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OVERHAUL COSTS IN PUBLIC AND PRIVATE SHIPYARDS: A CASE STUDY

Marianne Bowes

The Public Research Institute
A Division of the Center for Naval Analyses

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One difference that did emerge strongly concerned the length of time per overhaul, which was lower in the naval shipyards. We estimated the cost of extra time in overhaul from information on the amount spent by the Navy to buy and operate a submarine. Using this method in an illustrative calculation, we estimated that, in our sample, the total cost--production cost plus time cost--of an "average" overhaul done in a naval shipyard was lower than the total cost of an "average" overhaul done in a private yard.

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ABSTRACT

This study investigated whether overhaul costs differ in public and private shipyards, using data on overhauls of the Sturgeon class of nuclear attack submarines between 1971 and 1979. We began by estimating a cost function and using the regression coefficients to estimate the production cost of a hypothetical overhaul for each shipyard in each year. For the most part, it was found that estimated naval shipyard costs did not differ significantly from estimated private yard costs. There were, however, several instances in which naval yard costs were significantly higher than private yard costs.

Among the reasons for the differences in estimated production costs in our sample were higher wage rates and a lower cost of capital in the naval shipyards. Experience levels also differed among shipyards, but were not consistently higher or lower for the naval shipyards. There may be a difference in overhaul quality, but such a difference did not show up in the measures of material condition that we examined.

One difference that did emerge strongly concerned the length of time per overhaul, which was lower in the naval shipyards. We estimated the cost of extra time in overhaul from information on the amount spent by the Navy to buy and operate a submarine. Using this method in an illustrative calculation, we estimated that, in our sample, the total cost--production cost plus time cost--of an "average" overhaul done in a naval shipyard was lower than the total cost of an "average" overhaul done in a private yard.

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INTRODUCTION

Firms in the public and private sectors of an economy differ in several respects. One difference concerns the form of ownership. Private firms are owned by a relatively small number of shareholders, while public ownership is diffused among all members of society. Private firms exist to make profits; public firms usually have different goals.

Because of these factors, if we could observe public and private firms producing the same type of output, we might find that production costs differ for the two types of firm. Such a difference in costs could arise because of differences in the prices paid for inputs used in the production process and/or in the use of these inputs.

The preceding discussion implies that there are at least two questions of interest in a comparison of production costs for public and private firms:

- Do the costs of production differ?
- If so, why? That is, are the differences in production costs due to differences in input prices, differences in the use of inputs, or other reasons?

This paper discusses these questions for a particular type of production, namely, the production of overhauls of nuclear submarines in public and private shipyards.

The choice of shipyards as the type of firm for which to compare production costs has two advantages. First, unlike the output of many other government activities, the output of naval shipyards is tangible. Second, shipbuilding and repairing is one of the few types of production that occurs in both public and private firms. New construction and overhaul of naval vessels can be done in public or private shipyards; currently, however, this work is not evenly divided between them. At one time, ships were built in both types of yard, but since 1967, no new construction has been assigned to naval yards. In contrast, most overhaul work is done in naval yards.

Currently, there are eight naval shipyards, four on each coast (see table 1). In the private sector, the shipbuilding and repairing industry (SIC 3731) consists of a few large firms and many smaller ones. Eleven yards are considered capable of undertaking major Navy new construction work; these are listed in table 1. As of February 1, 1978, these eleven yards accounted for about 63 percent of total private shipyard employment ([23], pp. 18-19). Only three private yards--Newport News, Ingalls, and Electric Boat--are currently qualified to handle nuclear materials.

