}$ is one.

Ultimately this leads to estimates for the conditional expectation

$$E\left(ln\ (earnings)_{i,rs}\,|z_{i,s}=1\right) \;=\; B \;+\; \delta' x_{4i} \;+\beta_\lambda \lambda_i \;+\varepsilon_i \;, \qquad x_{4i} \subset x_{2i} \tag{4}$$

where λ_i is the inverse Mills ratio generated from (3). Note that x_{4i} is a subset of x_{2i}; this is because we only include officer i's steam engineering percentile in x_{4i}, excluding all other subject percentile scores. This is to isolate the effects of engineering skill on officer's earnings, using *all* subjects to model the sample selection mechanism.[20]

Finally, by changing r and s, we can gauge *changes* in the relationship between human capital and earnings over the course of one's career. This way we can compare how different skills are remunerated over time. Using wages as one metric of career success, we can compare across all the officers in our sample.

We would also like to know how our skill and experience measures directly affect rates of promotion. However because different career tracts have different promotion structures, we can only compare line officers with other line officers, and engineer officers with other engineer officers. Specifically, after commissioning from the Naval Academy, line officers began careers as ensigns (o-1). From this, they could advance through the ranks of lieutenant

[19]While typical Mincerian regressions also include personal characteristics like age, gender, and years of education, the officers in our sample have little to no variability in these traits.

[20]As we will see in the results section, other subjects besides steam engineering do not significantly affect earnings, but can significantly affect the length of one's service, making them ideal for inclusion in (3). The variable *sick* does have some predictive power over earnings, but only very early in one's career. Glaser and Rahman (2010) show that both *sick* and external wages are strong predictors of early separation.

junior grade (o-2), lieutenant (o-3), lieutenant commander (o-4) and commander (o-5)[21]. For a line officer's rank w_i, we analyze the probability of promotion using a reduced form ordered categorical model. That is, the latent variable w_i^* determining the likelihood of promotion is defined

$$w_i^* \;=\; A \;+\; \theta' x_{5,i} \;+\; \epsilon_i \;, \tag{5}$$

$$w_i \;=\; p \;, \quad if \;\; b_{p-1} < w_i^* < b_p \;, \qquad p = 1, ..., P-1 \;, \tag{6}$$

where the random disturbance ϵ has a logistic distribution, θ' represents a vector of parameters, and $x_{5,i}$ once again gives a subset of officer characteristics. The ranges defined by b_0 to b_{P-1} represent latent value thresholds of the function in (5) necessary for officers to achieve promotions. When $w_i^* < b_0$, officers were in the lowest rank[22]. As w_i^* increased, officers passed thresholds $b_0, b_1, ..., b_{P-1}$ and received promotions to the next rank.

$x_{5,i}$ includes Academy generated human capital (either as an order of merit percentile or a dummy variable indicating the officer was in the top 10% of his Academy class) and human capital accumulated over time within the fleet. Again this includes cumulative ship experience in both international and national waters and cumulative experience in command of a ship or in charge of a station. Additional dummy variables control for fixed effects during the periods prior to 1868, from the years 1868 − 1887, and for years after 1887.[23]

4 Data

We use data on naval officers compiled by the Navy Register and housed in the National Archives. Arranged by year, each volume contains the names of officers, their rank, and their duty or station. This information was compiled by the navy at the beginning of each year (typically January or February). Figure 1 illustrates the number of officers we track through these registers, arranged by class year.

Each navy register also maintains a list of active naval vessels, their present duty or station, and basic ship characteristics such as rate, number of guns and displacement. For each officer serving aboard a particular vessel we cross reference these ship characteristics. This allows us to determine on what kinds of vessels the officer served, and if he was in fact out to sea as opposed to serving on a docked or uncommissioned vessel. Officer assignments and ship duties changed quite frequently, which introduces a great deal of job heterogeneity

[21]More generally, for regular officers ranks range from admiral to cadet or midshipman. For engineer officers ranks range from chief engineer to cadet engineer. However, the definitions and ordering of rank for engineer and other "staff" officers fluctuates from year to year, and a clear structure of rank comparable across this frame of time does not exist.

[22]The "lowest" ranks increased as careers lengthen. For instance, the "lowest" rank for line officers with 5 years of experience was ensign (o-1), while the "lowest" rank for line officers with 20 years of experience was lieutenant (o-3).

[23]Individual class effects are not identifiable for these specifications. The motivation for including these periods are best described by Coletta (1987): "In consequence of the rapid demobilization of naval personnel following the Civil War, wartime Academy graduates rose quickly in grade until 1868. However, the retention of a number of wartime reservists and recalled regulars at the end of the war, the lack of a specified age for retirement, and continued output from the Academy meant that a promotion 'hump' persisted for the next twenty years."

into career paths and demonstrates how the Navy consistently moved officers into new duties, presumably at least in part due to differences in human capital and performance.

In order to construct earnings profiles for each officer, we combine both sets of data. Specifically, we match each officer's rank and duty station to the appropriate wage, constructing a time series of annual wages particular to each officer. If the officer served on a vessel during a particular year, we cross reference information on the ship to which he was assigned - if the ship is dry-docked, in ordinary, or otherwise incapable of being launched for sea service, we allocate shore duty pay for the officer.

Figure 2 illustrates the *average* earnings for certain graduating classes over time, both for regular officers and engineering officers. As is clear from the figure, the economic fortunes of each officer were highly sensitive to when he graduated. A graduate of the class of 1870 for example faced a crippling decline in commissioned war vessels, and so found his chances of promotion limited. A graduate of the class of 1890 on the other hand was fortunate to have a career during what now we can call a "naval renaissance." This heterogeneity compels us to include graduating class dummies or period dummies for all specifications. This allows us to compare the effects of human capital on career performance for officers who face similar career environments.

