Selection and Firm Survival

Evidence from the Shipbuilding Industry, 1825-1914

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Several theories of firm performance can explain the well-known observation that survival is positively related to age. However, a more mundane explanation – selection bias driven by variations in firm quality – may also underlie the phenomenon. This paper employs a 90-year plant-level panel data set on the US iron and steel shipbuilding industry of the 19th and early 20th centuries to discriminate between the two explanations. The shipbuilding industry exhibits the usual joint dependency of survival on age and size, but this dependency is eliminated after controlling for heterogeneity by using pre-entry experience as a proxy for firm quality. The evidence points to a dominant role for selection bias in creating the age-dependency of survival. At the same time, pre-entry experience is found to have a large and extremely persistent effect on survival, and this finding is inconsistent with standard explanations for the role of pre-entry experience on firm performance.

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I. Introduction

One of the most prominent empirical regularities to emerge in industrial organization is the age dependency of firm survival. The relationship has been observed in large multi-industry samples constructed from manufacturing censuses in several countries, as well as in numerous specialized samples.[1] Importantly, because age and size are positively correlated among surviving firms, and size and survival are positively correlated, the age-dependency of exit is robust to controlling for firm size.[2]

The relationship is an attractive target for modelers. Because age-dependency is an intriguing and challenging regularity to explain, we have come to expect that models able to do so will be revealing about the way industries evolve. A number of competing explanations now exist, but they all exploit the idea that age serves as a proxy for an omitted variable. First, firms may accumulate knowledge over time, through learning by doing or as the outcome of an active research program. Knowledge reduces the exit hazard but it is unobservable to the econometrician, so age appears to reduce directly the exit hazard. Second, Cooley and Quadrini (2001) construct a model in which financial market frictions induce variations in the debt-equity ratio that are correlated with age, that affect the survival rate, and that have not to date been included in hazard regressions.[3] Third, Klepper and Thompson (2002) construct a model in which industries are composed of distinct, but intrinsically unobservable, submarkets. Firm survival is increasing in the number of submarkets in which a firm is active and this number

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[1] Studies using census data include Dunne, Roberts and Samuelson (1988, 1989; US), Disney, Haskel and Heden (2000; UK), Baldwin *et al.* (2000; Canada), and Persson (2002; Sweden). Evans (1987a, 1987b) and Hall (1987) report similar results using Dun and Bradstreet data and Compustat data respectively. For more specialized samples, see Audretsch (1991), Audretsch and Mahmood (1995), Baldwin and Gorecki (1991), Mata and Portugal (1994), and Wagner (1994).

[2] And thus models in which size is a sufficient statistic for exit are inconsistent with the evidence.

[3] Clementi and Hopenhayn (2002) have shown that such financial market frictions are efficient in the presence of moral hazard.

is in turn correlated with age.[4]

However, there could be a more mundane explanation for the age-dependency of survival. It is well-known that unobserved heterogeneity in the exit hazard induces the appearance of age effects on survival. As a cohort of firms ages, the risk set becomes increasingly composed of firms with the lowest propensity to exit. The mean exit rate for the cohort therefore declines with cohort age, even if the exit hazard does not decline with age for any individual firm.

If age-dependency can be explained by unobserved heterogeneity, the regularity would turn out to be rather unrevealing. After all, no one expects all firms to be equally capable, and discovering that they are not teaches us little. We would therefore like to be able to discriminate between these competing classes of explanations. This paper presents the results of a particularly simple test, using a new panel data set on plant-level output in the US iron and steel merchant shipbuilding industry, covering the period 1825 to 1914. These output data are combined with proxies for firm quality, constructed from extensive textual records, that predict the propensity to exit. I show first that the familiar size-conditional age-dependency of exit is present in the data. I then ask whether the addition of the quality proxies to the hazard regression eliminates the age-dependency of the hazard. The answer is that it does: after conditioning on firm type the hazard is independent of age. The results therefore imply that the initial age-dependency can be explained by selection bias.

This paper uses data on firms' pre-entry experience as a proxy for firm quality. The results clearly show that the effects of pre-entry experience do not decay even over a very long horizon, and they are not diminished by controlling for size. We have long known that firms and entrepreneurs with prior experience closely related to their new venture survive much longer than those without rele-

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[4] Conventional wisdom is that Jovanovic's (1982) selection model was the first to predict a positive relationship between age and survival, but this interpretation is incorrect. In Jovanovic, the exit hazard must initially rise with age, before eventually falling to zero.

vant experience,[5] and there is now emerging a body of evidence that the pre-entry experience of a firm or its founders has extremely persistent effects.[6] These regularities by themselves may reflect nothing more than hysteresis effects from dynamic scale economies. However, the new finding in this paper that pre-entry experience effects show no tendency to diminish over long periods of time even after controlling for size is inconsistent with the standard rationalizations for the role of pre-entry experience. Theories that can explain this remarkable effect of pre-entry experience may well be revealing about the way industries evolve.

II. Notes on Iron and Steel Shipbuilding

Shipbuilding is an ancient industry, and one of the oldest in America. The first ship built in the English colonies, a 30-ton vessel called the *Virginia*, was launched on the Kennebec River in 1607. In the ensuing decades numerous coastal and fishing vessels were built, and by the end of the 17th century centers of activity had been established in Maine, Massachusetts, and on the Delaware. By the end of the revolutionary war, output had reached 35,000 tons annually

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[5] Lane (1989; ATM machines), Mitchell (1991; diagnostic imaging), Carroll *et al.* (1996; autos), and Klepper and Simons (2000; televisions) show that diversifying firms with experience in related fields perform better along a variety of dimensions than less experienced entrants. Dunne, Roberts and Samuelson (1988) find that diversifying firms survive longer and grow faster than *de novo* entrants. Sleeper (1998; lasers), Klepper and Sleeper (2001; lasers) and Walsh, Kirchhoff and Boylan (1996; semiconductor silicon) report that spin-offs survive longer than other startups, and Klepper (2002b; autos) further shows that the quality of a spin-off's parent matters. Eisenhardt and Schoonhoven (1990; semiconductors) report that firm performance is increasing in the industry experience of their founding teams. Helfat and Lieberman (2002) have a helpful review of the literature.

[6] See Carroll *et al.* (1996), Geroski, Mata, and Portugal (2002), Klepper (2002a, 2002b, 2003), and Klepper and Simons (2000). Their findings resonate with Jovanovic and Rousseau's (2001) observation that something about the firms that went public during the 1920s (which the authors attribute quite generically to firm quality and label "organization capital") has served them well enough to account for greater stock market capitalization than real cumulative investment would have predicted, even to the present day.

(Hutchins, 1948). In the first half of the 19th century, output fluctuated around 100,000 tons per year, until a dramatic rise in the 1850s associated with expanding trade increased output to almost 600,000 tons in 1855 (see Figure 1).

