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“Naval Engineering and Labor Specialization during the Industrial Revolution”

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Abstract

This paper explores the roles of capital- and technology-skill complementarities in labor allocation decisions within the U.S. Navy. During the latter 19th century the officer corps was highly specialized, and was split between groups of line and staff officers. This was also a time of dramatic technological changes which affected nearly every facet of naval operations. Specifically, naval technological developments tended to be "engineering-biased," in that they raised the relative importance of engineer-oriented skills. This created a dilemma for the Navy, as it navigated the balance between the benefits of a specialized workforce implementing increasingly complex technologies with rising communication and coordination costs. We first document the extent of capital- and technology-skill complementarities within the navy which fostered greater labor specialization. We then show how the Navy vitiated the specialized human capital of officers by blending the corps. The study offers insights into how an industry undergoing wrenching technological changes managed its labor and human capital allocation to help the U.S. become a world class naval power.

- *Keywords*: skilled-labor complementarity, skill-replacing and skill-using technology, labor allocation
- *JEL Codes*: J2, J7, N3, N7, O3

1 Introduction

This paper explores the effects of capital- and technology-skill complementarities in the U.S. Navy. Specifically, we explore how such complementarities influenced task specialization and labor allocation during the latter 19th and early 20th centuries. The exploration provides us a glimpse into how a large and complex bureaucracy handled dramatic technological changes during a formative period in American economic history. Goldin and Katz (1998) document capital-skill complementarities in U.S. manufacturing as far back as the beginning of the twentieth century. Earlier periods however remain mysterious to us due to data limitations. Here we look to the various relations between workers, capital and technologies in a critical and dramatically evolving organization.

We view the vessel as a floating firm, an island of productivity in which technology-embodied capital is employed by various types of skilled and unskilled labor in pursuit of the objectives of the voyage. The specific objectives, be they to blockade trade, or to engage in gunboat diplomacy, or to provide a vague appearance of power projection, are for the most part opaque to us. But as the United States during the latter 19th century transitioned from its traditional limited strategy of commerce raiding and shore protection (guerre de course) to a far more muscular naval strategy (guerre d'escadre), these endeavors grew increasingly vital to the health of U.S. commerce and security (Buhl 1978).[1] In this sense the Navy was a critical "industry" in the overall economy, one from which we can learn a great deal.[2]

This transition posed some major challenges for the Navy. One of the big debates among top naval brass was over the degree of specialization among members of the officer corps. The technological and structural changes happening within the Navy tended to be "engineering-biased," in that they raised the relative importance of engineering skill in naval operations. As these operations grew increasingly complex, they Navy could conceivably raise productivity through

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[1] Examples abound where the Navy was used as a tool of macroeconomic policy. One such example was the United States' "gunboat diplomacy" in Latin America, which began in the mid-1890s and was motivated in part by concerns over debt repayment (Reinhart and Rogoff 2009).

[2] See for example Glaser and Rahman (2011, 2012). Some words of caution from a military historian are worth noting - "The past - even if we could be confident of interpreting it with high accuracy - rarely offers direct lessons" (Paret 1986). Indeed, but the issues raised technological change within the naval steamship can surely provide *indirect* evidence of the effects of industrialization on labor for the other complex industries of the day.

a more extensive division of labor, where each officer could focus on a narrower range of tasks. However, these changes could also exacerbate communication and coordination costs among officers, in which case a more generic or superficial division of labor might be more productive. The balance is one which all productive entities need to strike - when should an organization maintain a highly-specialized workforce, and when should it have a more homogenous one (Borghans and Weel 2006)?

The U.S. Navy of the late 19th and early 20th centuries makes for an informative case study on this balancing act. This study provides an important glimpse into how how technology affected labor allocation and specialization in history.[3] During this time the officer corps was highly specialized, and due to legislation passed in 1867 was split between groups of line and staff officers (McBride 2000). More specifically, there were generally two kinds of skilled workers: regular line officers (who acted as managers) and naval engineers (who acted as technocrats); these skilled laborers worked with technology-embodied capital (the naval vessel) and unskilled labor (the vessel's complement of sailors). In this context, we attempt to observe the extent of each skilled labor-type's complementarities with capital, raw labor, evolving naval technology, and each other. We also study the Navy's reaction to these inherent complementarities, and how it balanced its needs of accomplishing many specialized tasks with its needs for a more homogenous workforce with similar naval skills and training.

We exploit a unique dataset that contains the names and profiles of officers who joined the Navy between the years 1865 to 1905, as well as the names and profiles of every serving naval engineer from 1870 to 1899. We match merge this information with their duty and service records. We also record the names, personnel, characteristics and station of every U.S. naval vessel from 1870 to 1911. The final compilation gives us the singular ability to link different kinds of physical capital, human capital and technologies for a dynamic and developing organization in the 19th and early 20th centuries.

Our analysis uncovers a number of things. Prior to 1899 (when the officer corps was delineated between line and staff officers), there were very clear capital-skill and technology-skill complementarities in "naval production." More specifically, proxies for technology and naval

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[3] "There is hardly any part of economics that would not be advanced by a further analysis of [labor] specialization" (Houthakker 1956).

capital positively affect the numbers of both officers and engineers assigned to active vessels. Further, these proxies also positively affect the number of engineers *relative* to officers. On the other hand, officers appear to strongly complement *unskilled* labor in service on active ships. The findings suggest that naval labor during this time was highly specialized - management-type skills worked closely with personnel, whereas engineer-type skills worked less with people and more with machinery and technical apparatus.

We also find that these technology-skill complementarities changed dramatically after 1899. Specifically, the Navy made a concerted effort of vitiating the specialized human capital of the officer corps through labor amalgamation. Through this the Navy stressed a more generalized skill set among all naval personnel rather than specialized skills. However the Navy was still able to allocate labor according to more *intensive* measures of human capital, through the skills and experience embedded in officers. This was likely important for the Navy to continue to develop and implement engineer-intensive technologies and keep apace of naval developments in England and elsewhere.

The rest of the paper is organized as follows. Section 2 provides some background and motivation. Section 3 gives some details on our empirical strategy, and section 4 describe the data. Section 5 details our results.

2 Background

2.1 The Engineer-Bias of Naval Technological Change

The late 19th century Navy employed a heterogenous fleet of vessels which were built between the 1850s and 1890s. All these were steamships, but they had dramatically different technological designs which were highly dependent on the years of their conceptions.[4] This was a transformative era for both the Navy and the greater economy; studying this era thus provides us with a unique opportunity to examine the use of capital, since each vessel embodied different types of technologies.

Naval operations have always been fairly technical.[5] Yet nearly every facet of the naval ship

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[4] "What a motley assemblage [the old ships] were! Monitors with rusting armor and rotting or rusting hulls, wooden cruisers limited to 7 or 8 knots under steam" (Vlahos 1989).

[5] Even back in 1637, the English warship *Sovereign of the Seas* was likely the most complex man-made con-

underwent radical technological transformation during the latter 19th century. These changes included the switch from sail to steam propulsion, the ironcladding of wooden hulls, the full construction of iron hulls, the switch from paddle-wheels to propellers, and the implementation of rifled barrels and exploding projectiles in naval ordnance. Indeed, "by century's end, warships were complex systems that bore little resemblance to those fifty years earlier"(McBride 2000).

All these changes occurred progressively and chronologically through the latter 19th century, and required officers who could master the technologies being newly implemented. The naval profession in fact was being transformed into a technology- and science-based profession. Similar transformations were occurring in many manufacturing industries throughout the Western world (Mokyr 2002), particularly in those involving steam and mechanical engineering.[6]

Change came sluggishly at first, particularly during the 1870s and early 80s. Some of this was due to American postbellum withdrawal from the international scene, and a renewed focus on southern reconstruction and westward expansion (Peterson 1986). But resistance to change was common even before the war - in 1857 for example, instead of experimenting with large steamships with screw propulsion designs and armored hulls to emulate the British Royal Navy, Congress approved the construction of five large but wooden hulled, shallow-draft sloops (Tomblin 1988). Battles over ship designs between line officers and naval engineers which began in the 1850s fostered a kind of technological stasis up through the 1870s - the Navy settled on romantic ship configurations rather than make bold changes to the battleship paradigm (McBride 2000).

Perhaps the biggest factor contributing to the chariness for change was the acknowledgement (and fear) that such developments would inevitably be *engineering-skill biased*, empowering engineers over traditional line officers. It became increasingly clear that engineering had grown in importance in the employment and maintenance of naval power during the Civil War (Davis and Engerman 2006), and was only becoming more important the post-bellum world.

Yet because of delays in technological adoption during the 1870s and 80s, the Navy also employed many ships of antiquated design and ability. The conversion of the fast cruising *Madawaska* to the steam frigate *Tennessee* during the early 1870s is a classic example. Like many vessel conversions during this time, the *Tennessee* essentially became a "totem of romantic

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struction in all of England at the time (McBride 2000).

[6] "The protestations of some economic historians notwithstanding, the steam engine is still widely regarded as the quintessential invention of the Industrial Revolution" (Mokyr 1990).

tradition," complete with white oak hull and all of the traditional ship fittings of the old sailing navy (Vlahos 1989). These ships were designed not so much to fight as to merely give the impression of being able to fight. Ship designers were in fact directed to embrace naval anachronisms. A general order in 1869 for example directed that"hereafter all vessels of the navy will be fitted with full sail power...Commanders of squadrons will direct that constant exercises shall take place with sails and spars" (Bennett 1896). Even as late as 1897, the Naval Academy authorized the building of training vessels propelled only by sail. Engineer-in-Chief George Melville found it "incredible that a sailing ship should be used for the training of men who are to serve on and command vessels entirely propelled by machinery and without any sails."[7]

But engineer-oriented change did come. During the 1880s there were two distinct waves of technological development - the construction of the armored ABCD ships, and the four modern heavy cruisers *Texas*, *Maine*, *New York*, and *Olympia*. The navy thus began its attempts to converge to the technological frontier in earnest by the 80s. For example in 1886 American officers made technical pilgrimages to Europe, paying $2500 to purchase foreign designs of naval warships (Vlahos 1989). The development of the *Charleston* in 1887 owed much of its design to imitations of British vessels (Bennett 1896).

After this an even greater push for modernization was made by Secretary of the Navy Benjamin Tracy, who established the Board of Construction in 1889 to coordinate the bureaus' efforts to produce optimal warship designs themselves (McBride 2000). The vessels subsequently built and launched were radically different in both design and ability. In fact to some, "the new navy [was] one so different from much that [had] preceded...as to make it a subject by itself, only slightly connected with all that [had] gone before" (Bennett 1896). Yet from the end of the war to the beginnings of this "new navy," some forty new war steamers had been added to the Fleet (Vlahos 1989), contributing to the radical mix of ship designs extant in the late 19th century Navy.

Along with propulsion, vessels began to develop steam engineering techniques to clear bilges of water. Further, as vessels began to increase in size, steering by manual labor became increasingly onerous and new steam techniques to steer ships were developed and implemented (Smith 1938).