TABLE 1

LOCATION OF MAJOR SHIPYARDS

Coast	Naval	Private
Atlantic	Portsmouth, NH	Bath (Bath, ME)
		Electric Boat (Groton, CT)
	Philadelphia, PA	Quincy (Quincy, MA)
		Bethlehem (Sparrows Point, MD)
	Charleston, SC	Newport News (Newport News, VA)
Pacific	Puget Sound, WA	Lockheed (Seattle, WA)
	Mare Island, CA	Todd (Seattle, WA)
	Long Beach, CA	Todd (San Pedro, CA)
	Pearl Harbor, HI	National Steel (San Diego, CA)
Gulf		Avondale (Avondale, LA)
		Ingalls (Pascagoula, MS)

The division of naval new construction and repair work between public and private shipyards appears to be based primarily on noneconomic considerations. Shipbuilding is felt to be an industry that is important for national security, and funds are allocated so that both public and private shipyards can maintain a state of readiness. Congress is not, however, insensitive to differences in construction cost, as will be seen below.

Historically, it has been felt that public shipyards have higher production costs than private yards. For example, during the debate on the Vinson-Trammell Act of 1934,* it was generally acknowledged that the costs of building ships were higher in naval shipyards, partly because these yards were oriented toward repairing rather than building ships and partly because of "the relative inflexibility and higher pay of Civil Service personnel." Since that time, higher public shipyard costs have been an important factor in the transfer of naval work from the public to the private sector ([3], pp. I-5, I-7). For example, in reference to the FY 1974 Navy shipbuilding program, it was reported: "Funds were also cut from the DLG conversions on the grounds that they could be saved by having the work done in private yards instead of naval shipyards where such jobs have normally been done." ([1], p. 71)

* The Vinson-Trammell Act provides that the first and each succeeding alternate vessel in each class of naval ships shall be built in naval shipyards, except if this is inconsistent with the public interest. Since 1948, the public interest clause has been exercised every year.

In 1972, Booz-Allen compared the costs of comparable ship work, including new construction, conversions, and overhauls in public and private yards for the fiscal years 1966-71. They found that the cost of new construction was, on average, about 35 percent higher in naval shipyards. An update of their study to 1977 indicated that although some convergence in cost had occurred, the cost of new ship construction remained significantly higher in naval shipyards. In both studies, higher wage rates and fringe benefits for naval shipyard employees were found to contribute significantly to the difference in cost ([3], p. I-7, Chapter VI).

Thus, in our investigation of overhauls of nuclear submarines, we might find both production costs and the price of labor to be higher in naval shipyards than in private ones. However, this would not necessarily imply that naval shipyards do not minimize costs. Although competition between public and private shipyards is not as intense as it would be if they were directly bidding against one another, the desire to lower production costs and increase productivity does influence naval shipyard managers. In Naval Engineers Journal, for example, new management techniques are advocated "with a view toward increasing productivity..., lowering costs, improving quality, and getting ships out earlier." ([27], p. 60).*

We turn now to a description of the data and methodology used to compare production costs in public and private shipyards.

* See also [12]; [16]; [21], p.1-38.

DATA

Because no new construction has been assigned to naval shipyards since 1967, there are no recent classes of ship that have been built by both public and private shipyards. Overhauls of nuclear submarines have, however, been done by both types of yard. Our data are for overhauls of the Sturgeon class of nuclear attack submarines (SSN 637) between 1971 and 1979.* Forty overhauls were performed during this time, 33 by naval shipyards and 7 by private yards.

As table 2 suggests, we analyzed two types of overhaul. Regular overhauls take about 12 months and include both repair and alteration work. The refueling overhauls in our sample lasted, on average, about 18 months; in addition to the type of work done during regular overhauls, they include replacement of the nuclear core that powers the submarine.

The unit of observation in our data is an overhaul. For each overhaul, we have total cost, $C = p_K K + p_L L + p_M M$, where K, L, and M are the inputs of capital, labor, and materials, respectively, and p_K, p_L, and p_M are their prices.

For each of the three inputs, price data were developed as follows. First, a monthly or quarterly time series was constructed for 1971-79. The input price for a given overhaul was then computed as a weighted average of the prices prevailing during the months when that overhaul took place. The construction of the time series for p_K, p_L, and p_M is discussed in detail in appendix B.