Only a tiny fraction of this output consisted of metal-hulled vessels. The first iron-hulled vessel, a minnow of 14 tons named *Codorus*, was launched in 1825 in York, PA. Although it undertook a widely-reported journey up the Susquehanna River as far as Binghamton, it failed to stimulate additional efforts. Over the next thirteen years, a couple of small experimental vessels were launched, and several iron steamboats were imported from England and employed with some success in the cotton trade on the Savannah River (Brown, 1951). The year 1838 marks something of a transition. In that year, the West Point Foundry Association of Cold Point, NY, built a steam catamaran, the *United States*. At 222 tons, it was far larger than any iron vessel previously built in the US, a significant advance on the state of the art, and was still in service 22 years later. More notable, perhaps, it was the first boat constructed by a firm that was eventually to launch more than one vessel, and the first to be launched by a firm of substantial size and identifiably relevant expertise. West Point's entry was followed in fairly short order by firms that were to undertake substantial production during their lives, including the Phoenix Foundry (founded in 1842), Harlan & Hollingsworth (1844), and Neafie, Levy & Co. (1844).

Nonetheless, as Figure 1 illustrates, iron shipbuilding did not amount to much until the last quarter of the 19th century. In the 50 years to 1874, only 61 firms entered the industry. Of these, 48 firms had abandoned production by 1875, only two of them having launched more than ten vessels. A mere 560 vessels had been launched and, with a total capacity of 300,962 gross tons, iron shipbuilding accounted for less than three percent of total shipbuilding. Average vessel size, at just 536 tons, had also remained modest, and only two vessels exceeding 5,000 tons had been launched. These numbers stand in stark contrast to their counterparts for the forty-year period 1875-1914, during which time 212 producers en-

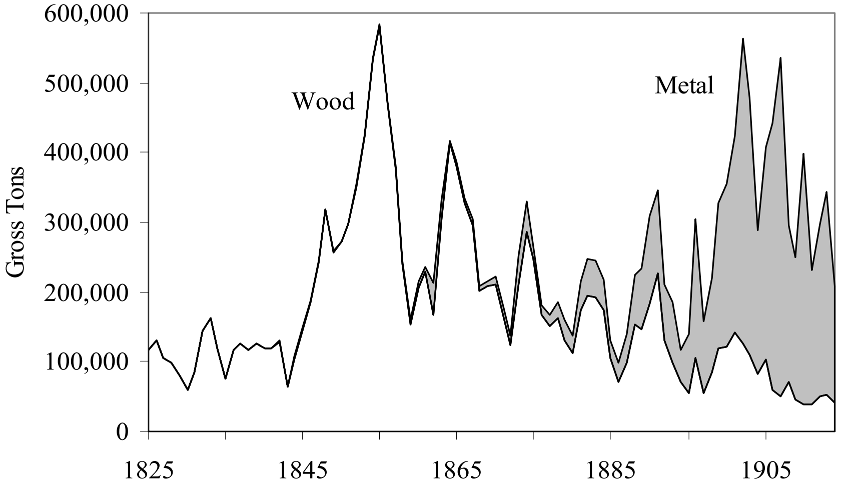

FIGURE 1. Production by hull type, 1825-1914, excluding barges. Sources: Smith and Brown (1948) and author's calculations.

tered, and 3,550 vessels with an average capacity of 1,729 tons were launched for a total of over 6.14 million tons, including 346 ships exceeding 5,000 tons (see Figures 2 and 3). By the end of this period, metal had fully supplanted wood as the material of choice, and vessels were being built of a size far in excess of anything ever launched by wood shipbuilders.

In some key respects, the evolution of the metal shipbuilding industry is quite typical of nineteenth century industries. It began slowly, with considerable experimentation, and initially occupied niches in the market. In particular, the shallow drafts of iron boats made them especially attractive on the western and Atlantic rivers.[7] Eventually, however, several factors converged to enable metal shipbuilding almost completely to displace wooden shipbuilding. First, increasing

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[7] It should be recalled that the western rivers were largely shallow rivers until the spread of dams late in the nineteenth century. The voyage of the *Codorus* up the Susquehanna River, which at that time not considered navigable, was primarily to show off the advantage of shallow-draft vessels.

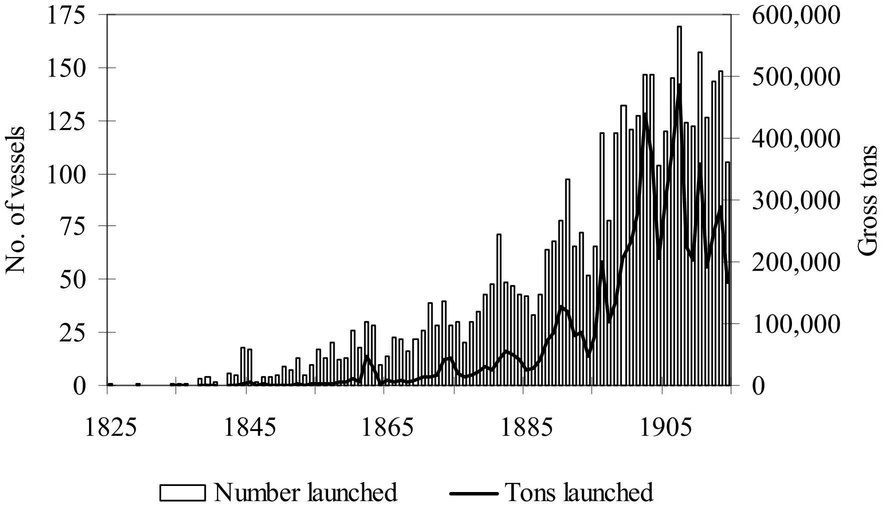

FIGURE 2. Iron and steel vessels launched by private yards, 1825-1914.

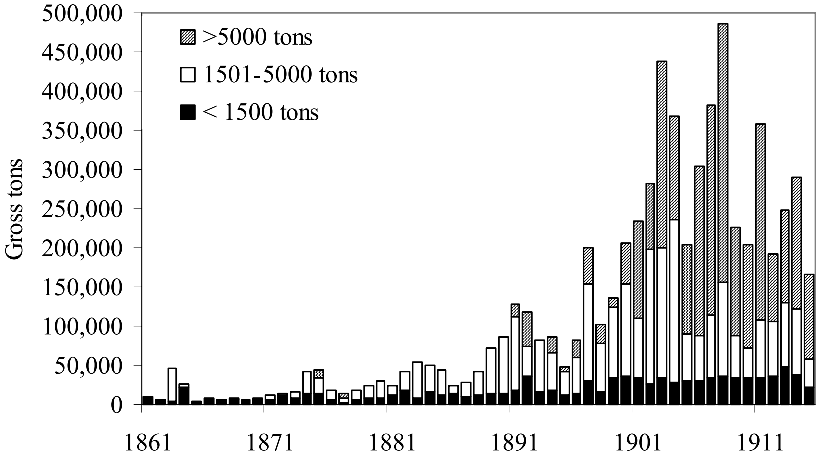

FIGURE 3. Total deliveries of metal-hulled vessels, by vessel size (gross tons).

industrialization around the Great Lakes and expanding overseas trade created a demand for vessels of a size exceeding the technical limits of wood hulls. Second, the substitution of metal for wood hulls in smaller vessels employed on the rivers and in the coastal trade accelerated as wood became increasingly scarce and declined in quality at the same time that iron, and subsequently steel, increased both in supply and quality. Third, technological advances, particularly in the automation of riveting, in the ability to produce large steel plates, and in engine design, made the construction of large vessels feasible (Hutchins, 1948). Finally, the increasing sophistication of financial markets provided the necessary capital.