The increase in the size of naval guns also led to the introduction of machinery for controlling them. As early as 1861 there existed a system of mounting heavy guns on a turntable, the

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[7] Melville's Stevens Institute Speech, Melville Papers.

revolution, gun motion and recoil all powered by steam. Such turrets worked by steam became standard in newer vessels, replacing wooden carriages and manual labor.

These are but a few examples of how technical changes were altering the optimal mix of skilled labor aboard vessels. Steam was applied to pumping, steering, the working of guns, the distilling of water, and the charging of torpedoes, along with its traditional role in propulsion. But how the Navy actually allocated engineering and traditional skills across the fleet remains unexplored. For example, according to one article from the late-19th century, a steam frigate of 1000 horsepower in 1865 had nine engineers; in 1896 an armored steam cruiser of 17,000 horsepower had only five.[8] We wish to inquire, among other things, whether this example was emblematic of replacement of engineers on technologically advanced vessels, or rather an interesting exception to the general rule of greater engineering skills employed on such vessels.

The convergence to the naval technological frontier happened in earnest starting in the 1890s, and culminated in the building and launching of the Great White Fleet in the nineteen-aughts. This clearly involved a massive and unprecedented embrace of engineering technologies. The technological developments of the navy thus mirrored in many ways American industry - relatively backward in the 1870s and 80s, yet rapidly developing by the 90s with a renewed focus on competing with the industrial superpowers of Britain and Germany (Vlahos 1989).

So how did these developments influence labor allocation in the Navy? Further, how did the Navy handle (and eventually overcome) the fear among traditionalists that their roles would be subservient and their skills would become irrelevant? The 19th century U.S. Navy, made up of a mongrel mix of old and new ships, provides us a rich environment to explore these questions.

2.2 Naval Engineering and the Pre-Amalgamated Line

The post-bellum navy was split into various officer-corps factions. By dint of legislation passed in 1867, the corps was split between traditional line officers and engineer officers, forming an organization with a fairly specialized labor structure. During this period naval personnel was "pre-amalgamated" - that is, line and engineer officers had explicitly separate duties. One primary question is would (and should) the Navy embrace such a specialized framework as new

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[8] from "Queer Doings in the Navy," *Scientific Machinist*, July 1, 1896.

technologies continued to be developed and implemented?

As studies such as Acemoglu (2007) suggest, capital-augmenting technological progress should increase the relative demand for labor in a two-factor production process when capital and labor are grossly complementary. This could be a fairly apt description of the Navy - technological developments embodied in vessels greatly raised the need for skilled personnel. One officer described the difficulties the navy had in progressing technologically as arising from the failure of "officers in high position to realize the duality of the naval profession; to realize that a navy consists of both personnel and material; the two of equal importance, and each useless without the other" (McBride 1992).

Further, such developments were likely biased towards *particular* skills. For example, Chin et al. (2006) find that technological developments in the merchant shipping industry during the late 19th century created a greater demand for engineers and tended to replace moderately-skilled able-bodied seamen. So how did naval technological developments influence skill-labor personnel in the 19th century?

Again, we need to look to the data to discern the patterns. The historiography suggest that during the latter 19th century officers and engineers had radically different functions. The engineers allegedly served as an indispensable corps with extensive scientific and technical expertise, the "inspectors and constructors of machinery," and those also with "practical ability if the ship's machinery were to be kept in an efficient condition" (Bennett 1896). Officers by contrast specialized in seamanship, navigation, weaponry and general strategy. This separation persisted up until the Amalgamation Act of 1899 - through this period the fear of "the sailor swallowing the engineer, or the engineer swallowing the sailor" had not yet come to pass (Bennett 1896). Thus in evaluating potential complementarities, we need to look at these two types of skilled workers separately in the usage and operation of vessels.[9]

At heart here is the debate over the role of specialization and the proper division of labor as technologies evolve.[10] In many respects progress and greater labor specialization go hand in hand. Specialization generates classic gains from trade, and expertise develops through learning

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[9] Edelstein (2001) stresses how proper complementarity measurements between different laborer-types is important for growth accounting, citing Field-Hendrey (1988, 1998) who demonstrate the lack of substitutability between labor of different servitude-status or gender.

[10] See Borghans and Weel 2006 for a study of labor specialization with computer technology adoption.

by doing particular tasks. Indeed, productivity can rise directly through the specialization of labor (Kim and Mohtadi 1992). And complicated tasks require a great deal of specialization to minimize the potential of failure (Kremer 1993).

Naval developments particularly suggested the need for a specialized officer corps. As technologies became more engineer-oriented, the Navy needed a core group of experts to manage and implement these changes. Bennett (1896) stresses the critical need for engineers during this time as the primary inspectors and constructors of machinery, and as directors of "the most needful fighting factor in the ship - power." Such responsibilities could not be heaped upon regular line officers, since they generally had no idea about the workings of steam technologies. A telling account comes from Commander R. S. Robinson of the Royal Navy, who wrote in 1839[11]

> *We go into the engine room, we look at the outside of an engine, various rods of highly polished iron are moving about, a beam is observed vibrating up and down, all is clean and bright and well arranged, but the working parts of the engine, the moving power is entirely shut out from our sight, and after staying a few minutes and, perhaps, asking a question or two, which from the very depths of ignorance it betrays, it is scarcely possible the engineer can or will answer, we walk up again, with no additions to our knowledge, and rather convinced that the whole subject is incomprehensible.*

This tale of technological bewilderment was a common refrain among line officers in the 19th century U.S. Navy, suggesting the deeply complementary and specialized nature of officer functions. Allen (1976) describes at length a new "corporate" form of organization needed to embrace and implement new naval technologies - "specialization had to replace Old Navy self-sufficiency and omni-competence; cooperation (between near-equals) or 'teamwork' had to replace aristocratic monopolization of command privileges." No longer could officers embrace "aristocratic individualism," where every officer understood every component of naval operations. In the New Navy, one type of officer relied on another type for guidance and expertise.

Yet there were also a number of perceived costs from such specialization, and the potential shortcomings of greater labor divisions occupied naval dialectics for decades. For one, economists have often described rising communication costs among personnel as a potential hindrance to

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[11] Taken from Robinson (1839), *Nautical Steam Engine Explained and its Powers and Capabilities Described for the Use of the Officers of the Navy.*

specialization patterns. Autor (2001) describes how infrequent use of specialized workers can reduce transaction costs and thereby raise gains from specialization. Yet naval developments during this time arguably worked in reverse - as technologies grew, the need for engineers grew with it. But this raised transaction costs, and thus decreased potential gains from specialization.

Another problem was the coordination necessary to link complementary officers and engineers with naval capital. Determining which ships and people were at which stations, and which should be matched upon deployment, was surely an impossibly complex process. An organization simply becomes less limber with a higher degree of specialized labor.[12] Coordination on the other hand becomes easier when all personnel have similar backgrounds and skills. Thus the "many sudden emergencies and trying circumstances attending the war operations of the navy" described by Bennett (1896) could require both theoretical knowledge and practicable ability for many officers, not merely a few engineering specialists. The "omni-competence" of labor described by Allen (1976) provides convenience, particulary given the uncertainties of future naval operations.[13] Technological changes that generate greater complementarities can also produce a more sclerotic structure. Indeed organizations of all kinds must strike a balance between the productivity of its individual workers and the limberness of its whole workforce.

Yet another concern over a highly specialized officer corps was that it could create a "separate but equal" dynamic in the workplace, stoking internal strife within the service and potentially fostering an internecine war between line and engineer officers. Engineers were physically separated from officers, working below decks out of sight and often out of mind (McBride 2000). This separation manifested itself in many adverse ways. The most common complaint among engineers was that they were typically not permitted the use of the wardroom for mess and sleeping quarters (Calvert 1967). Yet such petty issues could magnify into serious hindrances for naval development. High ranking officials such as David Porter (Superintendent of the Naval

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[12] Fleet limberness has been of key importance for modern navies. Fleet Admiral Ernest King attributed the U.S. Navy's victory in the Pacific during World War II to the "flexibility and balanced character of our naval forces." (Introduction, "Third Report of Operations of the United States Navy in World War II, 1 March 1945 - 1 October 1945," in Fleet Admiral Ernest J. King, USN, U.S. Navy at War, 1941-1945: Official Reports to the Secretary of the Navy, Washington, D.C.: U.S. Government Printing Office, 1946, 169.)

[13] Hadfield (1999) explains customary gender divisions of labor as a mechanism that mitigates coordination problems in the marriage market. But while household technologies have been fairly stagnant for millennia, technological changes in other organizations can severely disrupt such coordination. Thus a modern Navy might be considered like a modern marriage - everyone is responsible for everything.

Academy during the latter 1860s) and Alfred Mahan often referred to engineers pejoratively and resisted engineer-biased technological changes (Bennett 1896). Those who embraced a more homogenized corps envisioned an engineering background for all officers, so that engineer-oriented developments would be better understood and embraced. Furthermore, naval operations could be jeopardized if fighting efficiency depended upon the technical understanding of the captain and a close relationship with his engineers.[14]

Finally, conflicts stoked by the separation between the old guard of line officers and new staff officers may have contributed to technological stagnation and outright naval decline (Karsten 1972, Allen 1976). Because the old guard viewed engineer-oriented developments as destruction rather than progress, they resisted them, often successfully (Coletta 1987). This created a further impetus for engineers to leave naval service, as developments in private industry dramatically raised the relative pecuniary rewards in private-sector engineer-oriented professions (Glaser and Rahman 2012).[15] Such a hollowing out of the skilled workforce posed yet more problems for a Navy attempting to modernize.

2.3 Naval Education in the Pre-Amalgamation Era

During this period all line officers, and a great many staff officers, received their pre-service education at the United States Naval Academy. As the academic and educational arm of the Navy, the Academy likewise grappled with the tradeoffs between generalized and specialized human capital for the officer corps. While specialized education can improve worker productivity for a given activity, a generalized education renders workers more adaptable to a variety of activities (Kim 1989). Throughout this period the Naval Academy wildly oscillated in its focus between the former (training and educating future line and engineer officers separately for the last two years of their studies) and the latter (where midshipmen all went through the same program and took a combination of "traditional" and engineering classes).

The Academy always had its "generalists" who wished to combine the talents of line and

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[14] McBride (2000) draws the amusing parallel between the post-bellum U.S. Navy and the Starship Enterprise, where it seems that in both cases officers and engineers operated very separately. "[With] Captain Kirk's Star Trek dealings with Chief Engineer Scott,...the captain demanded more power, speed or shield strength with no interest in how Scott's engineers provided it."