We match merge this data on officer duties, promotions and earnings to their Naval Academy records. These records, housed in the Naval Academy archives, document each midshipman's overall order of merit rank for his particular graduating class, as well as orders of merit according to a variety of specific subjects. For overall order of merit, we compile both freshman-year merit scores (arguably a measure of more general ability as freshman classes tended to be less navy-specific and more academic, with classes like basic math and science, English and composition) and final-year (the end of four years) merit scores. Engineer cadets were ranked along with regular cadets during their freshman year (since both groups took the same classes during their first year); during their final year however engineer cadets were ranked as a separate group. Each officer i's overall Academy percentile is defined as

$$Academy\ percentile_i = 1 - \frac{classrank_i}{classsize_i}$$

so that scores are scaled from zero (bottom of the class) to one (top of the class). Subject-specific scores are similarly scaled.[24]

The final data set maintains the educational profile of every graduating officer from the academy from 1858 to 1905, and information concerning their service in the navy from 1859 to 1907.[25] This is the earliest example of matched education-work experience data at the

[24]One issue we face in compiling specific subject information is the lack of exact comparability across all subjects and graduating classes. For example, four-year scores on History and Composition, Grammar, Rhetoric and Drawing only exist for the classes 1871 and 1872. Fencing was apparently deemed an unnecessary skill for effective naval service and eliminated as a required course after 1875. Further, courses were often changed around and renamed (for example, a "navigation" course could be labeled "practical navigation," or "navigation and surveying," or even "astronomy and navigation"). We choose four primary subjects to include in our specifications, both for their high comparability across class years and for their potential relevance for effective naval service; these are "steam engineering" "seamanship," "navigation" and "ordnance and gunnery."

[25]1858 is the earliest class for which we could find information; our decision to end at 1907 is essentially arbitrary.

individual level in any industry of which we are aware, and provides us a glimpse into an industry undergoing rapid and uncertain technological change during the latter 19th century.

The distribution of line-officer ranks conditional on minimal years of experience appears in table 2. From this we see a fairly wide distribution of positions.

Table 2: Density Across Rank (conditional on years served)

	minimum years of service					
rank	5 yrs	8 yrs	10 yrs	12 yrs	15 yrs	20 yrs
O-0 (midshipman)	4.31	-	-	-	-	-
O-1 (ensign)	56.57	32.63	26.00	11.86	-	-
O-2 (lieutenant j.g.)	18.74	22.40	19.96	26.18	19.23	-
O-3 (lieutenant)	20.39	36.60	45.96	52.88	66.04	74.60
O-4 (lieutenant commander)	-	8.38	8.08	9.08	10.24	18.37
O-5 (commander)	-	-	-	-	4.49	7.03
# observations	1393	1134	1027	936	801	626

Frequencies reported for line officers serving from 1858 to 1902.

Descriptive statistics for line officer covariates conditional on minimal years of experience appear in table 3. Not surprisingly the cumulative experience variables each gradually increase as years of service increases; however, the average time working in various jobs as a percentage of total years served remains fairly constant across time.

Table 3: Descriptive Statistics for Line Officers (conditional on years served)

rank	minimum years of service 5 yrs	8 yrs	10 yrs	12 yrs	15 yrs	20 yrs
ship experience (national water)	0.898 (0.914)	1.654 (1.324)	2.103 (1.488)	2.507 (1.669)	3.161 (1.964)	4.080 (2.441)
ship experience (international water)	2.578 (1.020)	3.712 (1.332)	4.389 (1.614)	5.047 (1.807)	5.924 (2.078)	7.262 (2.329)
command experience	0.017 (0.148)	0.046 (0.248)	0.069 (0.328)	0.085 (0.394)	0.171 (0.593)	0.430 (1.002)
Academy order of merit percentile	0.507 (0.281)	0.516 (0.280)	0.519 (0.279)	0.521 (0.277)	0.529 (0.279)	0.527 (0.281)
Academy order of merit top decile	0.084 (0.277)	0.085 (0.278)	0.085 (0.279)	0.087 (0.281)	0.090 (0.286)	0.097 (0.297)
# observations	1393	1134	1027	936	801	626

Mean values reported for line officers serving from 1858 to 1902 with standard errors in parentheses.

5 Results

5.1 Human capital effects on duration

We first test the length of one's service in the navy by regressing the number of years of service on measures of skill and ability, as specified in (1). This requires right-censored regressions, as we have navy register information only up to 1907, while many officers in our dataset serve in the navy well beyond that point.[26] We also exclude from the sample here any officer who dies while in service (alternatively, including a dummy variable indicating death while in the Navy does not alter any results).

[26] For the graduates of the class of 1904, for example, the dependent variable can take values of 1 or 2 (the uncensored cases) or 3 (the censored case). Thus censored points will be class-dependent. The officer graduating in 1904 who lasts for at three years is thus *top coded*.

Table 4: Right-censored estimates of effects of education on career length (all personnel excluding those who die in service)

VARIABLES	1	2	3	4	5	6
Academy percentile	-	8.5***	-	-	8.2**	-
		(1.4)			(4.1)	
first-year percentile	-	-	5.3***	-	-	1.3
			(1.5)			(2.0)
steam percentile	-	-	-	-4.1*	-5.9**	-4.8**
				(2.3)	(2.4)	(2.4)
seamanship percentile	-	-	-	5.6***	3.5	5.4**
				(2.1)	(2.3)	(2.3)
navigation percentile	-	-	-	8.2***	5.1**	8.4***
				(2.4)	(2.8)	(2.6)
ordnance percentile	-	-	-	3.2	0.82	1.7
				(2.7)	(2.9)	(2.8)
engineer (dummy)	-0.14	-0.43	-0.05	-	-	-
	(1.4)	(1.4)	(1.6)			
sick (dummy)	-5.2***	-5.3***	-5.2***	-3.7***	-3.8***	-3.7**
	(1.3)	(1.3)	(1.3)	(1.5)	(1.5)	(1.6)
leave (dummy)	4.8***	4.6***	4.0***	6.1***	6.0***	5.6***
	(1.2)	(1.2)	(1.2)	(1.4)	(1.4)	(1.4)
observations	2125	2114	1970	1604	1598	1518
right-censored observations	1092	1090	1068	887	885	881
pseudo-R^2	0.03	0.03	0.03	0.05	0.05	0.05

Dependent variable is number of years of naval officer's career (up to 1907).
Constant and class dummies not reported.
Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 5: Right-censored estimates of effects of education on career length (all personnel excluding those who die in service and/or serve fewer than three years)