In other respects, however, the evolution of shipbuilding was less typical. A common, although not universal, feature of industry evolution is that output grows at a declining rate. As Figure 2 shows, this was not the case for shipbuilding. Many industries also experience a shakeout, in which the number of firms declines precipitously without a corresponding decline in output. This was also not the experience in shipbuilding. Figure 4 shows that the total number of active firms increased almost monotonically over the sample period, with no spike in exit or decline in entry.

It is easy to understand why shipbuilding did not experience a shakeout. Geography played an important role. For example, vessels as large as those that began to be employed on the Great Lakes at the end of the nineteenth century could neither leave nor enter the Great Lakes system at that time;[8] shallow draft vessels designed for the western rivers were not seaworthy enough to be built on the coast and sailed to the rivers; and the Panama Canal did not exist for most

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[8] The USS *Michigan*, intended for service on Lake Erie, was the US navy's first iron-hulled gunboat. The vessel was erected in downtown Pittsburgh in 1843 to exploit local expertise in iron work and engine building, but had to be dismantled for transportation to Lake Erie and re-erected there. (Ballard, 1995). During World War I, Benjamin Cowles, a Buffalo, NY, shipbuilder, made a good living cutting ships in half to transport them from the Great Lakes to the Atlantic. Upon repairing them, he sold them for Atlantic operations (from typescript notes kindly provided by the Lower Lakes Historical Society). The St. Lawrence Seaway did not open until 1959.

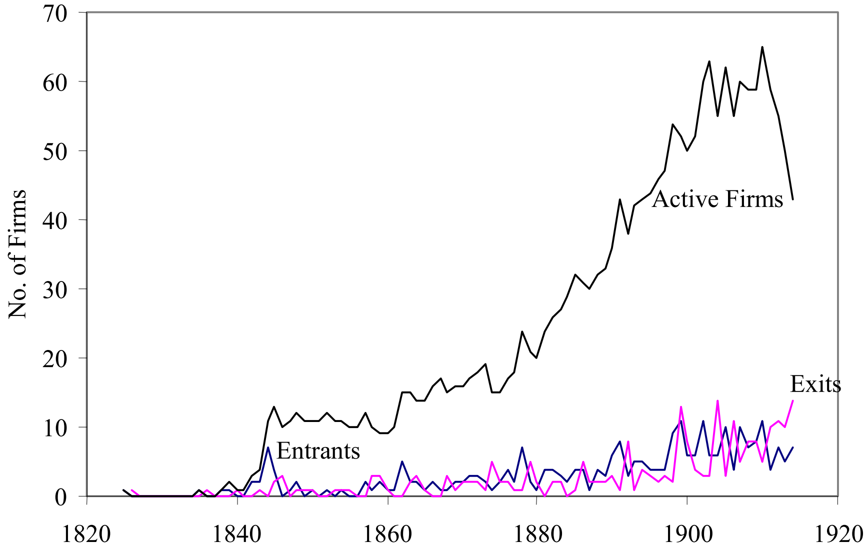

FIGURE 4. Annual Entry and Exit. Entrants are recorded as the first year in which a vessel is launched. Exits are recorded the year after their last vessel is launched.

of the sample period. Consequently, firms located near their markets and production was scattered widely throughout the Great Lakes, on the rivers, and on both seaboards.

Within geographic markets, capacity constraints prevented concentration of output. Building in iron required considerable capital and the construction of specialized buildings to house machinery.[9] An iron or steel shipbuilder, once established, was more or less immobile, and often faced insurmountable obstacles to expansion. So iron shipbuilders found themselves very much tied to the locational decisions they had initially made. How deep was the water? How wide was the waterfront? How many vessels could be accommodated at one time? How large

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[9] Cramp (1902) points out that the large Philadelphia yard of William Cramp & Sons owned a single derrick costing $30,000 the value of which was "considerably greater than that of William Cramp's entire ship-yard sixty years ago. . . which was not then surpassed by any other ship-yard on the Delaware." (p. 2)

could these vessels be? These were not constraints that could easily be changed, and the specificity of capital made it costly and unattractive for firms to relocate. In fact, between 1825 and 1914 only two firms did[10] and, with the exception of two shipbuilding trusts formed at the turn of the century that brought together existing yards, only three firms opened multiple yards. It is not surprising that even among firms that survived a long period of time, what they did at the outset colored their activities forever.

Figures 5 and 6 illustrate the consequences of these constraints. As we have seen, average vessel size increased dramatically in the late 19th century, but early entrants generally did not participate in the secular rise in vessel size. Figure 5 shows that as the increase in average vessel size began to accelerate in the 1880s the average size of vessels launched by the most successful and long-lived pre-1860 entrants remained unchanged. Their survival was predicated on the continuing and growing demand for smaller vessels evident in Figure 3. Figure 6 plots annual numbers of vessels launched for two of the most successful producers in Philadelphia (charts for other successful firms are similar). Within a fairly short period of time, each firm was producing at much the same rate of output that it would see for the rest of its long career, and no trend in output is visible. The contrast with other major industries at the turn of the century, such as automobiles, where firm success was typically associated with significant growth and innovation, is notable.

As even successful firms failed to grow and exploit the new market opportunities presented by the demand for larger vessels, the new markets

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[10] The Cleveland Ship Building Company moved its yard from Cleveland to Lorain in 1898, to facilitate expansion. The Racine Boat Manufacturing Company relocated from Racine, WI to Muskegon, MI in 1904. Although Racine newspapers had been speculating about the move for some time, it did not take place until a disastrous fire destroyed the yard, the landowner refused to renew the lease, and Muskegon offered free land, tax breaks and $20,000 in cash (Gunther, 1989; Wheeler, 1998).