[15] Evidence of the explosive growth in engineer employment in manufacturing abounds. In 1880 there were 7061 engineers in the U.S.; at the turn of the century there were 43,239 (Blank and Stigler 1957).

engineer officers into the same individuals, and they pursued their vision with intermittent vigor in the post-bellum period. Steam was made part of the curriculum for all students in 1861 (Calvert 1967). Engineer-in-Chief Benjamin Isherwood stressed to Secretary of the Navy Gideon Wells the need to revamp engineering instruction at the Academy. Soon after the Department of Steam Engineering was established. In his 1864 annual report, Secretary Wells described the labor allocation issues stemming from "the radical changes which have been wrought by steam as a motive power for naval vessels." Because it seemed that officers were capable of performing only a few specialized tasks, "[we should make] our officers engine-drivers as well as sailors...we should begin by teaching each midshipman to be able to discharge the duties of line officers and engineers, to combine the two into one profession, so that officers so educated can take their watch alternatively in the engine-room and on deck."[16] When the Academy returned to Annapolis in 1865, Congress appropriated $20,000 for new facilities for the engineering department (Bennett 1896). Secretary Wells applauded the new facilities, urging for their maximum use and warning that line officer untrained in steam engineering would be "taking a secondary position" within the profession.[17]

Yet due to the specialized needs of the fleet, the Academy also episodically offered a program that graduated engineer officers.[18] Cadet engineers would enroll in a two year program focused on steam and mechanical engineering after completing their first two years of regular officer instruction. The program began in 1866, graduating its first group of engineers in 1868, but ended immediately after due to funding. The program was reinstated in 1872, abolished again in 1882 due to the Personnel Act, and established once more in 1888 (Calvert 1967).

Thus in three distinct waves the Academy produced engineer officers who worked along with line officers aboard naval vessels. But 1899 was the last ever graduating class of the engineer-cadet program. Why did the program end?

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[16] From the Annual Report of the Secretary of the Navy, 1864.

[17] From the Annual Report of the Secretary of the Navy, 1866.

[18] Before this time engineers came exclusively from private organizations and were considered non-commissioned personnel.

2.4 The Post-Amalgamated Line

In 1899 engineering officers were simply absorbed into the “new line.” Deemed the Amalgamation Act of 1899, the action was a direct result of a study made by the Personnel Board under the chairmanship of Assistant Secretary of the Navy Theodore Roosevelt two years before (McBride 2000). According to Roosevelt, “On the modern war vessel, every officer has to be an engineer whether he wants to or not.”[19] Thus amalgamation was the implicit expression among naval leadership that the generalists had in effect won the debate, and the recognition of the necessity of engineering training for all naval officers. A common refrain was that “the modern ship is a machine...All the problems on a modern battleship are engineering in their nature, and there is no problem which cannot be solved by the man whose early education has been largely in mechanics and engineering.”[20]

More broadly, amalgamation manifested the awareness that America remained fairly weak in human capital, and that industrial technologies required a workforce with backgrounds in technical training and professionalism (Vlahos 1989). The embrace of naval engineering for its entire personnel suggested the Navy echoed broader industrial demands for the United States to become a global competitor and a world power.

The Navy had to respond to the order, both on the education and the labor allocation fronts. The Naval Academy retooled its curriculum to once again produce omni-competent officers, but there was the fear that new graduates would be long on breadth and short on depth. Furthermore, the Amalgamation Act in fact did not require midshipmen to study more engineering, while it did require naval engineers to pass a test on seamanship to qualify as deck watch officers (McBride 2000). The chief of the Bureau of Steam Engineering saw the potential flaw of the new design in 1904: “So few officers of the line are taking up engineering seriously that the situation is becoming alarming” (McBride 2000).

Yet amalgamation also had its staunch defenders. In a 1905 article lieutenant commander Lloyd Chandler presented an extensive defense of the new amalgamated line. He forcefully painted the merger of officer human capital as a necessary one in order for the U.S. to compete in world naval affairs, claiming that the “blindness of caste [that ruled]...that a man cannot be

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[19] Papers of George H. Melville, Manuscript Division, Library of Congress, Washington D.C.

[20] Ira N. Hollis quoted in the Army and Navy Journal in 1897.

a military officer and a mechanic at the same time" was once and for all destroyed.[21]

Amalgamation was a watershed in the institutional history of the U.S. Navy, one from which labor and historical economists may learn. It destroyed the *de jure* distinction between line and staff; there remained however a core group of erstwhile engineers who suddenly had line officer status. Were their education and backgrounds reallocated in a fundamentally different way? How did the Navy alter its labor allocation strategy? Did there remain a *de facto* extensive human capital margin upon which the Navy continued to operate, and if not would naval operations be jeopardized?

3 Empirical Framework

To empirically analyze some of the themes raised in the last section with reduced form specifications, we regress alternative measures of skilled labor and skill-intensity levels on a set of ship characteristics. These will be panel estimations at the ship-year unit of observation.[22] For many of these, we split the analysis between 1870-1899 (pre-amalgamation) and 1901-1911 (post-amalgamation). We are interested in learning how the Navy allocated its labor during a period when it, at least officially, embraced specialization, versus how it did so when it stressed homogenization.

3.1 Engineer and officer counts

To estimate the effects of capital and technology on the number of skilled workers assigned to specific vessels, we define y as a non-negative count variable with integer values $0, 1, 2, ...$ Specifically this represents the total number of engineers or officers assigned to ships. Poisson regression is a natural empirical specification for the analysis of count data such as this. An examination of the distribution of engineers and officers shown in figure 3 provides further motivation for the assumption of a Poisson model. Following Wooldridge (2002), the conditional mean given the vector $\mathbf{x}$ is defined $E(y|\mathbf{x}, \eta; \beta) = exp(\mathbf{x}\beta)\eta$. Initially, we assume $E(\eta|\mathbf{x}) = E(\eta) = 1$, which implies that standard quasi-maximum likelihood techniques (QML) consistently estimate the

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[21] Lt. Commander L. H. Chandler, "Is Amalgamation a Failure?" USNIP 31 (1905): 823-943.

[22] McBride (2000) describes how the battleship is the most relevant observational unit for our period of study: "During this period, the battleship technological paradigm was dominant, and the battleship retained strategic importance even after the attack on Pearl Harbor in December 1941."

parameters of the model. Our interest is in the $K \times 1$ vector of parameters in β.[23] Results from these regressions are reported in tables $2-5$ for ships serving at sea both for the 19th century and the early 20th century.

3.1.1 Endogenous engineer and officer counts

While convenience leads one to assume statistical independence of η and $\mathbf{x}$, our conceptual framework allows for the possibility that ship allocations of officers and engineers are both endogenous variables. In particular, the lack of substitutability between types of skilled labor suggests a failure of the assumption for conditional mean independence, which means $E(\eta|\mathbf{x}) \neq E(\eta)$. Mullahy (1997) details how standard QML techniques produce inconsistent estimates of β when this assumption fails; however, he also outlines estimation methods using two-stage QML and GMM techniques that mitigate the endogeneity problem and generate more consistent parameter estimates.

Similar to IV specifications found in standard contexts, our IV specifications will need a $p \times 1$ vector of exogenous instruments, $\mathbf{z}$, where $p \geq K$. The p instruments may include elements of $\mathbf{x}$ not correlated with η. We report estimates of IV estimations following from these methods in table 6.

3.2 Measures of skill intensity

We also exploit the various measures of skill and the panel structure of the data to evaluate how changes in the capital and technological characteristics of ships lead to changes in the mix of skills assigned to ships. Which attributes led ship operations to rely on more experienced (and possibly less technically savvy) officers, or on those officers who performed well in certain subjects in college (in this case the Naval Academy)? What causes the share of engineers relative to line officers in various vessels to change over time? To answer these questions, we uncover the factors that change labor skill intensity aboard vessels.

The unobserved effects model estimates various measures of skill intensity on ship i over time t following the specification

$$y_{it} \;=\; x_{it}\beta \;+\; c_i \;+\; u_{it} \;, \qquad t = 1, 2, ..., T \;. \tag{1}$$

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[23] We also include parameters estimated under Poisson specifications with random effects.

The random variable c_i controls for unobserved ship heterogeneity and improves estimate efficiency in the $K \times 1$ vector β. By construction, estimates follow from the assumption that c_i is not correlated with x_{it}. Results from FGLS estimation of a variety of skill measures on ships using (1) appear in tables $8 - 11$.

4 Data

Our core empirical strategy regresses various measures of skill on a variety of ship characteristics. In order to do this of course we need to match officers and engineers to particular vessels. We accomplish this primarily by exploiting information compiled in official U.S. Navy Registers. These annual volumes published by the United States Navy document the duty and station of every serving officer and every naval vessel. From these volumes we determine the names and numbers of officers and engineers assigned to each vessel each year, as well as the station (location/tour) of each vessel. There are typically core groups of each skilled labor-type during each ship's international tour, but nevertheless a remarkable degree of year-to-year fluctuation in personnel exists even during the same tours.[24]

Primary data extracted from the Navy Registers is matched with three other sources. The first is the appendix of Bennett (1896), which lists every serving naval engineer up until 1896. This is used to construct basic experience measures for each engineer. This work also includes a list of vessels and basic ship attributes such as displacement, ship dimension, and year of build. The second source, the Dictionary of Fighting Ships, augments ship information in Bennett (1896). This also includes newer vessels and other vessel traits such as the complement (the number of sailors and other crew members) and ship cruising speeds.

Finally, we use Naval Academy registers to document officer performance as midshipmen at the Academy on a variety of subjects for the graduating classes of 1865 - 1905.[25] This also allows us to track each officer's class year, and thus produce basic experience measures for ship personnel. We obviously do not have a one-for-one mapping between personnel and their Naval Academy education, and this is due to a number of factors. The primary reason is lack of

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[24] For example, a vessel could be stationed in the Pacific for five years while the officer and engineer counts aboard vessels vary year to year as the ship docks at ports and personnel change stations.

[25] See Glaser and Rahman (2011), where we discuss this data at greater length.

coverage - for vessels during the 1870s we only have information for relatively younger officers; for vessels after 1905 we do not have any information on newly commissioned officers. Further, many engineers employed by the Navy were not commissioned officers and did not go through the Academy; this is particularly true for the earlier part of our data series. Nevertheless, we are able to link officers with their Academy profiles for the majority of our sample.

The final match-merged data includes the personnel, personnel attributes, status and characteristics of every active U.S. naval vessel from 1870 to 1911. This span of time generates a wide range of steam vessel-types and enables us to track factors linked to very different technologically-embodied ships; technological proxies include the age of the vessel and its speed (the age profiles of all active vessels are illustrated in figure 1). At the same time, our study deals both in the pre-amalgamation age (so that we analyze two distinct skill-types) and the post-amalgamation age (where such distinctions were at least *de jure* eviscerated). Descriptive statistics for ship characteristics of vessels active in naval power projection (out at sea) appear in table 1.

Finally, we include year effects for all regressions. These conceivably important controls reduce bias from the omission of time-specific factors such as changes to naval budgets, variations in aggregate naval personnel, and shifts in strategy and international relations.[26]

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[26] Particularly important is controlling for the build-up and draw-down of battle readiness from 1897 to 1899 due to the Spanish-American War.