VARIABLES	1	2	3	4	5	6
Academy percentile	-	1.6	-	-	2.2	-
		(1.6)			(5.1)	
first-year percentile	-	-	0.24	-	-	-1.4
			(1.7)			(2.5)
steam percentile	-	-	-	-5.9**	-6.3**	-7.0***
				(3.0)	(3.2)	(3.0)
seamanship percentile	-	-	-	5.2*	4.4	5.8**
				(2.8)	(3.0)	(2.9)
navigation percentile	-	-	-	5.4*	4.6	6.1**
				(3.0)	(3.5)	(3.1)
ordnance percentile	-	-	-	-1.4	-1.9	-2.3
				(3.4)	(3.6)	(3.5)
engineer (dummy)	-3.3**	-3.3**	-4.0**	-	-	-
	(1.5)	(1.5)	(1.8)			
sick (dummy)	-8.6***	-8.6***	-8.4***	-7.8***	-7.9***	-7.8***
	(1.3)	(1.3)	(1.4)	(1.7)	(1.7)	(1.8)
leave (dummy)	0.43	0.42	-0.51	1.4	1.4	0.23
	(1.2)	(1.2)	(1.3)	(1.5)	(1.5)	(1.5)
observations	1687	1684	1574	1219	1216	1163
right-censored observations	983	981	959	778	776	772
pseudo-R^2	0.02	0.02	0.02	0.02	0.02	0.03

Dependent variable is number of years of naval officer's career (up to 1907).
Constant and class dummies not reported.
Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Tables 4 and 5 present our first set of results. We see in Table 4, which includes all living personnel, that line officers with greater engineering skill leave early, while those with navigation and seamanship skill stay longer. This makes sense, since engineering skill was likely to be far more transferable to other industries than seamanship or navigation. We further know that those line-officers gifted in engineering were more likely to become naval constructors - this was a group held in contempt by many line officers, which may have further motivated their departure. Finally we see that overall merit has a strong positive effect on duration of service.

One complication here however is that the Personnel Act of 1882 forced the navy to discharge many midshipmen throughout the 1880s; further, as we mention in the previous section, this decision was made *primarily* on the basis of overall merit. This creates a great many number of small observations for the dependent variable and overestimates the effects of *Academy percentile*. In order to address this we rerun the same specification, but limit our observations only to those who serve at least for three years, losing roughly 400 observations. These officers would not have been directly affected by the Personnel Act. Results are reported in Table 5. Coefficients for *Academy percentile* fall to insignificance but remain positive. However, now we observe a statistically significant negative effect on duration for both extensive *and* intensive measures of engineering skill. The more engineer-gifted officers tended to leave the service a good few years ahead of the rest; the more "traditionally" skilled on the other hand tended to remain in the service longer. It is important to note that the overwhelming majority of those officers who leave the service do so *voluntarily*, in that they are characterized as having "resigned" or "retired" (as opposed to being "dismissed" or "discharged"). Thus we feel confident in suggesting that these officers "voted with their feet" in exiting the service.[27]

The next sections attempt to empirically explore *why* officers with different skills left the service at different points in their careers.

5.2 Human capital effects on earnings across all officers

We regress the logged earnings officers received over a certain interval of their careers on individual measures of education obtained at the Naval Academy and ship experience from past naval service (specification 2). We consider year r the first year of their earnings history, and year s the last year of this history. Specifically, Table 6 has $r = 3$ and $s = 7$, so that we estimate the effects of education and the first *two* years of experience on *five* subsequent years of earnings. Table 7 sets $r = 3$ and $s = 12$, so that we estimate the effects of education and the first two years of experience on *ten* subsequent years of earnings.

[27] We also run a number of alternative specifications (not reported). First, when we exclude those who die in service from the sample, our results remain virtually the same. Next, we include quadratics for the skill terms; these non-linear terms do not come in as significant. Finally, we introduce interaction terms between cohort dummies and subject performance measures to gauge potential changes in course content over time. In each case the overall skill measure fall to insignificance; however, the steam interaction terms are *all* negative with the majority of them statistically significant, while the seamanship and navigation interaction terms are mostly positive with many of these being significant, albeit with no discernible pattern.

Table 6: OLS and Heckit estimates of effects of education and experience on earnings ($r = 3$, $s = 7$)

VARIABLES	1	2	3	4	5	6	7	8
Academy perc.	0.085***	0.06***	0.06***	0.04	0.087***	0.07***	0.07***	0.06***
	(0.01)	(0.015)	(0.03)	(0.04)	(0.01)	(0.016)	(0.02)	(0.02)
first-year perc.	-	0.04***	-	0.025	-	0.04***	-	0.02
		(0.014)		(0.016)		(0.016)		(0.02)
steam perc.	-	-	0.04**	0.04**	-	-	0.05***	0.045**
			(0.02)	(0.02)			(0.019)	(0.02)
seamanship perc.	-	-	0.003	0.01	-	-	-	-
			(0.02)	(0.02)				
navigation perc.	-	-	0.01	0.009	-	-	-	-
			(0.02)	(0.02)				
ordnance perc.	-	-	-0.003	0.004	-	-	-	-
			(0.02)	(0.02)				
blue sea exp.	-0.09***	-0.09***	-0.082***	-0.09***	-0.09***	-0.09***	-0.08***	-0.09***
	(0.01)	(0.015)	(0.02)	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)
brown sea exp.	-0.07***	-0.08***	-0.07***	-0.07***	-0.07***	-0.076***	-0.07***	-0.07***
	(0.01)	(0.015)	(0.02)	(0.015)	(0.01)	(0.01)	(0.01)	(0.01)
command exp.	0.01	0.013	-0.02	-0.015	0.01	0.01	-0.02	-0.02
	(0.03)	(0.03)	(0.03)	(0.03)	(0.04)	(0.04)	(0.04)	(0.04)
engineer (dummy)	0.27***	0.30***	-	-	0.26***	0.30***	-	-
	(0.02)	(0.02)			(0.01)	(0.015)		
(Acad.perc.)*(eng.)	-0.03	-0.04	-	-	-0.03	-0.03	-	-
	(0.06)	(0.06)			(0.04)	(0.04)		
mills	-	-	-	-	0.02	0.02	0.07	0.06
					(0.05)	(0.05)	(0.05)	(0.05)
obs.	1381	1271	965	904	2358	2248	1761	1700
censored obs.	-	-	-	-	977	977	796	796
R^2	0.82	0.82	0.86	0.85	-	-	-	-
OLS estimates	yes	yes	yes	yes	no	no	no	no
Heckit estimates	no	no	no	no	yes	yes	yes	yes

Dependent variable is the logged sum of annual earnings from year 3 to year 7 of naval officer's career.
OLS estimates include only observations on those officers who serve at least 7 years.
Constant and class dummies not reported.
Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 7: OLS and Heckit estimates of effects of education and experience on earnings ($r = 3$, $s = 12$)