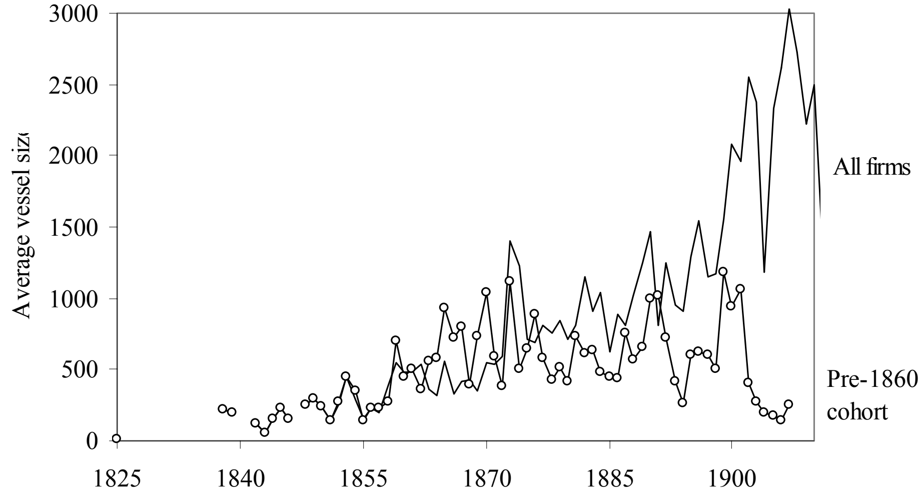

Figure 5. Average size of vessels launched by year. Shown separately for all firms, and for firms with entry date prior to 1860.

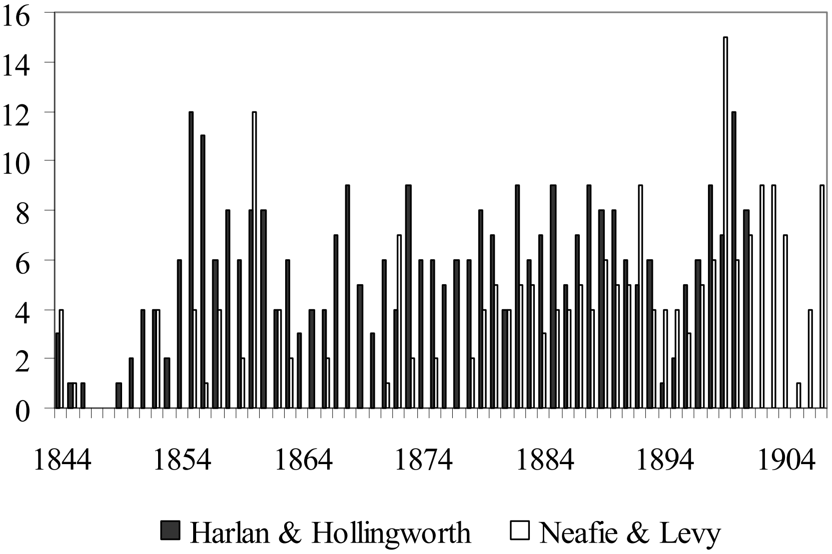

Figure 6. Number of vessels launched by year, by two successful Philadelphia yards.

emerging in the shipbuilding industry had to be met by entrants whose yards could be purpose-built to handle the new ships. Several of these late entrants – Bath Iron Works, New York Ship, Newport News, American Shipbuilding -- specialized in the construction of large ships exceeding 5,000 tons and would survive to become the major US shipbuilders of the latter half of the 20th century. In the process, they leave the casual observer with the impression that the typical yard of 1900 was an industrial massif owned by a corporate giant. But the impression is misleading. In fact, there remained to be filled a growing demand for small vessels, which existing yards were no more able to fill than they were to produce large ships. Consequently, the typical entrant in the latter half of the century looked much like its earlier counterparts.

III. Data

Since 1789, US law has required that all vessels exceeding 20 gross tons capacity be registered with the government. The registration documents contain basic technical details about each vessel but have always been of limited value to researchers because they are scattered, incomplete, and, above all, they do not record the builder. This study takes as a starting point a fortunate find in the National Archives (Bureau of Navigation, c.1920). Around 1920, William Lytle, an employee of the Bureau of Navigation with a penchant for making lists, constructed a record of metal vessels built in the United States since 1825. The register, a hand-written leather-bound volume, is based on official documents but, remarkably in view of the work it must have entailed, the register also lists the builder for most of the vessels. The register is not quite a finished product. A large number of early vessels were omitted entirely, others were not assigned to builders, and others were incorrectly assigned. Corrections were made using diverse sources, especially Brown (1951) and typescript vessel lists held in various specialized manuscript collections. A more extensive omission is that the register reports only merchant vessels. Vessels built by private companies for the U.S. Customs Service, the U.S. Coast Guard, and the U.S. Navy were added from official records provided in Bauer and Roberts (1991), Benham and Hall (1913), Canney (1993, 1995, 1998), Conway (1979), Still (1996), and US Coast Guard (1989).

The sample analyzed in this paper was restricted to producers who launched at least one vessel in excess of the 20 gross tons capacity required to trigger registration.[11] However, in order to track more precisely the dates of activity of the included firms, the sample includes all metal vessels known to have been produced by the firms, regardless of gross tonnage. The restricted sample contains technological details of exactly 4,000 vessels constructed by 273 producers. Figure 7 compares the number of vessels for which I have information with the US Department of Commerce's (USDC) official tally of metal vessels built during the period. To facilitate comparison with the USDC tally, the figure excludes military vessels in the sample, all vessels under 20 gross tons capacity, and all vessels for which no gross tonnage is available, leaving a count of 3,482 vessels. The USDC tally reports 3,222 documented merchant vessels, missing 260 merchant vessels that should have been included. I believe that, subject to the minimum size requirement, the database is the most complete record in existence of metal shipbuilding in the United States prior to 1915.

The only major omissions that I am aware of are vessels constructed for export, and which therefore were not documented in the United States. Few firms exported vessels and, for most of those that did, export activity formed a minor part of their total production. There are a couple of exceptions, however. Between 1878 and 1914, James Rees and Sons of Pittsburgh, PA, produced hundreds of knock-down iron and steel steamboats for service on South American

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[11] Not all of the vessels in the database were registered, and some of those that were registered were not required to be. Fifty-seven builders, accounting for 114 boats, were excluded by the minimum size criterion.