Table 1: Descriptive statistics of ships (conditional on active service)

ship characteristics	observations	mean	standard deviation	minimum	maximum
engineers (ship-year observation)	1370	2.19	2.01	0	10
officers (ship-year observation)	1327	7.05	3.22	0	18
perc. engineers (ship-year observation)	1297	0.216	0.174	0	1
age (ship-year observation)	1345	12.94	7.94	1	46
avg. officer experience (ship-year observation)	748	14.5	5.1	0.26	35.20
max speed (knots)	188	13.4	4.1	4	30
displacement (1000 tons)	205	3.86	4.19	0.042	20.38
length (feet)	205	259.54	91.70	70	518
complement (sailors)	175	297.04	231.04	12	1108
cumulative time at sea (ship-year observation)	1370	5.49	4.62	1	33

5 Results

5.1 Engineer counts

Our first empirical exercise regresses the concentrations of engineer personnel or line officers aboard active vessels on vessel characteristics including variables controlling for size, age, personnel measures and sea experience. For these we use Poisson pooled and Poisson random effects regressions, since dependent variables are count variables with nearly equal mean and variance. The count profiles of both engineers and officers aboard active vessels are illustrated in figure 3, while descriptive statistics for variables included in all regressions appear in table 1. Many ship-characteristic variables are not time dependent - these include measures of displacement (in thousand tons), length (in feet) and complement (the total number of ship personnel as recorded in the *Dictionary of Fighting Ships*). Variables that evolve over time include the age of the vessel, the cumulative number of years since 1870 that the ship has been active at sea ("cumulative sea"), and the number of naval officers assigned to the vessel. Some specifications (indicated on each table) include cohort interactions, which are combinations of vessel ages and the year dummy variables. These essentially capture and control for the vintage of ships. For example, a 5 year old ship observed in 1880 likely has less advanced technology than a 5 year old ship observed in 1885. Finally, given the heterogeneity in our sample of vessels (e.g. some ships as small as 70 feet long, with others over 500 feet long), we control for additional non-linearities in technology using quadratic regressors. These allows us capture points at which expanding demand for skilled labor on vessels begin to level-off.

Table 2: Poisson regressions of engineers assigned to active vessels on vessel characteristics (1870-1899)

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
vessel age	-0.011***	-0.010***	-0.013***	-0.020	-0.074	0.043	-0.029	-0.037
	(0.003)	(0.003)	(0.004)	(0.030)	(0.06)	(0.129)	(0.030)	(0.034)
vessel age squared	-	-	-	-	-	-	0.0003	0.002
							(0.0004)	(0.0005)
displacement (1000 tons)	0.135***	0.110***	0.085***	0.101***	0.472***	0.425***	0.403***	0.452***
	(0.017)	(0.018)	(0.02)	(0.02)	(0.097)	(0.111)	(0.034)	(0.073)
displacement squared	-	-	-	-	-	-	-0.023***	-0.024***
							(0.003)	(0.005)
length (feet)	0.002***	0.002***	0.003***	0.002***	0.004	0.007*	0.003*	-0.0005
	(0.0006)	(0.0005)	(0.0007)	(0.0007)	(0.0004)	(0.003)	(0.0015)	(0.003)
length squared	-	-	-	-	-	-	-6.54e-6**	-8.39e-7
							(2.94e-6)	(5.07e-6)
cum sea	-	-0.002	0.002	0.013	0.048	0.069**	0.049***	0.066***
		(0.005)	(0.006)	(0.008)	(0.033)	(0.033)	(0.016)	(0.019)
cum sea squared	-	-	-	-	-	-	-0.002**	-0.002**
							(0.0008)	(0.0008)
complement	-	-	0.00005	-0.00007	-	-0.0002	-	0.001
			(0.0003)	(0.0004)		(0.0014)		(0.001)
complement squared	-	-	-	-	-	-	-	-2.37e-6
								(1.66e-6)
officers	-	0.051***	0.044***	0.045***	0.081***	0.077***	0.092***	0.087***
		(0.001)	(0.011)	(0.013)	(0.029)	(0.039)	(0.0016)	(0.038)
officers squared	-	-	-	-	-	-	-0.0004***	-0.0004**
							(0.0016)	(0.0019)
observations	784	784	579	579	784	579	784	579
no. of vessels	123	123	92	92	123	92	123	92
pseudo R^2	0.14	0.15	0.15	0.16	-	-	0.18	0.18
year effects	yes	yes	yes	yes	yes	yes	yes	yes
age*cohort interactions	no	no	no	yes	yes	yes	yes	yes
χ^2 of age*cohort interactions	-	-	-	310.29***	112.33***	135.2***	109.96***	108.6***
random ship effects	no	no	no	no	yes	yes	no	no

standard errors shown in parentheses, bootstrap estimators except in random effects specifications
*** p<0.01, ** p<0.05, * p<0.1

Table 2 presents results for engineer counts serving on active ships at sea for the years 1870-1899, the estimates of which derive from the empirical methodology outlined in section 3.1. In pooled regressions, estimates support our basic hypotheses for the presence of technology-skill and capital-skill complementarities in naval activity. With respect to capital, displacement and length positively affect the roll of engineers. Columns (1)-(3) show results from pooled regressions which do not include cohort effects to control for vintage. In these specifications the results clearly indicate that larger, longer and newer ships received more engineers, i.e. the more technically inclined skilled labor. One consequence of pooling of course is that the disturbances may be correlated within groups, leading to serial correlation and less efficient estimates. One can think of the naive pooled regression as having a disturbance term divided conceptually into two parts, a random component, u_{it} and a group share c_i. The estimates in columns (5)-(6) should be more efficient than pooled regression, but still may run the risk of omitted variables, eroding the unbiasedness of estimates.

For most specifications, chi-squared tests support the inclusion of age-cohort interactions.[27] Regardless of their vintage, older ships always require fewer engineers than newer vessels. That is, 5-year-old vessels in 1884 require more engineers than 10-year-old vessels in 1884, and 5-year-old vessels in 1899 requires more engineers than 10-year-old vessels in 1899. Intercepts and slopes, however, do not remain consistent *and* do not show any trend across time. For example, 10-year old vessels in 1894 require fewer engineers than similarly aged vessels in 1884 but more than similarly aged vessels in 1899. A snapshot of these vintage effects (based on the results from column (8) of table 2 appears as figure 4.

We also observe a strong inter-skill complementarity - the number of officers aboard the vessel is closely associated with the number of engineers. These results may also be endogenous, which we explore further with IV regressions in a later section of the paper.

One might consider the use of a vessel's age as a proxy for technology. This is defensible on the basis of the historiography of the navy - technological progress happened in fits and starts, but it also happened *chronologically.* Thus the year of a ship's construction might give us a sense of the technological vintage of the vessel. As figure 4 indicates, however, these vintage effects

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[27] The authors will provide complete set of results for the vintage interaction coefficients upon request. Each chi-squared test is based on 30 degrees of freedom.

shift over time. The only consistently clear pattern (a negatively sloped function) indicates that during any given year, older ships had fewer engineers.

Along with improved fuel efficiency, a primary goal for the improvement of steaming technology was to increase the potential cruising speed of a vessel. We have this information for only 80% of the sample of vessels. Ceteris paribus, vessel speed does not appear to influence engineer numbers assigned to ships (results not reported).

Yet even after controlling for the speed (i.e. propulsion technology) of the vessel, a decline in engineering personnel continues to persist for every year that vessels age. Although we do not report the estimates for the 29 additional age-cohort interaction terms, the reader can be assured that these estimates echo the results shown in figure 4.[28] We also continue to observe robust positive effects on engineer numbers from the size of ships. Longer and heavier ships demanded more engineers on active vessels. These quadratic coefficients appear quite small but statistically significant, and if anything indicate a leveling-off of the demand for engineers rather than a shift in direction of the relationship as ships grew in size.

Finally, the typical complement on a ship appears to have no relationship with the assigned number of engineers. This suggests two things. First, it provides *a fortiori* evidence of capital-engineering skill complementarities, as greater numbers of engineers are associated with larger ships even controlling for overall size of labor. Thus we are not merely capturing a scale effect. Second, it suggests no engineer-unskilled labor complementarities.

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[28] Again, the authors will provide estimates of interaction coefficients upon request.

Table 3: Poisson regressions of engineers assigned to active vessels on vessel characteristics (1901-1911)

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
vessel age	0.015*	-0.002	0.022	-0.008	0.044***	0.070***	0.033	-0.012
	(0.008)	(0.012)	(0.021)	(0.137)	(0.016)	(0.024)	(0.124)	(0.201)
vessel age squared	-	-	-	-	-	-	0.0003	0.002
							(0.001)	(0.002)
displacement (1000 tons)	0.037	0.035	-0.043	-0.053	0.06**	-0.025	-0.06	-0.186
	(0.018)	(0.023)	(0.035)	(0.036)	(0.027)	(0.033)	(0.082)	(0.110)
displacement squared	-	-	-	-	-	-	0.0076	0.012
							(0.0047)	(0.006)
length (feet)	0.004***	0.004***	0.003***	0.004***	0.002*	0.001	0.0092**	0.002
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.004)	(0.006)
length squared	-	-	-	-	-	-	2.25e-6	2.91e-6
							(9.50e-6)	(8.28e-6)
cum sea	-	0.047***	0.021	0.018	0.050	0036	0.226***	0.212***
		(0.020)	(0.038)	(0.039)	(0.030)	(0.035)	(0.042)	(0.061)
cum sea squared	-	-	-	-	-	-	-0.009***	-0.011***
							(0.002)	(0.003)
complement	-	-	0.002***	0.003***	-	0.0023***	-	0.0071***
			(0.0006)	(0.0006)		(0.0007)		(0.0017)
complement squared	-	-	-	-	-	-	-	5.80e-6
								(1.65e-6)
officers	-	0.024	0.020	0.001	-0.008	-0.007	0.195***	0.11**
		(0.020)	(0.021)	(0.024)	(0.024)	(0.025)	(0.055)	(0.052)
officers squared	-	-	-	-	-	-	-0.013***	-0.0089***
							(0.0035)	(0.0029)
observations	531	492	455	455	492	455	492	488
no. of vessels	123	123	113	113	123	113	123	113
pseudo R^2	0.14	0.15	0.17	0.19	-	-	0.20	0.24
year effects	yes	yes	yes	yes	yes	yes	yes	yes
age*cohort interactions	no	no	no	yes	yes	yes	yes	yes
χ^2 of age*cohort interactions	-	-	-	20.04*	28.66***	32.21***	18.48***	30.84***
random ship effects	no	no	no	no	yes	yes	no	no

standard errors shown in parentheses, bootstrap estimators except in random effects specifications
*** p<0.01, ** p<0.05, * p<0.1

Table 3 presents results for the exact same exercise, but here we look strictly at the 1901-1911 period. This is the period directly following the Amalgamation Act, which officially abolished the distinction between line and staff officers. Our left-hand side variable now is the vessel counts of *erstwhile* engineers, who here have regular officer status and rank, aboard active vessels.

Differences in results between this and the earlier period are striking. In summary, those with engineering backgrounds and training appear to have been completely transmogrified into an entirely different creature. No longer is there any association between the displacement of a vessel and the number of engineers (there does remain a positive association between length and engineer numbers). Rather, there is now a strong relationship between the *complement* of the ship and its engineer-oriented crew. Thus scale still matters, but here it appears to operate through unskilled labor rather than capital.