* The basic data was obtained from PERA (Planning and Engineering for Repairs and Alterations), which is part of the Naval Sea Systems Command (NAVSEA). See appendix A. We would like to thank Dr. John Berning of the Institute of Naval Studies for providing us with this data and with background information for the study. The sample we have used is not ideal because only three private shipyards are represented, and fewer than 20 percent of the overhauls were done in private shipyards. However, the purpose of this study was not to do a comprehensive analysis of costs in public and private shipyards, but rather to illustrate a methodology for comparing costs. Accordingly, the generality of the conclusions that can be drawn from our analysis is limited.

TABLE 2

NUMBER OF OVERHAULS BY SHIPYARD AND TYPE

Shipyard	Regular	Refueling
Norfolk	8	0
Charleston	1	3
Portsmouth	7	1
Puget Sound	6	4
Pearl Harbor	2	0
Mare Island	0	1
Electric Boat[a]	3	1
Ingalls[a]	1	0
Newport News[a]	0	2
Total	28	12

[a]Private shipyards.

METHODOLOGY

There are a number of ways in which the question "do production costs differ?" could be answered using our data. The simplest way is to compute the average cost of an overhaul in each type of shipyard. This is done in part A of table 3. Part A indicates that refueling overhauls cost, on average, about 65 percent more than regular overhauls. It also shows that, for our sample, regular overhauls cost about 18 percent more and refueling overhauls 6 percent more in public shipyards than in private ones.

TABLE 3

AVERAGE VALUES PER OVERHAUL

	Regular	Refueling
A. Total Cost (1972 $)[a]		
Public	16,857,141	27,617,194
Private	14,287,437	25,975,177
B. Material Cost (1972 $)[b]		
Public	2,015,609	2,745,777
Private	2,104,714	3,425,244
C. Man-days		
Public	144,173	243,146
Private	151,133	237,652

Deflators:

[a]Implicit Price Deflator for DoD purchases of Ship Construction, from [17].
[b]Material Price Index as described in appendix B.

We are, of course, interested in determining not only whether production costs differ but also why they differ. Part B of table 3 indicates that the higher production costs of naval shipyards were not caused by higher material costs. Since we do not know the average cost of a man-day, Part C does not tell us whether public shipyards had higher labor costs than private shipyards. It does show, however, that the average quantity of labor used per overhaul was not substantially different in the two types of yard.

Although useful as a starting point, comparisons like those in table 3 do not tell the whole story. There are a number of variables besides type of overhaul and type of shipyard that might be expected to influence the cost of an overhaul. In our attempt to determine whether production costs differ in public and private shipyards, we will want to hold some of these other variables constant. In order to be able to do this, we used regression analysis to estimate a cost function. In the following sections, we discuss the variables included in the regression equations and the functional form chosen for the equations.

VARIABLES

In its simplest form, a cost function gives production cost as a function of input prices and output: $C = f(p_M, p_L, p_K, O)$.* Several other variables are relevant to our analysis:

A, the age of the submarine

X, the experience of the shipyard

T, time (the year in which the overhaul began)

Y, a dummy variable for the type of shipyard.

We expect C to be an increasing function of input prices and output. Moreover, the cost function should be homogeneous of degree 1 in input prices; that is, if all input prices increase by 1 percent, other things remaining the same, total cost should also rise by 1 percent. Age is added to the regression equation because older submarines are likely to need more work during overhauls than newer submarines.

X, the experience of the shipyard, is expected to have a negative effect on cost because of learning by shipyard workers. X can be defined in several ways. One definition involves letting X equal the number of overhauls of Sturgeon-class submarines previously done in the shipyard. This definition is probably too narrow, however, because overhauls of other types of nuclear submarines also add to a shipyard's experience. Accordingly, for each overhaul in the sample, X is

* Theoretically, the cost function for a shipyard should include data for all types of shipyard output, e.g., new ship construction as well as overhauls. We did not have cost data on activities other than Sturgeon-class submarine overhauls for the shipyards in our sample; accordingly, the cost functions we estimate apply only to these overhauls.

defined as the number of overhauls of nuclear submarines of any type done in the shipyard up to the time of that overhaul.*

Besides input prices, output, age, and experience, there are other variables that might also influence cost, such as changing technology and changes in the Navy's policy concerning the amount of work required in an overhaul. Because we cannot measure these variables directly, we use time as a variable to capture their effects. Finally, Y is included in the regression equation to allow us to determine whether, when all the other variables are controlled for, production costs are higher in public than in private shipyards.