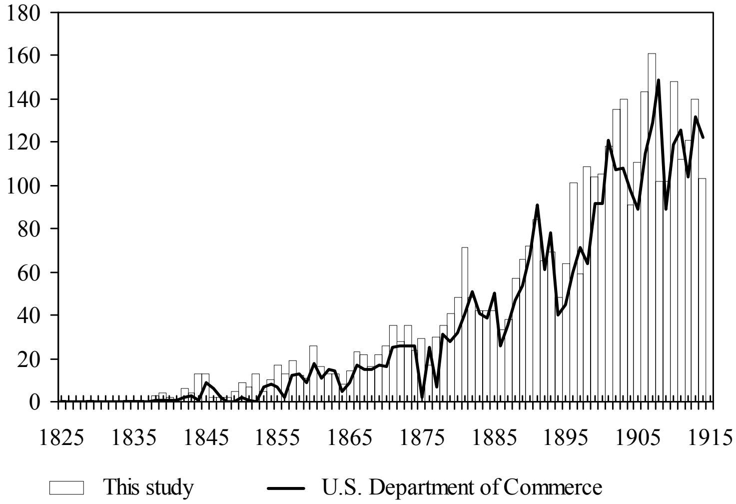

FIGURE 7. Metal Vessels Launched for Civilian Use, 1825-1914. Department of Commerce records allocate production vessels to year of registration or enrollment, whereas the data set allocates vessels to year of launching. These dates coincide in the majority of cases. Source for USDC data: Smith and Brown (1948, Table 6).

rivers (Rees and Sons, 1913), but only fourteen of their vessels are recorded in the United States. Marine Iron Works of Chicago, IL, also sold an unknown number of knock-down iron vessels to South America, although in their case the majority of their export trade consisted of the sale of machinery along with plans for wooden hulls to be built locally (Marine Iron Works, 1902).

To supplement the panel data on vessels, detailed textual histories have been produced for as many of the 273 recorded producers as possible. For some small producers, I have no information at all, while for others I have identified their pre-entry backgrounds only from city directories indicating their profession prior to entry. For most large producers, in contrast, extremely rich histories are available to document in some detail the way in which they entered and left the industry. The median producer lies between these extremes, and brief textual histories were constructed from a variety of sources, including manuscript records, county histories, obituaries, genealogical records, and (on several occasions) from information kindly provided by descendents of the shipbuilders. Further discussion of the data, especially of coding decisions made in the translation from textual firm histories to sample data, can be found in a companion paper (Thompson, 2004).

Coding of the pre-entry backgrounds of shipbuilders was concerned primarily with distinguishing firms or founders of firms that entered after gaining experience in manufacturing iron- and steel-hulled vessels, wood-hulled vessels or engines from those that entered with different backgrounds. Entrants with prior experience of vessel construction were experienced in hull design and marketing vessels, and had often earned a solid reputation for quality and reliability among vessel buyers. Firms with pre-entry experience in engine manufacturing were likely to be particularly technically competent, despite lacking direct experience in hull construction. In fact many shipbuilders, particularly builders of wooden vessels, were not equipped to manufacture engines and, although many operated small foundries to manufacture custom iron fittings, the normal practice was to sub-contract the major machinery to specialists. These indicators of relevant experience are compared with three other categories: firms whose pre-entry experience consisted of foundry work; firms with diverse pre-entry experiences including shipping, dredging, construction, railroads, rail car manufacturing, naval engineering, and iron milling; and firms whose pre-entry experience is not known.

Table 1 provides some summary statistics for the sample. Entrants that had previously been involved in shipbuilding or engine manufacturing are combined into a single variable, EXPERIENCED, and these firms are compared with others that had neither of these backgrounds. Of the 273 firms in the sample, 122 belong to the EXPERIENCED group, 48 had previously operated a FOUNDRY without having ventured into engine manufacturing, 50 are classified with prior experience in a range of MISCELLANEOUS fields, and 70 have UNKNOWN pre-entry backgrounds. The mean entry year for each group of firms is within five years of the overall sample mean, and the ranges and standard deviations are similar across groups. That is, there is no clear pattern over time in the types of firms entering.

Table 1

Entry Year, Life, and Entry Size, by Prior Experience

		SOURCE OF PRIOR EXPERIENCE			
	TOTAL	EXPERIENCED[a]	FOUNDRY[b]	MISCELLENOUS[c]	UNKNOWN
Number of Firms	273	122	48	50	70
Entry Year:					
MEAN	1889	1884	1886	1889	1894
MIN	1825	1825	1842	1844	1835
MAX	1914	1914	1914	1914	1914
STD. DEV	20.4	21.7	20.1	20.4	17.3
Duration (years):					
MEAN	10.2	15.4	6.1	12.2	2.4
MIN	0.5	0.5	0.5	0.5	0.5
MAX	110.5	92.5	57.5	110.5	21.5
STD. DEV	18.3	19.9	10.8	23.5	4.4

I use the first year in which a metal vessel was launched to mark a firm's entry, and the last year a vessel was launched, plus 0.5 (to avoid simultaneous entry and exit), to denote its time of exit. For firms with an unknown exit date after 1914, I code 1914 as the censoring year. [a] Shipbuilding or engine manufacturing. [b] Firms in this class include some also listed under Miscellaneous. [c] Includes shipping, dredging, construction, railroads, rail car manufacturing, naval engineering, and iron milling.

There are, however, significant differences across categories in survival and characteristics at entry. Experienced firms survived on average 15.4 years, longer than any other group. In contrast, foundry owners, the group with the least amount of recorded relevant experience, survived on average only 6.1 years. The diverse group of firms classified with miscellaneous backgrounds, comprising experiences in shipping, construction, and railroads among others, predictably fall between the two previous groups, with an average life of 12.2 years.

Inevitably, firms for which I have been able to code backgrounds are much more likely to be among the successful, the significant, or the strange. In the absence of further information, I take the crude approach of creating a category UNKNOWN, and run analyses both with this category and after excluding all firms with unknown backgrounds. However, the differences between survival rates of coded and uncoded firms are sufficiently large to raise the possibility that any measured effects of experience are biased upwards by the missing data. Fortunately, pre-entry experience is the only variable missing for these firms, and it is feasible to use Monte Carlo simulations to evaluate the potential effects of missing data. As I shall show later, the key results handily survive the simulation exercise.

IV. Results

The results are reported in four sections. If pre-entry experience serves as a proxy for firm quality, and if it to be capable of inducing spurious conditional age effects on survival, there must be a large and lasting effect of experience. Section A explores whether pre-entry experience meets these demands. Using a parametric hazard model that does not condition on quality, Section B shows that the data exhibit the usual joint effects of size and age on survival. Section C then shows that the introduction of the quality proxies eliminates the large and significant effect of age previously found. Finally, Section D reports results from the Monte Carlo simulations.

A. The magnitude and persistence of prior experience effects

Table 2 reports the results of four Cox proportional hazard regressions of the form

$$h(t, x_{it}, \beta, \lambda) = g(t)e^{x_{it} \ln \beta},$$

where $g(t)$ is a baseline hazard with unspecified form, x_{it} is the vector of covariates for firm i at age t, and β is vector of hazard ratios for the covariates. A hazard ratio of one indicates that the corresponding covariate has no effect on the baseline hazard. A coefficient less (greater) than one indicates that an increase in the value of the covariate lowers (raises) the exit hazard.