What about technology? Even without including a measure for speed (which remains insignificant - results not shown), there is no evidence that suggests that newer vessels were linked to more engineers. That is true whether we do or do not include age-cohort effects.

Finally, the evidence supporting officer-engineer complementarities is now much weaker.[29] In short, the complementarities between engineers and capital, technology and other skilled laborers embraced by naval strategists in the earlier era appears completely eviscerated with amalgamation. What is striking here is that the Navy of this era was deploying and embracing engineer-oriented technologies to an unprecedented degree. One would imagine that the Great White Fleet would require technocrats to manage and operate complicated machinery and technologies now more than ever. So did the regular officer corps pick up the slack? We explore this possibility in the next section.

5.2 Officer counts

Conceivably the kinds of skills officers provided prior to the Amalgamation Act differed from engineers. To test for differences, we estimate Poisson specifications for the number of officers on active vessels from 1870-1899 and present these in table 4.

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[29] There remains a positive association when we include quadratic terms. This suggests that while the officer-engineer link may have been important in small numbers, the link breaks down fairly rapidly for larger numbers.

Table 4: Poisson regressions of officers assigned to active vessels on vessel characteristics (1870-1899)

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
vessel age	-0.002*	-0.0037*	-0.006***	-0.0075	0.165**	0.02	-0.034***	-0.0072
	(0.0015)	(0.002)	(0.0024)	(0.017)	(0.077)	(0.086)	(0.010)	(0.015)
vessel age squared	-	-	-	-	-	-	0.0005***	-0.0001
							(0.00016)	(0.0002)
displacement (1000 tons)	0.069***	0.049***	-0.015	-0.015	0.264	-0.157	0.237***	0.074*
	(0.009)	(0.012)	(0.011)	(0.0095)	(0.17)	(0.126)	(0.029)	(0.042)
displacement squared	-	-	-	-	-	-	-0.015***	-0.0047
							(0.0021)	(0.0030)
length (feet)	0.0007*	0.0005	-0.00005	0.00005	0.011	0.005	0.003**	0.002
	(0.0004)	(0.00035)	(0.0004)	(0.0004)	(0.007)	(0.007)	(0.0013)	(0.002)
length squared	-	-	-	-	-	-	-8.61e-6***	-5.81e-6
							(2.59e-6)	(3.54e-6)
cum sea	-	0.0079**	0.0093**	0.0083***	0.083*	0.056	0.037***	0.013
		(0.0034)	(0.004)	(0.0035)	(0.045)	(0.046)	(0.009)	(0.0098)
cum sea squared	-	-	-	-	-	-	-0.001**	-0.00012
							(0.0004)	(0.00046)
complement	-	-	0.0013***	0.0013***	-	0.010***	-	0.003***
			(0.00017)	(0.0003)		(0.003)		(0.0007)
complement squared	-	-	-	-	-	-	-	-2.93e-6***
								(9.33e-7)
engineers	-	0.046***	0.031***	0.032***	0.21***	0.161*	0.086***	0.058*
		(0.009)	(0.008)	(0.009)	(0.079)	(0.086)	(0.026)	(0.030)
engineers squared							-0.007***	-0.0048
							(0.0025)	(0.003)
observations	784	784	579	579	784	579	784	579
no. of vessels	123	123	92	92	123	92	123	92
pseudo R^2	0.05	0.06	0.08	0.08	-	-	0.09	0.09
year effects	yes	yes	yes	yes	yes	yes	yes	yes
age*cohort interactions	no	no	no	yes	yes	yes	yes	yes
χ^2 of age*cohort interactions	-	-	-	44.92***	66.86***	47.20***	102.12***	39.02*
random ship effects	no	no	no	no	yes	yes	no	no

standard errors shown in parentheses, bootstrap estimators except in random effects specifications
*** p<0.01, ** p<0.05, * p<0.1

First, while we do find some evidence of capital-officer skill complementarity, the evidence is much weaker in this case. Compared with results in Table 2, the comparable coefficients on displacement are either insignificant or are notably smaller. Further, the coefficients on length tend towards insignificance.

Instead, we find a very strong association between the total complement aboard vessels and the number of officers. This makes sense, as officers served a primary role as managers of sailors rather than as direct operators of machinery. This is in stark contrast to the results for engineers.

With respect to technology, evidence for technology-officer skill is weaker or essentially non-existent. Columns (1)-(3) show negative coefficients on vessel age that are nevertheless much weaker than corresponding results in Table 2. Further, coefficients on age-cohort interaction terms are all insignificant, again in notable contrast to results for engineers. This is true whether or not we include speed as an additional control, which also remains insignificant (results not reported).

The evidence suggests that prior to amalgamation officers functioned very differently from engineers, and the roles and responsibilities of each group profoundly complemented the other.

Notice also that prior engineers in the 20th century behave much like officers in the 19th century - they complement unskilled ship personnel but not capital or technology. That is, erstwhile engineers take on more traditional officer roles in leadership and management and less technocratic tasks. Could the reverse be said of officers in the 20th century?

Table 5: Poisson regressions of officers assigned to active vessels on vessel characteristics (1901-1911)

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
vessel age	-0.005	-0.018***	-0.022***	-0.04*	0.131**	0.20***	-0.068***	-0.020
	(0.004)	(0.006)	(0.006)	(0.025)	(0.067)	(0.072)	(0.022)	(0.027)
vessel age squared	-	-	-	-	-	-	0.0006*	0.00007
							(0.00035)	(0.0005)
displacement (1000 tons)	0.048***	0.051***	0.033***	0.030***	0.46***	0.20*	0.029	-0.07**
	(0.008)	(0.0076)	(0.010)	(0.01)	(0.075)	(0.12)	(0.029)	(0.033)
displacement squared	-	-	-	-	-	-	0.001	0.005***
							(0.002)	(0.0018)
length (feet)	0.002***	0.0018***	0.0013***	0.0014***	0.005	0.002	0.010***	0.0078***
	(0.0005)	(0.0004)	(0.0005)	(0.0005)	(0.004)	(0.0039)	(0.0017)	(0.0021)
length squared	-	-	-	-	-	-	-0.00001***	-0.00001***
							(2.43e-6)	(3.13e-6)
cum sea	-	0.038***	0.041***	0.040***	0.160***	0.135**	0.065***	0.021
		(0.0076)	(0.0084)	(0.007)	(0.054)	(0.058)	(0.014)	(0.014)
cum sea squared	-	-	-	-	-	-	-0.0017**	-0.0008
							(0.0008)	(0.0008)
complement	-	-	0.0005*	0.00065**	-	0.007***	-	0.0045***
			(0.00028)	(0.0003)		(0.003)		(0.0007)
complement squared	-	-	-	-	-	-	-	-2.58e-6
								(7.13e-7)
engineers	-	0.029	0.024	0.014	-0.119	-0.010	0.063	0.016
		(0.023)	(0.019)	(0.022)	(0.17)	(0.18)	(0.042)	(0.054)
engineers squared	-	-	-	-	-	-	-0.022	-0.019
							(0.014)	(0.016)
observations	492	492	455	455	492	455	492	455
no. of vessels	123	123	113	113	123	113	123	113
pseudo R^2	0.22	0.24	0.24	0.24	-	-	0.26	0.28
year effects	yes	yes	yes	yes	yes	yes	yes	yes
age*cohort interactions	no	no	no	yes	yes	yes	yes	yes
χ^2 of age*cohort interactions	-	-	-	11.54	50.94***	40.90***	22.27**	18.65**
random ship effects	no	no	no	no	yes	yes	no	no

standard errors shown in parentheses, bootstrap estimators except in random effects specifications

*** p<0.01, ** p<0.05, * p<0.1

Table 5 presents the results of Poisson regressions of officers during the Post-Amalgamation era. The evidence suggests that there was some task convergence from the officer side as well.

For one, there appear to be stronger capital-skill complementarities. Columns (3)-(6) show positive and statistically significant effects of displacement on officer numbers, whereas none existed for corresponding regressions for the 19th century. Results for vessel length are also much stronger for the 20th century compared with the 19th. On the other hand, the positive association between ship complement and officers appears notably weaker (at least when we do not include quadratic terms).

The bottom line is that amalgamation appears to have been "successful," in that engineers behaved more like officers and officers more like engineers. Part of this was surely due to educational and curricular changes at the Naval Academy, which by the turn of the 20th century made a robust effort to train the *whole* brigade in propulsion, metallurgy, and all courses related to naval engineering. However, as we mentioned earlier there remained resistance to the Navy's return to omni-competence for its officer corps, as it related more to competence in the engineering-focused technologies of the new Navy and not to traditional naval training. Indeed, a cursory comparison across tables 2-5 may suggest that the old engineering corps was transformed much more radically than the old officer corps. And as mentioned earlier, there remained concern that such an asymmetric amalgamation may result in a reactionary corps unprepared and ill-suited for 20th century, state-of-the-art naval developments.

5.3 Engineer intensity

From our Poisson regressions, it appears that officers and engineers before 1900 had very different functions on active vessels. To get a somewhat different perspective of the engineer skill intensity required on ships, we estimate the *ratio* of engineers to officers on a ship. (Hence we estimate a relative measure for engineers.) Estimates from these regressions appear in table 6.

Table 6: Engineer intensity on active vessels (engineers/officers)

VARIABLES	70-99	70-99	70-99	70-99	01-11	01-11	01-11	01-11
vessel age	-0.006**	0.0038	-0.020**	-0.0068	0.003	0.007	0.003	-0.004
	(0.0029)	(0.017)	(0.009)	(0.017)	(0.004)	(0.01)	(0.012)	(0.015)
vessel age squared	-	-	0.0003	0.0003	-	-	.00008	0.0003
			(0.0002)	(0.0002)			(0.0003)	)(0.0004)
displacement (1000 tons)	0.057***	0.063***	0.192***	0.220***	-0.008	-0.009	-0.026	-0.023
	(0.016)	(0.017)	(0.058)	(0.064)	(0.006)	(0.007)	(0.019)	(0.019)
displacement squared	-	-	-0.010***	-0.012***	-	-	0.0013	0.001
			(0.0036)	(0.004)			(0.0009)	(0.0009)
length (feet)	0.001*	0.0010	-0.0019	-0.002	0.0003	0.0003	0.0007	0.0009
	(0.00058)	(0.0007)	(0.0036)	(0.002)	(0.0003)	(0.0003)	(0.0009)	(0.001)
length squared	-	-	2.97e-6	2.28e-6	-	-	-3.63e-7	-7.38e-7
			(3.23e-6)	(3.14e-6)			(1.23e-6)	(1.36e-6)
cum sea	0.006	0.010**	0.19***	0.022***	0.003	0.003	0.024*	0.034**
	(0.005)	(0.005)	(0.007)	(0.008)	(0.008)	(0.008)	(0.013)	(0.015)
cum sea squared	-	-	-0.0004*	-0.0003	-	-	-0.001**	-0.0016**
			(0.0002)	(0.0003)			(0.0004)	(0.0006)
complement	-0.0005**	-0.0006**	-0.001*	-0.0013**	0.0002	0.0002	0.0004	0.0003
	(0.0002)	(0.00025)	(0.0006)	(0.0006)	(0.0001)	(0.0001)	(0.0003)	(0.0003)
complement squared	-	-	7.28e-7	9.34e-7	-	-	-2.75e-7	-1.61e-7
			(6.87e-7)	(6.83e-7)			(2.06e-7)	(2.12e-7)
observations	563	563	563	563	435	435	435	435
no. of vessels	92	92	92	92	112	112	112	112
pseudo R^2	0.28	0.31	0.31	0.35	0.16	0.18	0.21	0.24
year effects	yes	yes	yes	yes	yes	yes	yes	yes
age*cohort interactions	no	yes	no	yes	no	yes	no	yes
χ^2 of age*cohort interactions	-	330.31***	-	265.82***	-	20.83**	-	24.50**

standard errors shown in parentheses, bootstrap estimators except in random effects specifications
*** p<0.01, ** p<0.05, * p<0.1

Results here echo those from Poisson regressions. During the pre-amalgamation period (columns 1-4), we find a consistently positive relationship between ship displacement and engineer to officer ratios. Thus the "scale effect" of larger more capital-intensive vessels creating greater demands for skilled labor occurred asymmetrically. Yet if we "scale" ships by complement size, we find the reverse. More unskilled labor assigned to vessels was associated with smaller engineer-to-officer ratios. Thus the greater demands for skilled personnel on larger vessels were not merely due to scale through constant returns - they were also *biased* towards particular skills.