The exact definitions of the independent variables used in the cost equation are given in appendix B. Output is defined as the number of overhauls. Two complications arise with this definition. First, the two types of overhaul are sufficiently different from one another that it would be inappropriate to treat them as equivalent, yet there are not enough observations to estimate separate cost functions for each type. Therefore, a multioutput cost function should be used, with two outputs: O_1 = regular overhauls, O_2 = refueling overhauls. This leads to problems in choosing a functional form for the cost function. These problems are discussed below.

The second complication is that our unit of observation is one overhaul. This implies that the variables O_1 and O_2 are, for our sample, equivalent to dummy variables for the type of overhaul, and one of them must be omitted from the regression equation if a constant term is included.

FUNCTIONAL FORM

The simplest functional form conventionally used for production and cost functions is the Cobb-Douglas. This form has been used in previous shipbuilding studies ([9], [15]). The disadvantage of the Cobb-Douglas is that it places restrictions on certain elasticities; more flexible functional forms such as the translog do not. However, the Cobb-Douglas is much easier to estimate than the usual alternative functional forms. Accordingly, this was the form we used.

A problem was encountered in trying to formulate the multiproduct cost function. There is a multioutput Cobb-Douglas production function, but it has undesirable properties (see [10], pp. 253-4). In order to avoid using more complicated functional forms, we made a simplifying

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* Another aspect of experience concerns the building of nuclear submarines. However, when we added a variable representing building experience to the regression equation, we got unusual results. See appendix D.

assumption about the relationship between regular and refueling overhauls.

Specifically, we assumed that both types of overhaul involve essentially the same kind of work but in different amounts. That is, with given quantities of capital, labor, and materials, a shipyard could accomplish X percent of a regular overhaul or Y percent of a refueling overhaul. If this is true, the cost function may be expressed as

$$C = e^{\beta_0} p_L^{\beta_1} p_K^{\beta_2} p_M^{\beta_3} X^{\beta_4} e^{(\beta_5 A + \beta_6 T + \beta_7 Y + \beta_8 O_1)} \quad . \qquad (1)$$

Taking logs and subtracting $\ln p_M$ to insure linear homogeneity in input prices gives the estimating equation

$$\ln(C/p_M) = \beta_0 + \beta_1 \ln(p_L/p_M) + \beta_2 \ln(p_K/p_M) + \beta_4 \ln X \qquad (2)$$

$$+ \beta_5 A + \beta_6 T + \beta_7 Y + \beta_8 O_1 \quad .$$

In the next section of the paper, the regression results for (2) will be presented and used to compare production costs in public and private shipyards.

RESULTS

Table 4 gives the coefficients and t-statistics obtained by running ordinary least squares on (2).* The difference among the three equations is in the definition of X. In equation 1, X is defined as the total number of overhauls of nuclear submarines done in the shipyard before the observed overhaul. Because overhaul experience might "decay" with time, two alternative definitions of X were also tried. In equation 2, X is defined as the number of overhauls done in the 10 years prior to the observed overhaul. In equation 3, X is defined as the number of overhauls done in the 5 years prior to the observed overhaul.

The results in table 4 are, for the most part, consistent with our expectations. The coefficients of $\ln p_L$ and $\ln p_K$ are positive, and their sum is less than 1, as economic theory would predict. However, these coefficients are not statistically significant. The coefficient of experience is negative, and the coefficient of age is positive, as expected; in addition, both coefficients are significant.