Columns 1 and 3 report the results with right-censoring of observations at 2001.[12] Column 1 excludes the 70 firms with unknown pre-entry backgrounds, while column 3 includes them. The baseline hazard is calculated for firms with foundry experience only, and the coefficient estimates reflect that their performance differs substantially from other experience groups. All regressions include controls for location and year of entry, the coefficients of which (not reported) do not suggest any noteworthy patterns.[13]

The key result is the estimated hazard ratio for firms with pre-entry experience in shipbuilding or engine manufacturing.[14] Column (1) returns a ratio for EXPERIENCE of 0.47. Entry with relevant experience reduces the hazard rate upon entry by about one half relative to the baseline. However, the significant

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[12] Although output data are available only through 1914, firm survival is observed to the present day.

[13] The location dummies allocate production to four regions: the Atlantic and Gulf coasts, the Pacific coast, the Great Lakes, and the western rivers. Five time dummies distinguish entrants before 1861 and in each decade thereafter. Alternative specifications tried for the location and time dummies had no impact on the results.

[14] As one would expect, the hazard ratio for firms with unknown backgrounds, when these are included in the sample, is large. The ratio for the diverse firms categorized into MISCELLANEOUS does not differ significantly from one.

coefficient of 1.042 on the Experience x Age interaction indicates that the effect of pre-entry experience is not persistent. Each year of post-entry experience raises the hazard ratio for experienced firms by 4.2 percent. Thus, after ten years the hazard ratio for Experience has risen to 0.69, while the effect of pre-entry experience is eliminated entirely after eighteen years of post-entry experience. These results are replicated in column (3), which includes the 70 firms whose backgrounds are unknown.

Table 2

Hazard Ratios from Cox Proportional Hazards Models

Unknown backgrounds:	excluded		included	
	(1)	(2)	(3)	(4)
Censoring Year:	2001	1945	2001	1945
Experienced	0.467** (.10)	0.539*** (.12)	0.442*** (.09)	0.501*** (.11)
Miscellaneous	0.865 (.21)	0.913 (.22)	0.823 (.20)	0.865 (.21)
Unknown	----	----	1.755** (.41)	1.882*** (.44)
Experienced x Age	1.042** (.02)	1.003 (.02)	1.043*** (.02)	1.006 (.02)
Miscellaneous x Age	1.003 (.02)	0.989 (.02)	1.004 (.02)	0.990 (.02)
Unknown x Age	----	----	1.008 (.05)	0.985 (.05)
Test of Proportionality	$\chi^2_{12}=3.9$	$\chi^2_{12}=7.1$	$\chi^2_{14}=4.2$	$\chi^2_{14}=7.4$
Number of Yards	203	203	273	273
Number of Failures	173	167	236	230

Standard errors in parentheses. Significance levels: *=10%, **=5%, ***=1%. Not reported are the hazard ratios for three location dummies and five time dummies. Tests on the proportionality assumption are as implemented in Stata-SE, version 8, with a logarithmic transformation of the time scale.

It turns out that the apparent decay of experience effects indicated in columns (1) and (3) is due entirely to a modest number of firms that survived through World War II, some of which continued operations for many years after.[15] Columns (2) and (4) repeat the analysis after censoring all observations at 1945. Doing so eliminates entirely the slow decay of the experience effect. As columns (2) and (4) indicate, the hazard ratio for experienced firms is still about one half that of inexperienced firms, but there is now no evidence that the effect decays with time.

It is certainly no surprise that the enormous changes experienced by the industry during the war years should undermine the effects of experience obtained at least 35 years previously.[16] But until the war, experienced firms have a persistently lower hazard than inexperienced firms. Although the sample contains only firms that entered by 1914, there is no evidence that the effects of experience decline before the onset of World War II.

B. Size, age and survival without conditioning on quality

It is useful to explore the joint effects of size and age within the framework of a fully parametric model. The logarithm of the baseline survival curve from the proportional hazards model of Table 2, column (1), is plotted in Figure 8. The curve is convex, consistent with a hazard declining monotonically with respect to firm age. Thus, a Weibull hazard model may provide an acceptable parametric representation. The remainder of the analysis is therefore based on hazard func-

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[15] The firms are (dates of operation in parentheses): American Shipbuilding's Lorain yard (1899−1985), American Shipbuilding's Buffalo yard (1900−1962), Dubuque Boat and Boiler Works (1905−1972), Charles Seabury and Co. (1893−1955), Pusey and Jones (1854−1946), Bath Iron Works (1905−) Great Lakes Towing Co. (1907−), and Newport News (1891−).

[16] Lane (1951), the official history of the wartime shipbuilding program, provides extensive details of the unique conditions brought about by the demands of war production. In particular, yards with significant structures and equipment paid for by the government were able to secure ownership of this capital on extremely favorable terms after the war.

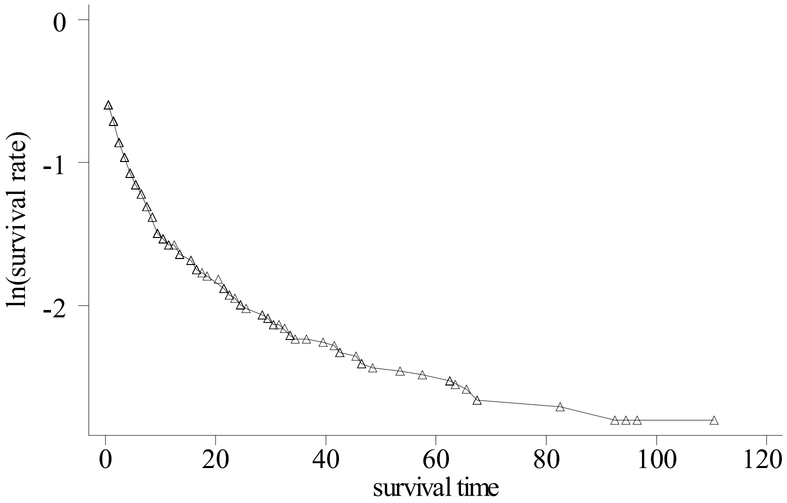

Figure 8. Log survival rates. Baseline hazards from column (1) of Table 2. The symbols indicate the baseline hazard corresponding to each observed failure time. The curve is a cubic spline fitted through these points. The baseline corresponds to a firm entering in 1859 on the Atlantic coast with prior experience in foundry work.

tions taking the form

$$h(t, x_{it}, \beta, \lambda) = (\lambda + 1)t^{\lambda}e^{x_{it} \ln \beta} ,$$

where λ has a useful interpretation as an elasticity: it measures the percentage change in the hazard induced by a one-percent increment to age.