Further, older vessels are associated with smaller engineer-officer ratios. When we include age-cohort interaction terms, the average age effect disappears but the interaction terms are negative and statistically significant. Thus naval technologies evolving over time in the 19th century appear to be biased towards engineers.

The post-amalgamation age (columns 5-8) paints a starkly different picture. With the exception of cumulative sea experience, there are no statistically significant coefficients. After 1900, there are essentially no statistically discernible differences between engineers and officers. This provides further evidence on the effective convergence between the two.

5.4 Instrumental variable strategy

As discussed in section 3.1.1 and outlined in Mullahy (1997), Poisson specifications with an endogenous variable produce biased estimates. In particular, the number of officers on a ship is likely endogenous in engineer regressions for the pre-amalgamated Navy, as officers and engineers likely were *simultaneously* assigned to ships. Following Wooldridge (2002), we can confirm the endogeneity of officers by first estimating the residuals from an OLS regression of *officers* on *age*, *displacement*, *length*, *cumulative sea* and *complement*, as well as cohort and time effects. We then estimate a Poisson regression similar to column (4) of table 3 and include the residuals from the first stage as an additional covariate. The p-value associated with these residuals in the second stage equals 0.002, a result that makes it appear desirable to use IVs.

We use the *complement* (the number of enlisted sailors) of a ship as an instrument and justify this based on two claims. First, *complement* is a rather strong predictor of the number of officers on a vessel. In fact, it is the only robust predictor of the number of officers assigned to a vessel in OLS specifications. As table 5 highlights, most Poisson specifications also support this claim. Quite confidently, we can state that *complement* robustly predicts approximately 26% of the variance in officer appointments on vessels.[30] Secondly, a test does not exist to prove instrument exogeneity in exactly identified models as estimated here. We can claim, however, with a fair amount of statistical support that *complement* has no statistically significant effect on the number of engineers. Although it strongly correlates with the size of ships and the number of officers serving on ships, in repeated specifications (as shown in Appendix table A2), *complement* has no direct effect on the assignment of engineers to vessels.

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[30] Results of various OLS first-stage specifications are reported in Appendix A1).

Table 7: IV regressions of engineers serving on active vessels (1870-99)

VARIABLES	QML (Poisson) (1)	OLS (Linear) (2)	GMM (IV transformation) (3)	2S-QML (Poisson) (4)	2SLS (Linear) (5)
age of vessel	-0.019	0.009	-0.084	-0.019	0.007
	(0.024)	(0.021)	(0.060)	(0.024)	(0.020)
disp. (1000 tons)	0.099***	0.137***	0.155***	0.101***	0.131***
	(0.024)	(0.021)	(0.022)	(0.026)	(0.021)
length (feet)	0.0023**	0.002***	0.0014	0.002**	0.002**
	(0.0009)	(0.0007)	(0.0009)	(0.0010)	(0.0007)
cumulative sea	0.013	0.010	0.034***	0.014	0.009
	(0.0010)	(0.007)	(0.0106)	(0.010)	(0.006)
officers	**0.044*** **	**0.033*** **	**0.053***	**0.045*** **	**0.051*** *
	(0.012)	(0.009)	(0.032)	(0.013)	(0.024)
observations	579	562	579	579	562
number of vessels	all specifications include the 92 vessels with data for ship *complement*				

Columns (1) & (2) included as baseline, not estimated with instrumental variables.
Columns (3) - (5) include *complement* as an identifying instruments.
Columns (4) and (5) use $\widehat{officers}$ as regressors estimated from linear first stage regressions.
For marginal effect comparisons, columns (2) & (5) use $ln(engineers)$ as the dependent variable.
All specifications include year (cohort) effects as well as age*cohort interactions.
Significance implied by *** p<0.01, ** p<0.05, * p<0.1. 2SQML standard errors not adjusted.

Table 7 summarizes output from IV regressions and corresponding uncorrected estimates for comparison. Results from baseline (uncorrected) Poisson regressions appear in column (1), while the semi-elasticities from an OLS regression that uses the natural log of engineers as the dependent variable appear in column (2). The IV problem is tackled using the three alternative strategies: the Mullahy (1997) GMM estimator (column (3)), a 2-stage quasi-maximum likelihood procedure (column (4)), and a two-stage least squares estimator (column (5)). Aside from the coefficient for *officers*, the core set of coefficients remain robust to IV corrections. In general, an increase in the number of officers on ships results in a corresponding increase in vessel needs for engineers.

So far the analysis suggests that there was a great deal of labor specialization, but only before amalgamation. As we have described, amalgamation was motivated by rising communication and coordination costs within the corps, as well as the fear that division within the fleet could stifle technological developments and paralyze naval strategy. But amalgamation generated its own concern that a homogenous corps would be a less technologically savvy one, and this could itself endanger technological progress. However, while the post-amalgamation Navy was limited in its ability to specialize along the *extensive* margin of human capital (officer versus engineer), it could perhaps allocate tasks along more *intensive* margins of human capital, and thus could help it continue to operate complex and engineer-oriented technologies. We explore the roles of these intensive measures of human capital on specialization patterns in the following sections.

5.5 Personnel Experience

On the job experience can serve as a proxy for human capital development in a number of ways. One, work experience can produce firm or industry-specific knowledge accumulation. Two, technological or structural changes within the industry can either augment or erode one's existing level of human capital through work experience over time. If workers receive formal education prior to working, job experience measures may capture the *vintage* of such education.

We have two different measures of worker job tenure, originating from two separate sources. The first comes from Bennett (1896), which lists the names and start dates of every engineer who served in the Navy, from its inception to 1896.[31] We match the data with navy registry information to construct an *average* experience measure for the longevity of service for engineering personnel assigned to vessels. The second measure documents the average experience of *all* officers (line and engineer) associated with active vessels; this comes from linking officers listed in navy registers with their Naval Academy profiles (these indicate year of graduation). Thus the former measure includes all engineers but no line officers, while the latter contains all line and engineer officers but no uncommissioned engineers. Note also that our Naval Academy documentation only goes back to 1865 - earlier observations for our second measure will then systematically over-report experience. The inclusion of year effects helps us control for such systematic bias.

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[31] We are able to extrapolate the information up to 1899.

Table 8: Average Experience of Engineers on Active Vessels (in days, 1870-1899)

VARIABLES	(1)	(2)	(3)
age	36.35**	30.06	-30.94
	(16.61)	(21.1)	(68.99)
displacement (1000 tons)	-338.6***	-222.4***	-259.81***
	(52.59)	(75.70)	(81.19)
length	4.12	1.62	2.79
	(3.06)	(3.02)	(3.17)
cum sea	0.23	0.186	-0.269
	(0.278)	(0.328)	(0.397)
complement	-	-1.05	-0.94
		(1.20)	(1.15)
observations	735	543	543
number of vessels	123	92	92
overall R^2	0.55	0.53	0.56
year effects	yes	yes	yes
age*cohort interactions	no	no	yes

Random effects included for all regressions (FGLS)
Bootstrap standard errors shown in parentheses, with *** p<0.01, ** p<0.05, * p<0.1.

Table 8 displays results from FGLS regressions of average engineer experience associated with active vessels on vessel characteristics.[32] Strikingly, older vessels (measured either through age or age-cohort interactions) are associated with more experienced engineers, while more capital-intensive vessels (measured by displacement) are associated with *less* experienced engineers. This likely captures human capital vintage effects, as earlier-trained engineers were likely less familiar with the workings of newer and more advanced vessels. Thus newer and larger ships were manned by younger and larger groups of engineers, a result that we would expect in an environment with capital- and technology-skill complementarities.

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[32] The inclusion of speed measures do not meaningfully alter results. The inclusion of quadratic terms somewhat weaken the results.

Table 9: Average Experience of All Officers
on Active Vessels (in years, 1870-1899)

VARIABLES	(1)	(2)	(3)	(4)
age	0.028*	0.073	0.017	-0.011
	(0.015)	(0.051)	(0.020)	(0.10)
displacement (1000 tons)	-0.27**	-0.27**	-0.23*	-0.19
	(0.11)	(0.11)	(0.13)	(0.14)
length	0.0007	0.0003	0.004	0.002
	(0.003)	(0.004)	(0.006)	(0.006)
cum sea	-0.023	-0.02	-0.03	-0.02
	(0.03)	(0.035)	(0.03)	(0.035)
complement	-	-	-0.004	-0.004*
			(0.002)	(0.0023)
officers	-0.049	-0.048	-0.027	-0.20
	(0.037)	(0.04)	(0.04)	(0.04)
engineers	-0.245***	-0.233***	-0.190***	-0.178***
	(0.049)	(0.050)	(0.055)	(0.059)
observations	746	746	552	552
number of vessels	118	118	88	88
overall R^2	0.84	084	0.84	0.84
year effects	yes	yes	yes	yes
age*cohort interactions	no	yes	no	yes

Random effects included for all regressions (FGLS)
Bootstrap standard errors shown in parentheses, with *** p<0.01, ** p<0.05, * p<0.1.

These results are generally echoed when we look at *all* officers assigned to active vessels (Table 9), although the results are somewhat weaker. Even after controlling for the number of engineers (who tend to be systematically younger than their line-officer counterparts) more experienced members of the officer corps tend to be assigned to less capital-intensive vessels.

These findings are only for the 19th century, yet they do suggest another avenue for the 20th century Navy to allocate human capital across its fleet. As the Naval Academy adjusted its curriculum to meet the needs of the modernizing fleet, it stands to reason that newer and less seasoned personnel would better serve more modern vessels. Such an allocation strategy could mitigate potentially negative effects arising from amalgamation.