VARIABLES	1	2	3	4	5	6	7	8
Academy perc.	0.07***	0.06***	0.06***	0.04	0.08***	0.07***	0.064***	0.05***
	(0.01)	(0.01)	(0.02)	(0.03)	(0.01)	(0.014)	(0.02)	(0.02)
first-year perc.	-	0.02**	-	0.02	-	0.02**	-	0.02
		(0.01)		(0.015)		(0.01)		(0.015)
steam perc.	-	-	0.04**	0.045**	-	-	0.04**	0.04**
			(0.015)	(0.015)			(0.015)	(0.015)
seamanship perc.	-	-	0.0002	0.004	-	-	-	-
			(0.01)	(0.01)				
navigation perc.	-	-	0.008	0.01	-	-	-	-
			(0.01)	(0.015)				
ordnance perc.	-	-	-0.01	-0.007	-	-	-	-
			(0.02)	(0.02)				
blue sea exp.	-0.03***	-0.034**	-0.02*	-0.02	-0.015	-0.015	-0.01	-0.01
	(0.01)	(0.015)	(0.012)	(0.015)	(0.01)	(0.01)	(0.01)	(0.01)
brown sea exp.	-0.02**	-0.027**	-0.01	-0.015	-0.002	-0.01	-0.007	-0.007
	(0.01)	(0.015)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
command exp.	-0.07***	-0.07***	-0.08***	-0.08***	-0.075	-0.076	-0.08	-0.08
	(0.01)	(0.01)	(0.015)	(0.015)	(0.12)	(0.1)	(0.09)	(0.09)
engineer (dummy)	0.22***	0.28***	-	-	0.21***	0.27***	-	-
	(0.016)	(0.017)			(0.013)	(0.014)		
(Acad.perc.)*(eng.)	-0.06	-0.03	-	-	-0.07**	-0.045	-	-
	(0.05)	(0.06)			(0.035)	(0.04)		
mills	-	-	-	-	0.11***	0.088***	0.055*	0.06*
					(0.04)	(0.03)	(0.03)	(0.035)
obs.	1015	927	711	665	2358	2270	1761	1715
censored obs.	-	-	-	-	1343	1343	1050	1050
R^2	0.88	0.88	0.9	0.88	-	-	-	-
OLS estimates	yes	yes	yes	yes	no	no	no	no
Heckit estimates	no	no	no	no	yes	yes	yes	yes

Dependent variable is the logged sum of annual earnings from year 3 to year 12 of naval officer's career.
OLS estimates include only observations on those officers who serve at least 12 years.
Constant and class dummies not reported.
Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Note that for these results we only include officers who lasted at least s years in the service (so that we always measure s years worth of earnings for each officer). This however creates a selection bias, so we alternatively produce Heckit estimates (specification 4). Both tables include both OLS and Heckit estimates.

Academy percentile generally shows up as positive and significant. We can see from our 5-year measures that someone who graduates from the top of his class is predicted to earn roughly 6% to 9% more over a 5 year stretch of time compared to someone who graduates at the bottom of his class. First year relative merit, arguably a better gauge of innate general intelligence, seems to echo this. Interestingly, engineers with high Academy scores do *not* earn higher wages (captured by the Academy score-engineer dummy cross term) - it seems that the pecuniary benefits from having a high Academy order of merit fail to materialize on the engineer career path.

We also include subject specific ability measures. Engineering ability, as captured by scores in steam engineering classes, pays a premium early in one's career. Someone graduating at the top of their class in engineering makes somewhere between 4 to 5% more than someone at the bottom of the class over a 5-year period (depending on the specification). [28] Interestingly, *steam* performance is the only specific subject that generates a measurable premia for line officers.[29]

We can also see that engineer officers (no matter what their Academy standing) were paid a sizable premium; they received around 25 to 30% more over 5 years relative to line officers. Note that while most historical studies of wage premia can not control for innate ability, we can do so here. Specifically, we include first-year relative merit scores, which compare all the officers together. This also addresses another selection issue - the possibility that engineer officers were just smarter than regular line officers. We account for this in specifications 2 and 6 (testing this *extensive* measure of engineering skill), which include the first-year order of merit as an additional explanatory variable.

5.3 Relative wage declines

This gives us a sense of the magnitude of wage premia, both for more general skills and engineering skills (intensively and extensively measured). However, this gives us only a snapshot: to gauge how these premia change over the course of officers' careers, we simply increase r and s by yearly increments, and re-run all specifications. What we find is that engineering-premia decline over the early part of one's career, but has the potential to rise much later in one's career. Figures 3 and 4 display these results (for both 5 and 10 year stretches of earnings).[30] We dot those estimates that are statistically significant, include bands indicating two standard deviations from each estimate, and include 2nd-order polynomial trend-lines that highlight this non-monotonic relationship between relative earnings and engineering skill.

For at least the first two decades of an engineer-officer's career, his wage premium falls

[28]Not included are other subject areas, such as *physical science*, *political science* and *foreign languages*. None of these came in as statistically significant or altered any of the other results.

[29]We also try each specific subject one by one as well as subject-cohort effects; these terms do not show any significance.

[30]For example: notice how $s - r - 1 = 5$ for figure 3, while $s - r - 1 = 10$ for figure 4.

over time. From earning 25-30% more than his line-officer counterpart, he earns less than 10% more than twenty years later. And line officers who score at the top of their class in engineering earn roughly a 5% premium at the start of their careers but end up earning a *negative* return after twenty years or so (although this finding is not statistically significant). At a time when engineer skills should have been of greater value to the Navy, they commanded less and less of a return for most officers over time.