The coefficient of time is positive and slightly significant. This is inconsistent with the hypothesis that technological change has lowered costs. But other possible explanations include the following:

- The definition of an overhaul has expanded over time, so that a given type of overhaul requires more work now than it did several years ago.
- Regulation of shipyard activities by agencies such as EPA and OSHA has been increasing over time. Such regulation will raise measured costs if, for example, inputs that are used to comply with regulations are reported as being used to produce overhauls.

We have no direct evidence that the first explanation holds for Sturgeon-class submarines,** but it does seem likely that regulation has increased the cost of overhauls over time ([22], p. 1-40; [27], p. 62).

The coefficient of Y is small and insignificant. This indicates that, for our sample, there is no significant difference in overhaul costs in naval and private shipyards that is not explained by the other independent variables. Finally, the coefficient of Q_1 is negative as

* As a check on our use of the shipfitter's wage to represent the price of labor, equation 2 in the table was also run using wage rates for other occupations. See appendix D for the results.
** See, for example, [2], p. 3.

TABLE 4

REGRESSION RESULTS

Dependent Variable: $\ln(C/p_M)$

Coefficient (t-statistic)

Equation No.	$\ln(p_L/p_M)$	$\ln(p_K/p_M)$	lnX	A	T	Y	Q_1	Adjusted R^2
1	.286 (.85)	.296 (.68)	-.161[a] (-1.97)	.00763[a] (2.12)	.0325 (1.41)	.050 (.27)	-.097 (-.60)	.708
2	.409 (1.28)	.117 (.28)	-.246[a] (-2.99)	.00634[a] (1.85)	.0415[a] (1.90)	-.038 (-.21)	-.144 (-.94)	.744
3	.477 (1.42)	.162 (.39)	-.219[a] (-2.80)	.00680[a] (1.97)	.0289 (1.38)	-.034 (-.19)	-.108 (-.70)	.737

[a]Significant at the 5-percent level, using a one-tailed test.

expected (regular overhauls cost less than refueling), but insignificant.

The results in table 4 were used to answer two questions: whether production costs differ in public and private shipyards and why these costs differ. The next two sections explain how these answers were obtained.

PRODUCTION COST DIFFERENCES

One question that is undoubtedly of interest to Congress is where naval overhaul work can be done most cheaply. To answer this question for our sample, we used the regression coefficients to estimate the cost of a hypothetical overhaul of a Sturgeon-class submarine for each shipyard for each of the years 1972-78.* Because equation 2 gave a slightly better fit than the other two equations, this was the equation we used.** In table 5, the estimated cost of a regular overhaul on a submarine of age 65.6 months (the sample average for A) is shown.

Several patterns are evident in table 5. Estimated cost is consistently the lowest for Electric Boat, followed by Portsmouth and Newport News. Estimated costs for Pearl Harbor and Ingalls, on the other hand, are always among the highest.

Table 5 prompts two questions:

- How different are the estimated costs for naval and private shipyards? That is, are the differences in cost statistically significant?
- Why do estimated costs differ for naval and private shipyards?

The first question was answered in the following way. Using the variance-covariance matrix for the regression coefficients, confidence intervals were computed for the random variables $\ln(C_G/C_p)$, where C_G is the estimated overhaul cost in a naval shipyard and C_p is the estimated cost in a private yard. In most cases, it was found that naval shipyard costs did not differ significantly from private yard costs. There were, however, a few exceptions. Estimated costs for Charleston and Pearl Harbor were found to be significantly higher (at the 5-percent level) than those for Newport News in at least 5 of the

* Due to data limitations, costs could not be predicted for 1971 or 1979.