5.6 Personnel Education

Another intensive measure of human capital includes the education officers received while students at the Naval Academy. For the graduating classes of 1865 - 1905, we document each officer's first-year order of merit (this tends to capture basic proficiency in math, science and languages) and overall order of merit (over all four years), as well as class rank in four specific subjects - steam engineering, seamanship, ordnance and gunnery, and navigation.[33] Dividing rank measures by graduating class size gives us percentile score measures for each officer. We use these percentile scores to produce average human capital measures associated with active vessels, as well as maximum and minimum scores.

Perhaps not surprisingly, we do not get any statistically significant results when we regress average officer education measures on ship characteristics. Each ship crew consisted of a motley mix of officers with varying academic performance scores - averages appear merely to wash away this heterogeneity. However, regressing the *top* score obtained by a member of the ship crew on ship characteristics produces some interesting results. The most striking findings are those pertaining to steam engineering (Table 10) and first-year scores (Table 11).

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[33] These four sub-fields tend to have the most consistency and relevance across graduating classes and years (Glaser and Rahman 2011).

Table 10: Maximum Steam Engineering Percentile on Ship Characteristics (1870-1911)

VARIABLES	(1)	(2)	(3)	(4)
vessel age	-0.002**	-0.0084**	-0.007**	-0.01***
	(0.001)	(0.003)	(0.003)	(0.004)
vessel age squared	-	-	-	0.0002**
				(0.00008)
vessel speed	-	-	0.009**	0.045**
			(0.004)	(0.020)
vessel speed squared	-	-	-	-0.0012**
				(0.00055)
displacement (1000 tons)	-0.002	-0.0006	0.0024	0.011
	(0.003)	(0.004)	(0.004)	(0.010)
displacement squared	-	-	-	-0.0005
				(0.0005)
length (feet)	0.0004**	0.0005**	0.0002	0.0005
	(0.0002)	(0.0002)	(0.0003)	(0.0007)
length squared	-	-	-	-9.65e-7
				(1.01e-6)
officers	0.013***	0.011***	0.010***	0.020**
	(0.002)	(0.002)	(0.0024)	(0.008)
officers squared	-	-	-	-0.0006
				(0.0004)
engineers	0.0003	-0.002	-0.004	-0.010
	(0.003)	(0.003)	(0.004)	(0.009)
engineers squared	-	-	-	0.001
				(0.0009)
observations officers	1212	1212	1094	1094
no. of vessels	205	205	188	188
overall R^2	0.22	0.25	0.26	0.27
year effects	yes	yes	yes	yes
age*cohort interactions	no	yes	no	yes

Random effects included for all regressions (FGLS)
*** p<0.01, ** p<0.05, * p<0.1

Table 11: Maximum First-Year Percentile on Ship Characteristics (1870-1911)

VARIABLES	(1)	(2)	(3)	(4)
vessel age	-0.002*	-0.010**	-0.007	-0.005
	(0.00085)	(0.0045)	(0.004)	(0.005)
vessel age squared	-	-	-	-0.00005
				(0.00009)
vessel speed	-	-	0.011**	0.060***
			(0.005)	(0.018)
vessel speed squared	-	-	-	-0.002***
				(0.0005)
displacement (1000 tons)	0.0005	0.002	0.0048	0.009
	(0.0031)	(0.003)	(0.004)	(0.011)
displacement squared	-	-	-	-0.0002
				(0.0005)
length (feet)	0.0002	0.0003	-0.0001	-0.0004
	(0.0002)	(0.0002)	(0.0003)	(0.0007)
length squared	-	-	-	3.65e-7
				(9.31e-7)
officers	0.014***	0.011***	0.010***	0.016**
	(0.002)	(0.002)	(0.0024)	(0.008)
officers squared	-	-	-	-0.0004
				(0.0004)
engineers	0.005	0.004	0.005	0.0025
	(0.0029)	(0.003)	(0.004)	(0.008)
engineers squared	-	-	-	0.0004
				(0.0010)
observations officers	1216	1216	1098	1098
no. of vessels	205	205	188	188
overall R^2	0.23	0.26	0.26	0.28
year effects	yes	yes	yes	yes
age*cohort interactions	no	yes	no	yes

Random effects included for all regressions (FGLS)
*** p<0.01, ** p<0.05, * p<0.1

When we consider steam engineering scores, there does appear to be ability-technology complementarities. As before, newer vessels are associated with greater engineering skill. This time however, we measure skill as the skill pertaining to only one individual. Both for pre- and post-amalgamated navies, what appears to matter is not that the entire crew is good at engineering, but rather at least *someone* is good at engineering. Again this points to further specialization; as those with stellar engineering backgrounds were tasked with the newer aspects of naval operations, other officers could focus on more traditional tasks. Note that these age effects are quite strong. In contrast to our previous count analysis, vessel age remains negatively related to engineering skill even when we control for age-cohort effects (these are also negative).

Another new feature now is that vessel speed positively predicts engineering skill. Specifically, each knot is associated with anywhere between 1 and 4.5 extra percentile points of higher engineering scores for the highest-scoring member of the crew. Further, our age effects remain robust even with the inclusion of speed. The bottom line is that we observe significant technology-skill (but no capital-skill) complementarities when we focus on the officer with the highest demonstrated ability in steam engineering.[34]

What about other subject areas? Here the results are notably weaker or nonexistent. Tellingly, steam engineering skills appear to be the most important skill for a crew member to be linked up with more advanced ship technology.[35] That includes our percentile scores for overall order of merit. However, as demonstrated in Table 11, maximum first-year percentile scores are also positively related technological proxies. During this time (and even today) first-year classes at the Naval Academy were devoted almost entirely to basic subjects (math, history, English) and virtually no course focused on navy-specific material. This may suggest that first-year scores proxy for basic or general knowledge (as opposed to navy-specific knowledge), and one who has such knowledge may benefit the crew of a technologically sophisticated vessel more than anyone with traditional naval skills.

Again, the results suggest that the Navy was able to match skills with capital and technologies with more subtlety than just through the extensive margin of matching officers with some tasks and engineers with others. As amalgamation obscured and ultimately obliterated the distinction between line and engineer officers, the Navy had the ability to compensate by matching through more intensive human capital measures like education and experience.

6 Conclusion

As the nation proceeded through the second Industrial Revolution, naval vessels became increasingly more technical. The most advanced vessels (faster, heavier and newer) required larger

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[34] The inclusion of *complement* does not produce a statistically significant coefficient, does not significantly alter our coefficients, and simply limits the number of observations.

[35] Detailed results for all subjects available upon request.

shares of technically-proficient workers for operation. Skilled workers were highly specialized, and the late-19th century Navy was one where complementarities abounded.[36]

Yet in the early 20th century, when engineer-oriented technologies were being rapidly developed and implemented, we observe far less labor specialization. This was because the efficiency gains that typically arise from specialization did not appear to outweigh the large communication and coordination costs associated with a divided corps. The Navy was still able to link capital and technologies with more intensive human capital measures, but the extensive divide between line and staff was dead by 1900.

The U.S. Navy today remains committed to the model of the omni-competent naval officer, employing policies such as the "division officer shuffle" where officer reassignments occur frequently to produce well-rounded sailors. This paper studies the antecedents of our current military paradigm. Yet the study also offers historical lessons on the dynamics of change pertinent to nonmilitary societies as well. The tradeoffs of labor specialization, and how organizations restructure when technologies change, should be a valuable study for businesses of all kinds.

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[36] Such inferences can only be made indirectly for this time period. Details on the task content of specific occupations are typically not available for the 19th century (the first edition of the *Dictionary of Occupational Titles* which would have such information was published in 1939).

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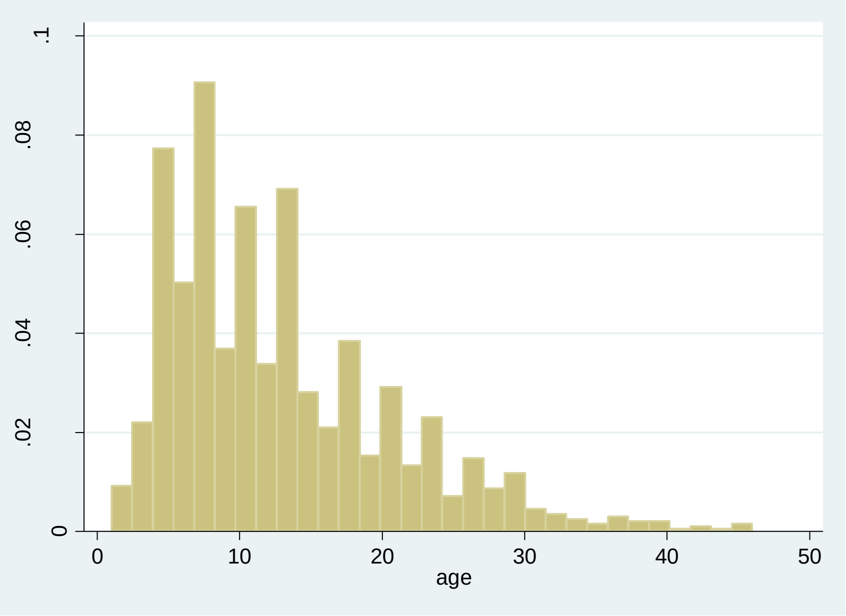
Figure 1: Age and displacement profiles of active vessels

Age of all active vessels across all years (years)



Displacement of all active vessels across all years (thousand tons)

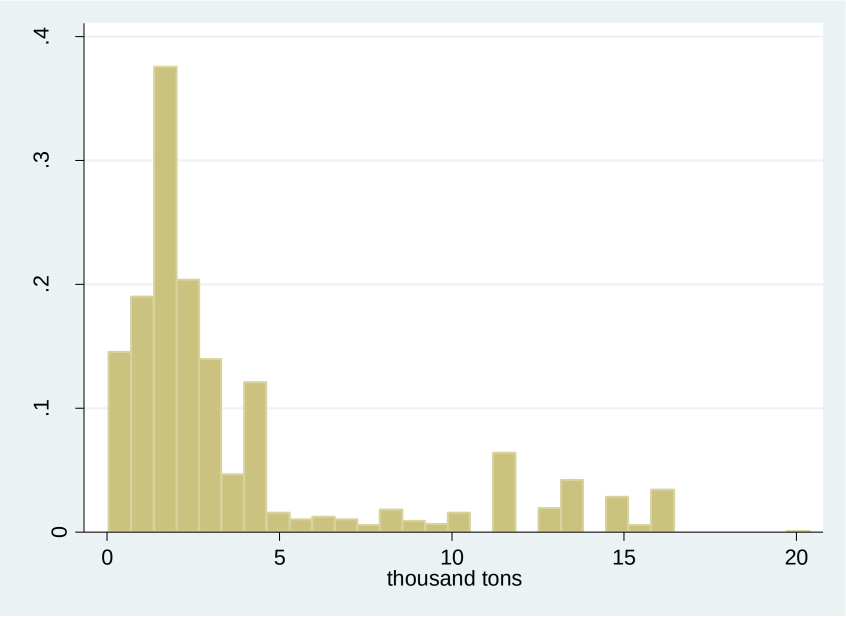
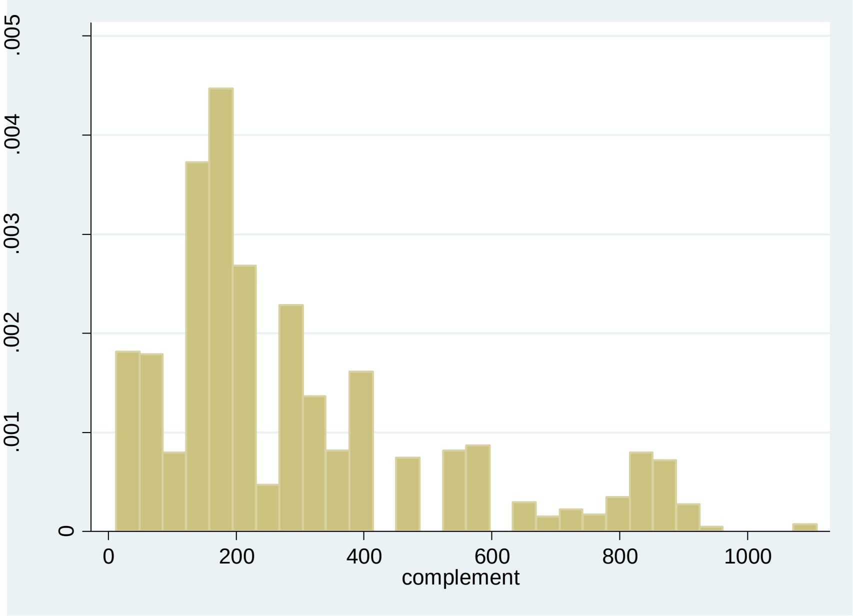