The general cause for these declines was the lack of promotion opportunities in the engineer promotions tournaments. The engineer and naval construction corps had few windows for advancement (typically going from "assistant" to "passed assistant" to "chief"). While each promotion was accompanied by a large salary increase, these promotions were rarely granted. Line officers of course made similar complaints over their lack of advancement opportunities. Here we demonstrate that in fact things were worse for engineers (see Lazear and Rosen 1981 on how the lack of promotion windows in tournaments can hurt both worker effort and morale). However, if engineers stuck it out and forged a true naval career for themselves, their relative earnings scenario eventually improved. How was this possible? As it happens, at this point many engineer officers were able to switch into the line officer tournament! That is, instead of becoming chief engineers, many were absorbed into the regular line and become lieutenant commanders. These engineers from the Academy classes of the early to mid 1870s saw their relative earnings steadily improve as they competed against regular members of the officer corps. Of course by then many erstwhile naval engineers and constructors had already left for better opportunities in other industries.[31] The relative wage declines of engineer-tracked officers during the formative part of their careers induced many to resign their commissions, during a period of engineer-biased technological transition.[32]

5.4 Promotions among line officers

Finally we look to the determinants that affect the promotion of *line* officers. Table 8 reports estimates from the ordered logit specification outlined in (5) that controls for Academy order of merit as a percentile ranking. Table 9 controls for career 'fast-tracking' of midshipman who finished in the top 10% of their Academy class as theoretically discussed in Bernhardt (1995). Results remain robust across both specifications - higher order of merit implies faster promotion. When we perform this exercise for engineer officers, we find no positive effect of rankings on promotions (results not reported). And as demonstrated in tables 6 and 7, engineers with higher Academy scores do not earn more than those with low scores, while there is a positive earnings effects for line officers with high scores. The implication is clear - the regular line was a more meritocratic organization than the engineering corps in that higher ability officers were promoted more rapidly, another reason to suspect that talented engineers left the Navy with greater frequency.

[31]Empirically we see that engineers exit the service mainly during the first two decades of their careers. We rerun (1), once only for those who serve between 3 and 20 years, and again only for those who serve for at least 20 years. The coefficient on the engineer dummy is strongly negative and statistically significant in the former specification, while it falls to insignificance in the latter (results not reported).

[32]We can look to the analysis of Frank (1985) to suggest that engineers had to be paid more than line officers to compensate for the diminished stature they endured in naval service. As income differentials narrowed the compensation needed to retain these engineers eroded away.

Note also the role played by cumulative fleet experience on promotions. In particular, serving on any type of ship had a slight positive effect on promotion likelihoods earlier in a career. The type of service (international or national) does not appear to matter, only that an officer served on a ship. This effect diminishes over time as careers advanced beyond 15 years and even has a negative relationship for officers by their 20th year. Indeed, officers who spent too much time at sea especially without command experience stagnated in their careers with fewer promotions. This makes some sense, as those who demonstrate capability are often moved off of vessels and out of engine rooms and into office positions which focus on leadership and strategy.

In contrast to this, command experience demonstrates a positive effect on promotions, a result which does not diminish over time. Achieving command serves as a gateway to better jobs later in a career, mitigating or perhaps preventing an officer from languishing on ships his entire career. Using estimates reported in table 9, the *ceteris paribus* predicted probability of achieving specific grades conditional on command experience is shown in table 10. Most notably, this demonstrates how any command experience insulated officers from stagnating in the lowest grades. While most officers (but not all) reached at least lieutenant by year 8, officers with any command experience *never* ranked lower than a lieutenant. After 15 year careers, the impact of command experience remained positive, albeit not quite as strong. After the initial round of sorting that occurred in the first 8 years, command experience had a dwindling effect. As it became more common for officers to achieve some command experience later in their careers, its value as a sorting mechanism for promotions commensurately became diluted.

Table 9 reports results using a dummy variable for officers who graduated in the top 10% of their Academy class. This essentially serves as a proxy variable to indicate officers slotted onto a 'fast-track' promotion path upon graduation (Bernhardt 1995, Gibbons and Waldman 1999). Notably the estimated effects on promotions of finishing in the top 10% remain fairly consistent across the span of careers with only mild fluctuations. The statistical significance of these coefficients diminishes, however, as time away from the original signal lengthens and standard errors increase.

The overall picture suggests that line officers were rewarded for their human capital. Both education at the Academy and experience in the Navy are powerful predictors for promotion. The same cannot be said for engineers or naval constructors. The bureaucratic structure of the Navy thus incentivized those with more traditional skills to stay in the Navy and those with engineering skills to leave.

Table 8: Ordered logit with academy performance as percentile (USNA line officers, classes of 1858-1902)

VARIABLES	year 5	year 8	year 10	year 12	year 15	year 20
ship experience (national water)	0.167	0.272***	0.241***	0.161***	-0.007	-0.142***
	(0.189)	(0.079)	(0.050)	(0.060)	(0.070)	(0.055)
ship experience (international water)	0.111	0.129	0.218***	0.183***	0.079	-0.056
	(0.152)	(0.079)	(0.057)	(0.062)	(0.067)	(0.061)
command experience	0.072	1.553***	0.827**	0.289	0.302***	0.447***
	(0.169)	(0.453)	(0.344)	(0.199)	(0.086)	(0.114)
Academy percentile	0.729***	0.315*	0.376	0.720**	0.760**	1.035**
	(0.272)	(0.161)	(0.259)	(0.314)	(0.382)	(0.447)
Academy class (1868-1887)	-4.915***	-4.275***	-4.733***	-5.659***	-4.035***	-2.490**
	(1.280)	(1.434)	(1.726)	(1.058)	(0.679)	(1.017)
Academy class (1888-)	-5.490***	-3.167**	-2.376*	-2.522***	-0.135	-
	(1.294)	(1.329)	(1.365)	(0.781)	(0.920)	
o0-o1 cut	-7.249***	-	-	-	-	-
	(1.532)					
o1-o2 cut	-3.118***	-3.161***	-3.360***	-5.387***	-	-
	(1.489)	(1.529)	(1.774)	(0.986)		
o2-o3 cut	-0.827	-1.845	-2.014	-3.358***	-3.987***	-
	(0.937)	(1.365)	(1.602)	(0.879)	(0.718)	
o3-o4 cut	-	2.030***	2.711***	2.583***	1.520	-0.636
		(0.764)	(0.801)	(0.829)	(0.925)	(1.369)
o4-o5 cut	-	-	-	-	3.054***	1.393
					(0.994)	(1.293)
observations	1393	1134	1026	936	801	626
number of categories	4	4	4	4	4	3
pseudo-R^2	0.320	0.212	0.252	0.276	0.212	0.226
χ^2	27.61	70.02	60.81	48.03	102.9	44.95

Coefficient estimates reported with standard errors clustered by USNA class year in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 9: Ordered Logit with academy performance as top decile (USNA line officers, classes of 1858-1902)