** The cost predictions are not substantially different if equation 1 or 3 is used instead.

TABLE 5

ESTIMATED COST OF A REGULAR OVERHAUL
USING EQUATION 2 ($000)

	Public Shipyards						Private Shipyards		
	Norfolk	Charleston	Portsmouth	Puget Sound	Pearl Harbor	Mare Island	Electric Boat	Ingalls	Newport News
1972	18,195	17,629	16,838	17,980	19,552	18,516	15,276	21,084	17,077
1973	19,412	19,299	17,670	18,607	21,363	20,663	16,071	21,678	17,832
1974	22,597	23,471	20,251	21,531	25,512	23,278	18,796	24,694	20,767
1975	26,820	28,899	23,588	25,408	30,320	27,358	22,142	28,149	24,631
1976	28,885	31,770	26,301	28,085	34,425	30,130	25,006	30,508	27,032
1977	32,028	34,328	29,140	30,996	37,734	32,738	27,842	32,603	29,400
1978	36,099	39,020	32,738	34,790	42,800	36,303	32,341	36,730	33,889

7 years for which costs were computed. In addition, estimated costs for Norfolk, Charleston, Puget Sound, Pearl Harbor, and Mare Island were significantly higher than those for Electric Boat in at least 5 years.

We turn now to the second question.

REASONS FOR DIFFERENCES IN PRODUCTION COSTS

Why are the estimated overhaul costs in table 5 different for naval and private shipyards? Since A and Q_1 are the same for each calculation in the table, and since p_M and T are the same for all calculations in a given year, (2) implies that differences in estimated costs arise from differences in p_L, p_K, X, and Y (the type of shipyard). In this section, we discuss the differences in input prices and experience that were found in our sample, without trying to assess their precise contributions to the differences in estimated costs.

Differences in Input Prices

The ideal way to analyze factor price differences in naval and private shipyards is to regress the price of a factor on the characteristics of that factor for each type of yard. For example, in the case of labor, we might regress the hourly wage rate on the skill and experience levels associated with that wage rate. Statistical tests could then be used to determine whether naval shipyards pay the same amount for increases in skill or tenure as private shipyards do. We do not have enough information on input prices to do such a rigorous analysis. We can, however, make some simple comparisons.

Table 6 lists ranges of hourly wages in naval and private shipyards for 26 occupations in September 1976; the information is taken from [20]. The occupations are listed roughly in order of skill. No strong conclusions can be drawn from this table. For a given occupation and coast, the ranges of wage rates in public and private yards always overlap to some extent. For the Atlantic Coast, starting wages in naval shipyards are higher than the lowest observed wages in private yards except for the least skilled jobs. A similar pattern can be seen for the Pacific Coast, although the conclusion is less strong here.

In table 7, annual average values of the wage data used in the empirical work are given. Bearing in mind the limitations of the data--i.e., starting wages for shipfitters in private yards are estimated rather than observed--we note that the wage rates are uniformly lower in the private shipyards. Wages are also higher in the West Coast naval shipyards than in the East Coast naval yards.

Table 8 lists annual averages of the capital price data used in the empirical work. It can be seen that p_K is consistently lower for the naval shipyards. There are two reasons for this. First, r (the interest rate on borrowed funds), which is a component of p_K, is lower