The first column of Table 3 includes current output, measured by the number of vessels launched each year, as the only covariate. Size is negatively related to the exit hazard. Each one unit increment to output reduces the exit hazard by about 7.5 percent so that a yard launching, for example, five vessels is about 33 percent more likely to survive the next year than one launching a single vessel. At the same time, the elasticity of the hazard with respect to firm age is a highly significant –0.25, indicating that increases in firm age induce a marked reduction in the hazard. That is, the shipbuilding industry exhibits the familiar dependence of survival on size *and* age.

Table 3

Joint Size and Age Effects on Survival

(Hazard Ratios from Weibull Hazard Models)

	Output as Number of Vessels			Output as Gross Tonnage ('000s)
	(1)	(2)	(3)	(4)
Current Output	0.924** (.03)	––––	––––	––––
Scale of Plant	––––	0.698*** (.06)	0.674*** (.06)	0.944** (.02)
Current Market Share	––––	––––	1.019*** (.00)	1.008 (.01)
Industry Output	––––	––––	1.000 (.00)	1.000 (.00)
λ	–0.254*** (.03)	–0.126** (.04)	–0.094** (.04)	–0.201*** (.04)
ln L	–453.7	–443.4	–439.0	–442.8

Standard errors in parentheses. Significance levels: *=10%, **=5%, ***=1%. All regressions include the location and time indicators given in footnote 13.

The strong effect of age reported in column (1) may exaggerate its true role if size is poorly measured. Yards produced vessels in small numbers and the number of contracts won could vary markedly from year to year. Consequently, output in the current calendar year may be a rather poor measure of effective size. Column (2) attempts to smooth out these large variations in annual output rates with an alternative measure of firm activity, denoted Scale, which measures for each year the average annual rate of output since entry. On the basis of the log likelihood, this variable explains rather more than current output. Moreover, although current output and SCALE have the same units of measurement, the hazard ratio on SCALE is much smaller: a firm with an average annual rate of output of, say, three instead of two vessels, faces a 30 percent lower hazard. As expected, the age effect is reduced, but it remains economically important and statistically significant.

Finally, columns (3) and (4) introduce further controls for size. In column (3), market share (simply firm annual output divided by industry output) and industry output are added. In column (4), each output measure is replaced with data on gross tonnage launched rather than numbers of vessels launched. In both cases the (size-conditional) age-dependency of firm survival remains strong and significant.[17]

C. Effects of quality on the relationship between age, size and survival

It has been shown so far that (i) pre-entry experience has large and persistent effects on survival, and therefore meets the minimal demands for a meaningful proxy for firm quality; (ii) the industry exhibits the familiar size-conditional age-dependency of survival that has appeared in so many previous studies. This section addresses two questions:

- Is the first result robust to the inclusion of controls for firm size (thereby eliminating the possibility that experience effects are due to hysteresis)?
- Is the second result robust to the inclusion of proxies for quality?

The results are reported in Tables 4 and 5. Column (1) of Table 4 combines

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[17] The inclusion of two measures for firm size, plus one for industry size may simply help to pick up nonlinearity in the size-survival relationship. This is consistent with the hazard ratio for market share exceeding unity. If market share is the sole size control, its hazard ratio is less than one.

the three size variables from column (3) of Table 3 with the experience indicator variables. On the first question, note that the point estimates for the hazard ratios on EXPERIENCED and MISCELLANEOUS are essentially unchanged from those obtained under the Cox proportional hazards specification, even though the regression now has several controls for size. Even after conditioning on age, size, location, and entry period, the exit hazard of firms with prior experience in shipbuilding or engine manufacturing is about half the hazard for firms with prior experience in foundry work. On the second question, note that the elasticity of the hazard with respect to age has declined by half to a statistically insignificant –0.05. That is, about fifty percent of the hazard reduction initially attributed to age is explained by the fixed measures of heterogeneity. Selection bias induced by the early failure of low-quality firms is clearly important, while models based on unobserved variables correlated with age do not seem to be. Moreover, to the extent that unobserved heterogeneity continues to exist within experience groups, this estimate of the dominant role of selection bias must be a lower bound.

The remaining columns in Table 4, and Table 5, report further regressions designed to test the robustness of these results. In column (2) of Table 4, experience is decomposed into its component parts of shipbuilding and engine building. Both are found to have similar effects on the hazard. Column (3) removes from the sample firms with unknown backgrounds. The measured effect of experience is not altered by the change in sample, although the estimate of λ has increased sufficiently that it is significant at the 10 percent level. Because experience may be more important in the early, experimental days of the industry, column (4) restricts the sample to firms entering after 1875. Experience continues to matter as strongly as before, and age continues to have no impact on the hazard.

Table 5 reports additional regressions that allow for three piecewise constant effects for experience at different ages and adds a further control for size, cumulative output. First, consistent with the Cox regressions of Table 3, there is no evidence that the effects of experience decay with firm age. In fact, the effect of pre-entry experience on the exit hazard is even greater for firms over 20 years of age than it is for firms under 10 years of age, and these results are obtained despite the inclusion of several controls for size. Second, this alternative treatment of prior experience strengthens the result that age no longer influences survival.

Table 4

Hazard Ratios from Weibull Hazard Models

			UNKNOWN BACKGROUNDS EXCLUDED	ENTRY POST-1875
	(1)	(2)	(3)	(4)
SCALE OF PLANT	0.734^{***} (.06)	0.725^{***} (.06)	0.779^{***} (.06)	0.746^{**} (.09)
CURRENT MARKET SHARE	1.018^{***} (.00)	1.018^{***} (.00)	1.017^{***} (.01)	1.060 (.05)
INDUSTRY OUTPUT	1.000 (.00)	1.000 (.00)	1.000 (.00)	0.997 (.00)
EXPERIENCED	0.531^{***} (.12)	––––	0.581^{**} (.13)	0.507^{***} (.13)
. . . . IN SHIPBUILDING	––––	0.623^{**} (.14)	––––	––––
. . . . IN ENGINE BUILDING	––––	0.538^{***} (.13)	––––	––––
MISCELLANEOUS	0.760 (.20)	0.783 (.20)	0.839 (.22)	0.769 (.24)
UNKNOWN	1.687^{**} (.42)	1.729^{**} (.43)	––––	1.683^{**} (.42)
λ	–0.047 (.04)	–0.043 (.04)	-0.088^{*} (.05)	–0.006 (.04)

Standard errors in parentheses. Significance levels: *=10%, **=5%, ***=1%. All regressions include the location and time indicators. Log-likelihoods are not comparable across columns and are not reported.