VARIABLES	year 5	year 8	year 10	year 12	year 15	year 20
ship experience (national water)	0.163	0.275***	0.243***	0.147**	-0.020	-0.152***
	(0.191)	(0.065)	(0.053)	(0.059)	(0.070)	(0.056)
ship experience (international water)	0.110	0.130*	0.218***	0.173***	0.068	-0.065
	(0.152)	(0.076)	(0.058)	(0.059)	(0.068)	(0.058)
command experience	0.055	1.545***	0.827**	0.257	0.286***	0.441***
	(0.175)	(0.454)	(0.346)	(0.195)	(0.092)	(0.116)
Academy top decile	0.520***	0.445***	0.472**	0.634***	0.435	0.514
	(0.168)	(0.147)	(0.230)	(0.243)	(0.355)	(0.378)
Academy class (1868-1887)	-4.886***	-4.276***	-4.742***	-5.636***	-4.010***	-2.448**
	(1.263)	(1.432)	(1.726)	(1.045)	(0.676)	(1.030)
Academy class (1888-)	-5.478***	-3.158***	-2.362*	-2.483***	-0.085	-
	(1.288)	(1.328)	(1.367)	(0.782)	(0.927)	
o0-o1 cut	-7.553***	-	-	-	-	-
	(1.545)					
o1-o2 cut	-3.437***	-3.273***	-3.521***	-5.774***	-	-
	(1.511)	(1.549)	(1.834)	(1.030)		
o2-o3 cut	-1.145	-1.955	-2.171*	-3.750***	-4.434***	-
	(0.950)	(1.390)	(1.661)	(0.891)	(0.679)	
o3-o4 cut	-	1.921***	2.557***	2.174***	1.054	-1.231
		(0.766)	(0.855)	(0.804)	(0.922)	(1.212)
o4-o5 cut	-	-	-	-	2.578***	0.783
					(0.972)	(1.100)
observations	1393	1134	1027	936	801	626
number of categories	4	4	4	4	4	3
pseudo-R^2	0.318	0.213	0.254	0.275	0.209	0.221
χ^2	37.40	69.61	60.15	100.9	137.7	33.91

Coefficient estimates reported with standard errors clustered by USNA class year in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 10: Predicted probabilities of rank (conditional on command experience)

command	year 8 rank				year 15 rank			
experience	o-1	o-2	o-3	o-4	o-2	o-3	o-4	o-5
0 years	0.037	0.088	0.748	0.128	0.012	0.730	0.188	0.071
1 year	0.008	0.021	0.564	0.407	0.009	0.674	0.225	0.092
2 years	0.002	0.005	0.231	0.763	0.007	0.612	0.263	0.119
3 years	-	-	-	-	0.005	0.544	0.299	0.152
4 years	-	-	-	-	0.004	0.474	0.330	0.193
5 years	-	-	-	-	0.003	0.404	0.352	0.241

6 Conclusion

This paper is an empirical study of an industry struggling with technological transition amidst a technologically dynamic economy. We consider two broadly-defined types of skills - traditional skills (such as seamanship and navigation, which were industry specific) and modern skills (such as engineering, which were increasingly becoming applicable to more and more industries). If technical progress was "engineering-biased" (as arguably was the case during the second Industrial Revolution), an industry would need to train and retain its engineer labor pool in order to effectively modernize. In this sense the Navy was not particularly good at modernization. The technically-gifted corps entered separate career paths and promotion tournaments that earned a wage premium early on, but these premia deteriorated as careers stagnated due to the lack of promotion opportunities. Line officers (a.k.a. less engineer-oriented positions) on the other hand were on a more meritocratic path; those with higher orders of merit or with some early command experience were promoted earlier and were "fast-tracked." The result was that the Navy retained those with traditional naval skills, and lost those with engineer skills. Such an industry would likely suffer delays in its technological transition.

We can induce some broader lessons from this. Why some industries stagnate (or outright die) while others thrive is an important subject of economic study. Many industries have traditional and modern skilled workers coexisting. Wage and promotion rigidities mean that often wages will often not equal marginal products - in such an environment modern-skill biased technical change can induce an exodus of modern-skilled workers. Here we suggest that industries that do not adequately reward those with modern skills and instead reward those with traditional skills may lose those modern skills and thus fail to modernize. This paper suggests that insights from the personnel economics literature (Lazear and Oyer 2009) can help us further understand industrial and technological history.

This also echoes the "appropriate technology" literature (Basu and Weil 1998, Acemoglu and Zilibotti 2001) that suggests that you need the proper human capital in place before you can adopt a new technology. One could thus view the Amalgamation Act of 1899 as the Navy's belated admission that they had put the cart before the horse - they had attempted to modernize the fleet without an adequately skilled workforce. By this line of reasoning, training the entire officer corps in the requisite technical skills allowed the Navy to regain its technological superiority during the 20th century.

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Figure 1: Number of Officers in Data by Class Year