TABLE 6

WAGES IN PUBLIC AND PRIVATE SHIPYARDS, SEPTEMBER 1976

Occupation	Range of Hourly Wage Rates in Naval Shipyards		Range of Straight-Time Hourly Earnings in Private Shipyards	
	Atlantic	Pacific	Atlantic	Pacific
Janitor	3.31-5.42	4.39-5.97	3.60-6.00	3.60-7.20
Laborer	3.55-5.42	4.63-5.97	3.80-6.20	--
Equipment cleaner	4.10-6.04	5.10-6.76	4.60-7.40	5.40-7.60
Forklift operator	4.39-6.04	5.34-6.76	--	5.40-7.60
Helper	4.39-6.04	5.34-6.76	4.00-6.20	--
Truck driver	4.68-6.25	5.58-7.09	4.40-6.40	5.40-8.00
Painter	4.98-6.50	5.81-7.41	4.20-8.00	5.60-7.80
Bridge crane operator	4.98-7.29	5.81-8.05	4.80-8.00	7.40-7.80
Hand welder, class B	5.25-6.89	6.05-7.73	5.00-6.40	5.60-7.60
Machine welder	5.25-7.69	6.05-8.37	5.00-8.00	5.40-7.60
Carpenter	5.50-7.29	6.29-8.05	5.00-6.60	--
Machine-tool operator	5.50-7.29	6.29-8.05	4.80-5.60	--
Boom crane operator	5.50-8.10	6.29-8.00	5.20-6.80	6.00-8.00
Boilermaker	5.76-7.69	6.53-8.37	5.00-8.00	5.60-7.60
Marine electrician	5.76-7.69	6.53-8.37	4.80-8.00	5.60-7.60
Maintenance electrician	5.76-7.69	6.53-8.37	4.80-6.80	--
Maintenance machinist	5.76-7.69	6.53-8.37	5.00-6.80	5.60-7.60
Mechanic	5.76-7.69	6.53-8.37	4.80-6.80	--
Marine pipefitter	5.76-7.69	6.53-8.37	4.80-8.00	5.60-7.60
Maintenance pipefitter	5.76-7.69	6.53-8.37	4.80-6.80	--
Rigger	5.76-7.69	6.53-8.37	4.80-6.80	5.60-7.60
Sheet-metal worker	5.76-7.69	6.53-8.37	--	5.60-7.60
Shipfitter	5.76-7.69	6.53-8.37	4.80-8.00	5.60-7.60
Shipwright	5.76-7.69	6.53-8.37	4.80-6.60	5.60-8.00
Hand welder Class A	5.76-7.69	6.53-8.37	5.20-8.00	7.40-7.80
Electronics technician	6.01-8.50	6.76-9.00	5.40-6.80	7.60-8.00

TABLE 7

ESTIMATED STARTING WAGES FOR SHIPFITTERS IN PUBLIC AND PRIVATE SHIPYARDS, 1972-78

	PUBLIC SHIPYARDS						PRIVATE SHIPYARDS		
	Norfolk	Charleston	Portsmouth	Puget Sound	Pearl Harbor	Mare Island	Electric Boat	Ingalls	Newport News
1972	4.07	4.25	4.20	4.70	5.17	5.05	3.65	3.05	3.70
1973	4.32	4.51	4.38	4.97	5.46	5.33	3.94	3.19	3.83
1974	4.73	5.19	4.70	5.46	6.01	5.88	4.15	3.43	4.05
1975	5.17	5.86	5.41	6.09	6.59	6.54	4.47	3.74	4.60
1976	5.58	6.37	5.92	6.75	7.32	7.27	4.94	4.05	4.74
1977	5.96	6.73	6.49	7.34	8.05	7.90	5.32	4.34	4.94
1978	6.35	7.32	6.86	7.96	8.71	8.59	5.79	4.92	5.36

TABLE 8

CAPITAL PRICES IN PUBLIC AND PRIVATE SHIPYARDS, 1972-78

	Naval shipyards		Private shipyards	
	r(%)	P_K	r(%)	P_K
1972	5.54	.189	7.35	.241
1973	6.21	.196	7.60	.245
1974	6.88	.193	8.78	.257
1975	6.96	.245	9.25	.322
1976	6.79	.272	8.84	.349
1977	7.53	.287	8.28	.339
1978	8.40	.321	8.90	.380

for the government than for private firms. Second, corporate tax laws during the 1970s had the net effect of raising the cost of capital for private firms.*

In short, for our sample, wage rates were higher and the cost of capital was lower for naval shipyards than for private yards.

Differences in Experience

Table 9 shows the overhaul experience of each shipyard, defined as the number of nuclear submarine overhauls done in the previous 10 years. The differences between naval and private shipyards are not as consistent here as they are for input prices. Electric Boat has the most experience of any of the shipyards, and Ingalls has the least, with Newport News falling in between. Among the naval shipyards, Portsmouth, Puget Sound, and Mare Island have the most overhaul experience.