Table 5

More Hazard Ratios from Weibull Hazard Models

	(1)	(2)	(3)	(4)
			Entry Post- 1875	
		Unknown backgrounds excluded		
Scale of plant	0.589***	0.654***	0.541***	0.429***
	(.08)	(.08)	(.09)	(.09)
Current Market Share	1.019***	1.018***	0.978	1.053
	(.00)	(.01)	(.05)	(.05)
Industry Output	0.998	0.999	0.990**	0.993**
	(.00)	(.00)	(.01)	(.00)
Cumulative output	1.011***	1.009***	1.042***	1.050***
	(.00)	(.00)	(.01)	(.01)
Experienced (Age <10)	0.597**	0.639*	0.557**	0.544**
	(.13)	(.15)	(.16)	(.14)
Experienced (Age 10- 20)	0.399***	0.462**	0.444**	0.389**
	(.14)	(.16)	(.18)	(.15)
Experienced (Age >20)	0.378***	0.443**	0.442	0.334*
	(.13)	(.17)	(.28)	(.21)
Miscellaneous	0.697	0.787	0.759	0.677
	(.19)	(.21)	(.26)	(.23)
Unknown	1.644**	– – –	– – –	1.641**
	(.42)			(.46)
λ	–.008	–0.048	–0.058	0.010
	(.05)	(.05)	(.06)	(.06)

Standard errors in parentheses. Significance levels: *=10%, **=5%, ***=1%. All regressions include the location and time indicators. Log-likelihoods are not comparable across columns and are not reported.

These results are unchanged regardless of whether one includes or excludes firms with unknown prior experience, or whether one restricts the sample to post-1875 entrants.

D. Monte Carlo simulation of missing data.

The 70 firms with unknown backgrounds performed worse than any other group. It is likely that the majority of these firms were inexperienced, not only because they performed poorly, but also because their absence from the hundreds of shipbuilding and county histories, city almanacs, and biographical compendiums consulted during data collection suggests that the firms and their founders had not previously been active in any related business. Nonetheless, it is also likely that some of these firms were experienced, and have just fallen through the cracks. If a sufficient number of them were experienced, the missing data will have led us to exaggerate the effect of pre-entry experience.

In this section, I report the results of a simulation exercise that assesses the extent to which the missing data could account for the reported results. The simulation imagines what could be considered a worst case scenario, namely that the firms with missing data were just as likely to be experienced as the firms for which data are available. To implement this, each of the 70 firms with unknown background was assigned at random to either the foundry, experienced, or miscellaneous groups with probabilities equal to the proportion of each of these three groups found in the data. The hazard regression from column (1) of Table 4 is then run with these artificial assignments of firms.

Figure 9 plots the estimated hazard ratios for EXPERIENCE obtained from 1,000 replications of this exercise. The mean hazard ratio is 0.65, compared with 0.53 in Table 4, and only one estimate in the 1,000 runs exceeds 0.80. Figure 9 also reports the significance levels: 76 percent of the estimates are significant at the five percent level or greater, and fully 95 percent of the estimates are significant at the ten percent level or greater. By any reasonable standard, the

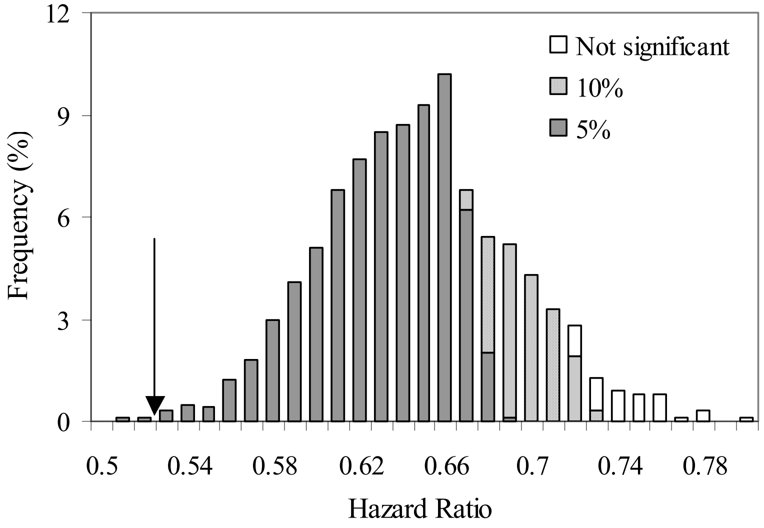

FIGURE 9. Estimated hazard ratio for experience from random assignment of firms with unknown backgrounds to experienced and inexperienced firms, 1,000 replications. Regression specification is identical to column (1) of Table 4. Arrow indicates point estimate from column (1) of Table 4.

simulation results clearly show that the effect on survival of pre-entry experience is not driven by missing data.

V. Conclusions

A number of complex theories of firm performance can explain the well-known observation that survival is negatively related to age, but all of them exploit the idea that age serves as a proxy for an omitted variable. However, a more mundane explanation – selection bias driven by variations in firm quality – may also underlie the phenomenon. Using new data for the US iron and steel shipbuilding industry, this paper has presented the results of a simple test to discriminate between these two classes of explanations for the age-dependency of survival. It was found that the age-dependency observed in the data can be explained by selection bias, leaving nothing for the more complex theories to explain.

Assuming these results apply more generally[18], they suggest that complex theories to explain the size-conditional effects of age on firm survival may well be barking up the wrong tree. Instead, simple models of firm performance may well be consistent with the evidence on age-dependency. For example, in Hopenhayn's (1992) model of exit driven by exogenous productivity shocks, age has no effect on the exit hazard after conditioning on size. However, the simple addition of some fixed firm effects – either in the variance of the productivity shocks, or the sensitivity of firm profitability to the shocks – are sufficient to make the model consistent with the evidence presented in this paper.

This paper used the pre-entry backgrounds of firms as a proxy for firm quality. It was found that relevant pre-entry experience has large effects on survival, that the effects showed no tendency to diminish as firms gained post-entry experience, and that they were not diminished by controlling for firm size. The observed persistence of experience effects is inconsistent with traditional rationalizations of why experienced firms may outperform inexperienced firms. On the contrary, the evidence suggests that the circumstances surrounding a firm's birth permanently conditions what it does throughout its life. Moreover, this persistence matters for policy. As Geroski, Mata, and Portugal (2002) point out, while a government may readily intervene to alter current conditions, there is little it can do to change *ex post* the historical circumstances surrounding a firm's birth. Consequently, they argue, greater attention should be directed toward the devel-

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[18] Some features of the shipbuilding industry, notably the absence of a shakeout, distinguish it from some of the more frequently studied episodes in US manufacturing history (e.g. the automobile industry), and more work needs to be done to replicate the findings of this paper in other industries. But the early signs are that what distinguishes shipbuilding from industries where scale economies might be more important will not be a factor in the results. In the US automobile industry, where dynamic scale economies appear to be central to understanding the industry's evolution, Klepper (2003) has found that controlling for a firm's background can all but eliminate the effect of age even without controls for size.

opment of appropriate neonatal policies.

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