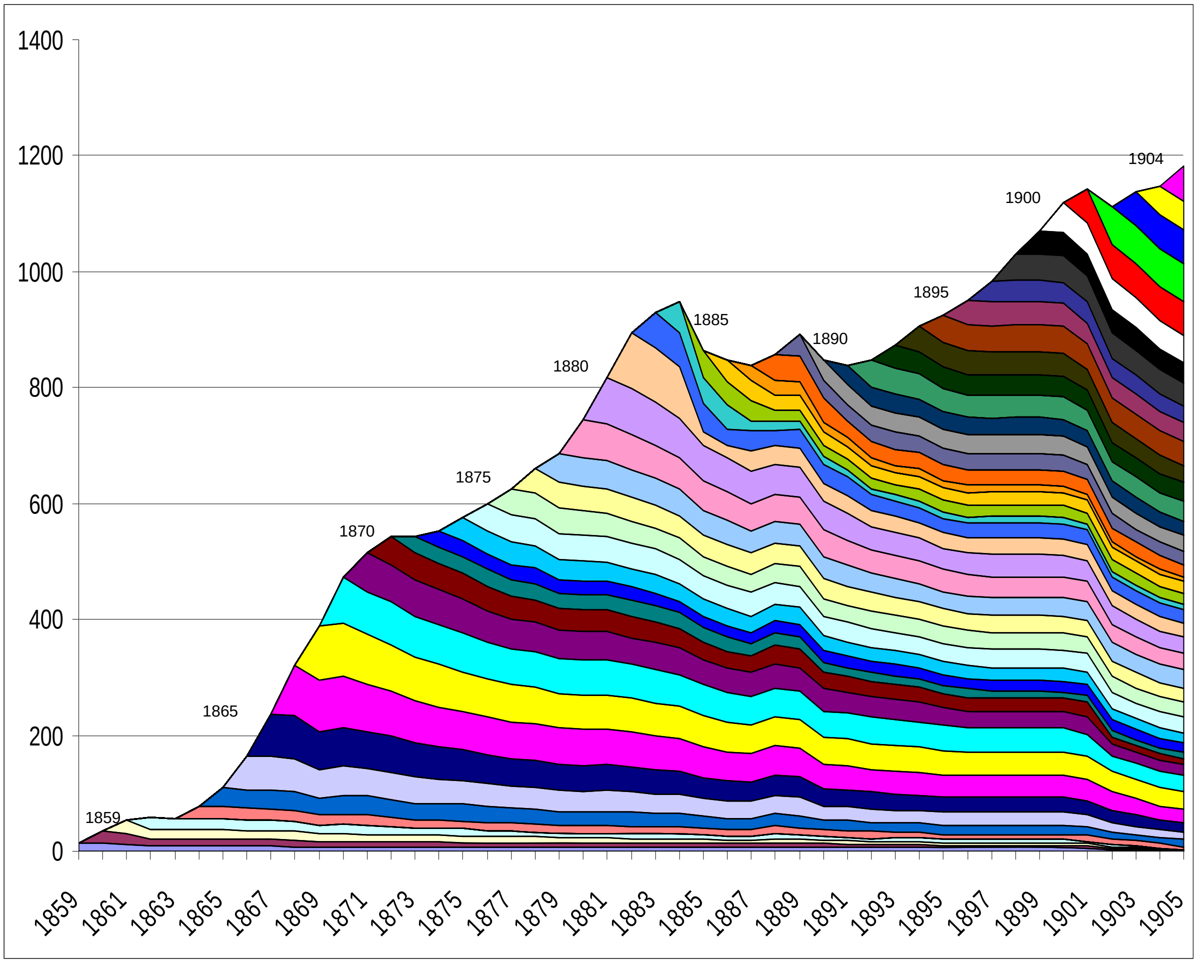
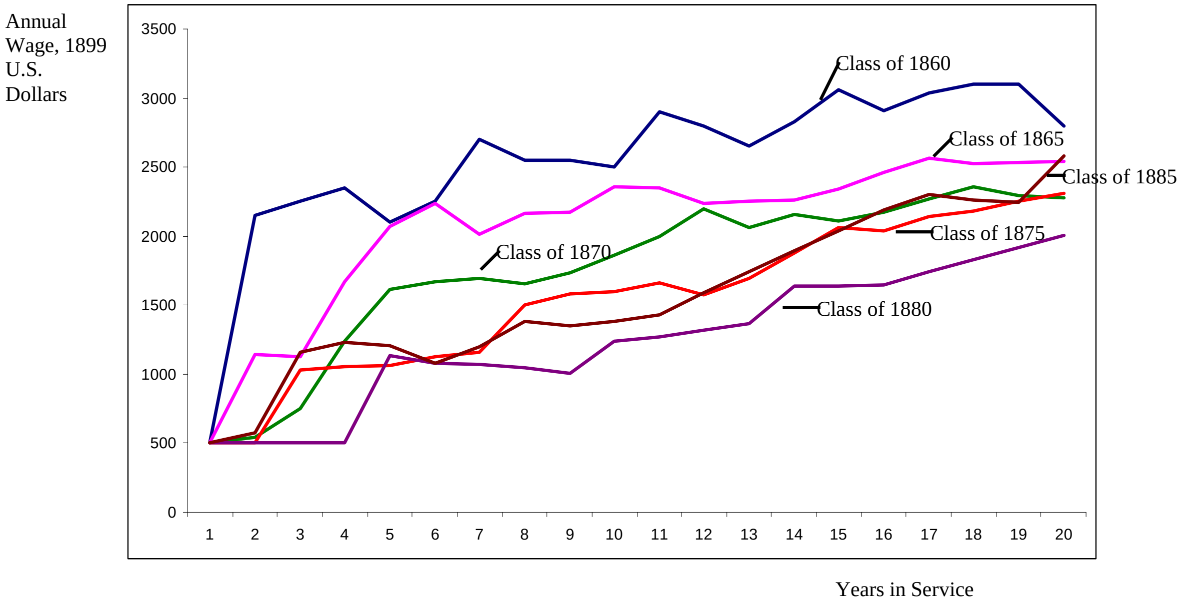


Figure 2: Class-Average Earning Profiles for Selected Graduating Classes

Regular Officers



Engineer Officers

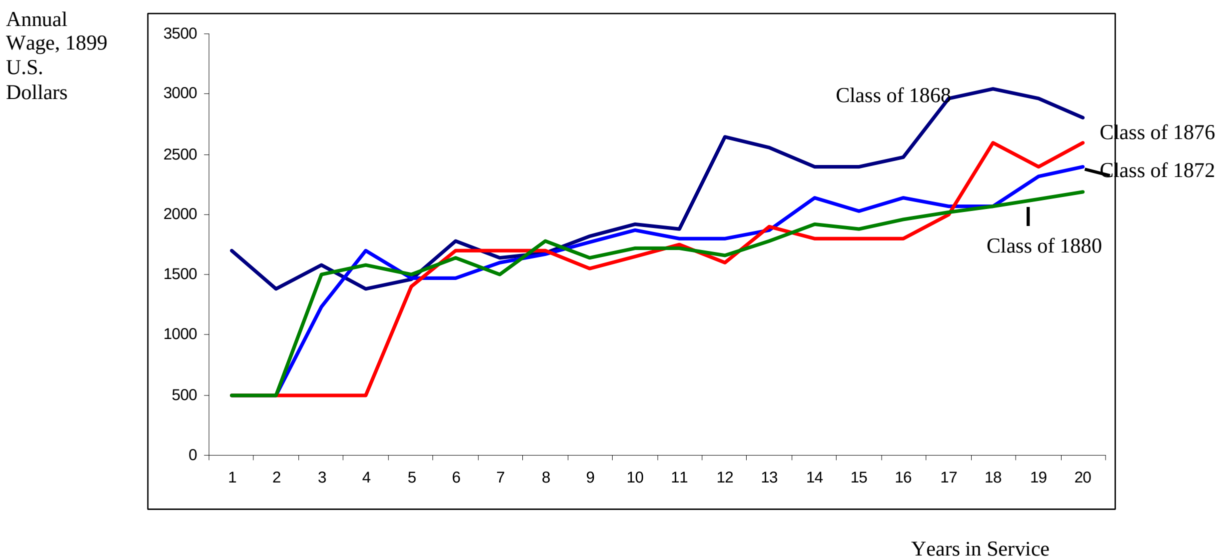
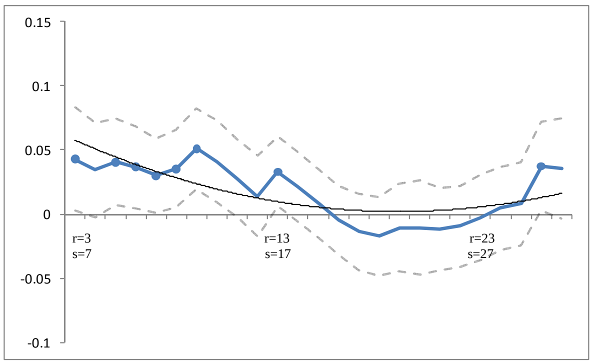
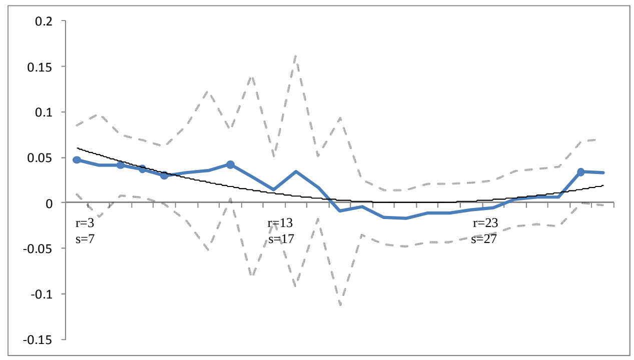