Figure 2: Complement and speed profiles on active vessels

Complement of all active vessels across all years (number)



Speed of all active vessels across all years (knots)

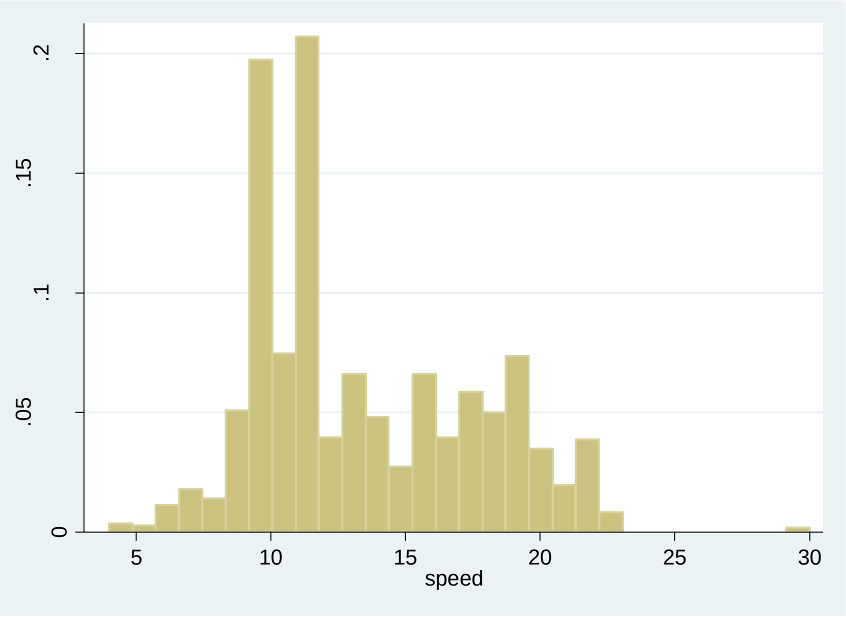
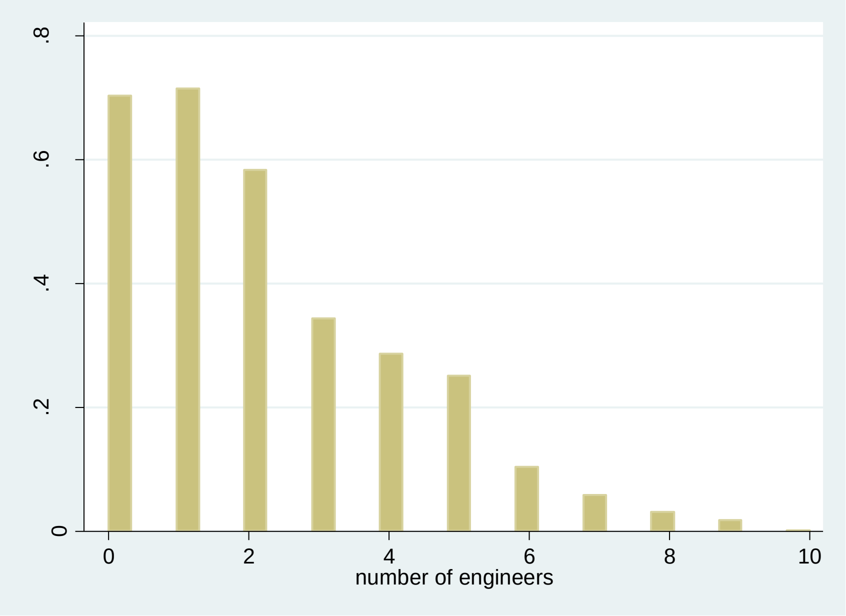
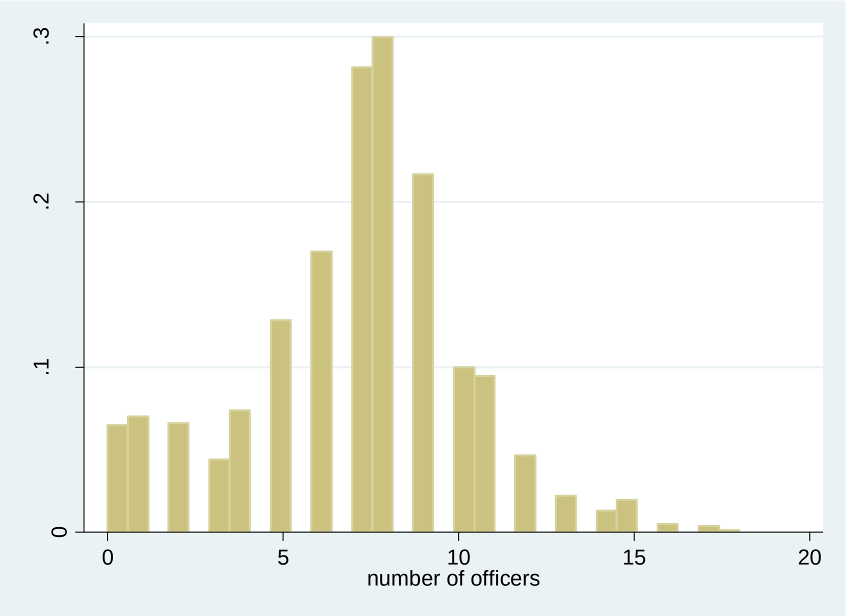


Figure 3: Numbers of skilled labor on active vessels

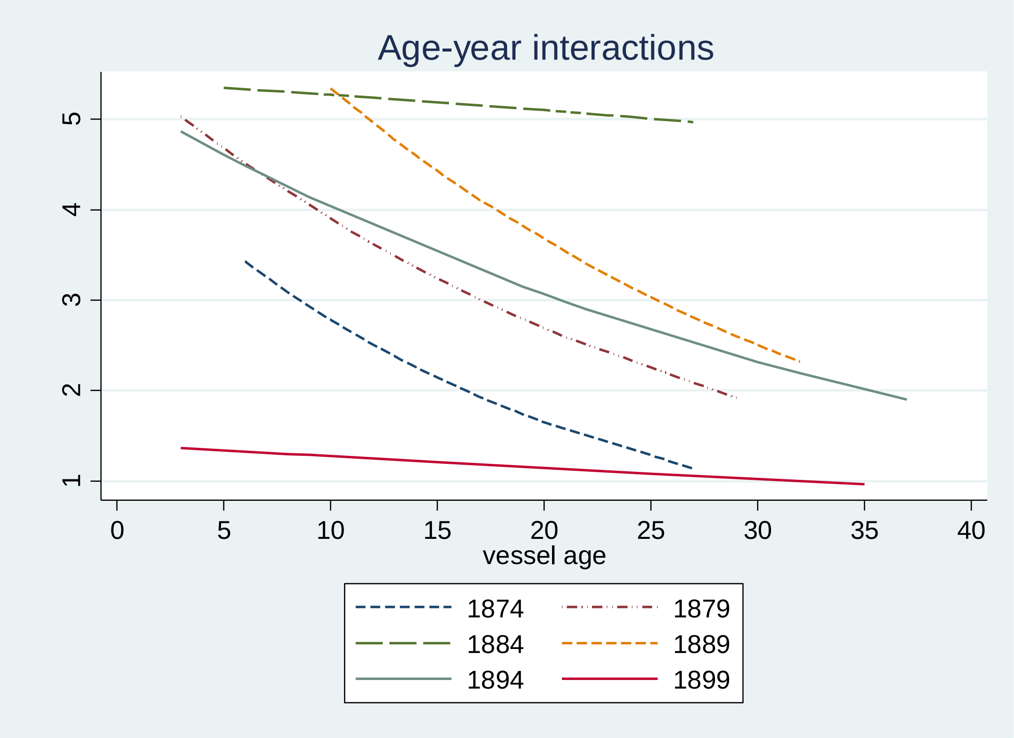


Numbers of engineers aboard active vessels across all year



Number of officers aboard active vessels across all years

Figure 4: Vintage effects over time - predicted number of engineers (vertical axis)



8 Appendix

Table A1: First-Stage OLS for *Officers* (used in IV regressions)

	(1)	(2)	(3)
complement	0.0104***	0.0107***	0.0108***
	(0.0013)	(0.0008)	(0.0008)
age of vessel	-0.0720	-	-
	(0.0676)		
displacement (tons)	-0.00002	-	-
	(0.0001)		
length (feet)	0.0011	-	-
	(0.0036)		
cumulative sea	0.0763**	-	-
	(0.0341)		
observations	563	includes only observations with *complement* data	
number of vessels	87		
χ-squared test of age*cohort interactions	0.82	1.10	-
R^2	0.4374	0.4324	0.2636
Model fit F-stat	6.63	6.53	210.9

Columns (1)-(4) include year effects as well as age*cohort interactions.
Significance implied by *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table A2: (Lack of) effect for *Complement* on *Engineers*

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
complement	0.0005	0.0006**	0.0002	0.0002	0.00008	0.0008
	(0.0003)	(0.0003)	(0.0004)	(0.0004)	(0.0005)	(0.00008)
complement-squared	-	-	-	-	-	-1.7e-6
						(1.3e-6)
observations	563	includes only observations with ship *complement* data				
number of vessels	87					

each column represents same specification as table 3 with addition of *complement* regressor(s)
other coefficients not reported
standard errors in parentheses, bootstrap estimators except in random effects specifications
*** $p<0.01$, ** $p<0.05$, * $p<0.1$