Figure 3: OLS and Heckit Estimates of Effects of Technical Skill on 5-Year Earnings for Varying Values of r and s.

Steam percentile effect on earnings (OLS)



Steam percentile effect on earnings (Heckit)



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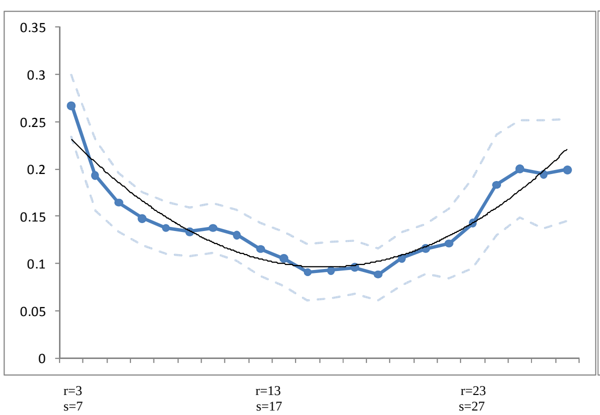


Engineer effect on earnings (Heckit)

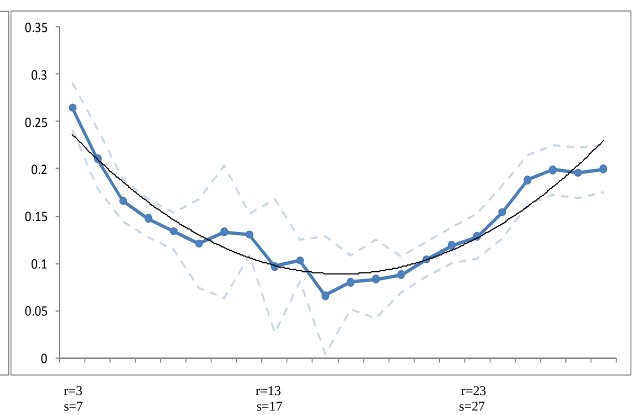
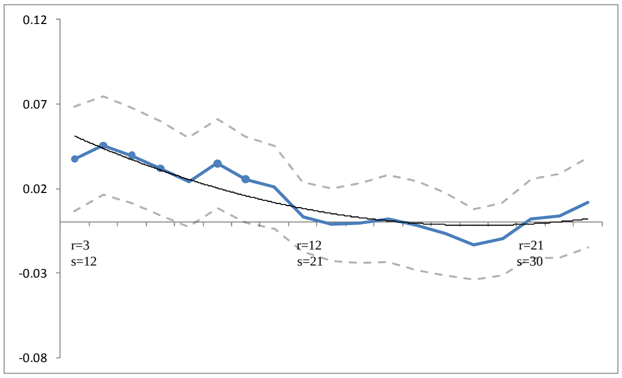
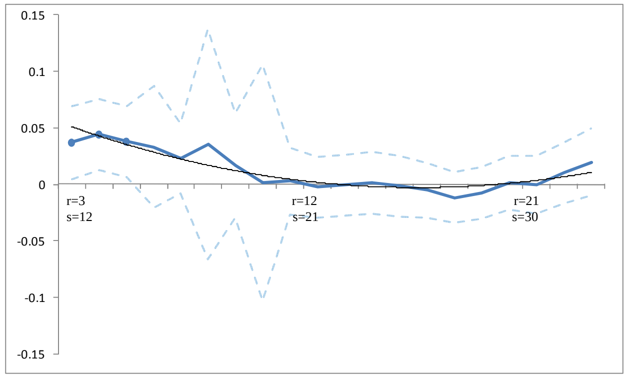


Figure 4: OLS and Heckit Estimates of Effects of Technical Skill on 10-Year Earnings for Varying Values of r and s.

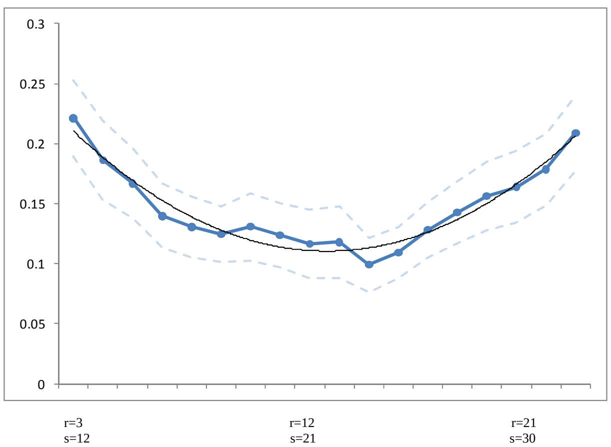
Steam percentile effect on earnings (OLS)



Steam percentile effect on earnings (Heckit)



Engineer effect on earnings (OLS)



Engineer effect on earnings (Heckit)