Differences in Overhaul Quality

In the statistical analysis, it was assumed that all overhauls of a given type are of equal quality. But it may be that naval shipyards do better work than private shipyards do. It is difficult to test this proposition because there is no really good measure of the quality of an overhaul.

One possible proxy for overhaul quality is the submarine's material condition after overhaul. We considered three measures of material condition:

- Hours of maintenance downtime listed in Casualty Reports, or CASREPs
- Hours that the ship's force spent repairing the submarine
- Hours spent in Intermediate Level Maintenance Activity (IMA hours).

We assume that the higher any one of these measures is, other things remaining the same, the lower the quality of the preceding overhaul.

Table 10 gives averages of the three measures, by type of overhaul and type of shipyard, for the 10 months after overhaul.** The results

* See appendix B for a more detailed discussion.

** The comparisons made here are not ideal because other variables which influence material condition, such as the age of the submarine and its activity after overhaul, have not been held constant.

TABLE 9

OVERHAUL EXPERIENCE IN PUBLIC AND PRIVATE SHIPYARDS, 1972-78

	Public Shipyards						Private Shipyards		
	Norfolk	Charleston	Portsmouth	Puget Sound	Pearl Harbor	Mare Island	Electric Boat	Ingalls	Newport News
1972	8	10	12	11	9	11	19	3	12
1973	9	10	14	14	9	10	23	4	14
1974	10	10	16	16	9	13	24	5	15
1975	10	9	19	17	9	14	24	6	16
1976	12	10	20	19	9	16	24	7	16
1977	12	11	21	20	10	18	23	8	16
1978	12	11	21	21	10	20	21	9	15

are inconclusive. For regular overhauls, CASREP and IMA hours are lower for submarines overhauled in naval shipyards, but ship's force hours are higher. For refueling overhauls, both IMA and ship's force hours are higher for submarines overhauled in naval yards. Thus, in our sample no strong conclusion emerges about the quality of naval versus private overhauls.

TABLE 10

MEASURES OF MATERIAL CONDITION
AFTER OVERHAUL

		Regular	Refueling
• CASREP maintenance downtime (hours)			
	Naval	754	942
	Private	890	1,197
• Ship's force hours			
	Naval	261	140
	Private	227	82
• IMA hours			
	Naval	1,365	500
	Private	1,591	81

DIFFERENCES IN OVERHAUL DURATION

So far, this report has focused on differences in the production cost of an overhaul, which is defined as the value of the man-hours, machine hours, and materials used to perform the overhaul. Another aspect of cost concerns the length of time spent in overhaul. The longer a submarine is in overhaul, the less it is available for duty and so the lower the Navy's state of readiness. The total cost of an overhaul includes the production cost and the time cost.

As a first approach to determining whether the time spent in overhaul differs in naval and private shipyards, we computed the average length of the overhauls in our sample. The results are shown in table 11. The table indicates that regular overhauls took 12 percent longer and refueling overhauls took 16 percent longer in private shipyards. These differences are statistically significant.*

TABLE 11

AVERAGE LENGTH OF OVERHAUL (DAYS)

	Regular	Refueling
Naval	355	525
Private	399	606

To estimate the cost of extra time spent in overhaul, we assumed that the value of a submarine to the Navy is at least as high as the amount spent to buy and operate the submarine. Following this assumption, we estimated the value of having a Sturgeon-class submarine available (i.e., out of overhaul) as about $72,000 per day in 1972 dollars.**

This figure can be used to compare production and time cost differences for overhauls done in public and private shipyards. To illustrate how the method would work, we made these comparisons for the "average" overhauls of each type in our sample, i.e., those described in tables 3 and 11. From these tables we see that, on average, a regular overhaul cost $2.6 million more but took 44 days less in a naval shipyard. The difference in time costs is therefore $3.2 million. A refueling overhaul, on average, cost $1.6 million more but took 81 days less in a naval shipyard. The difference in time costs here is $5.8 million. Thus, for our sample, we would conclude that the total cost of an average overhaul done in a naval shipyard, whether regular or refueling, was lower than the total cost of an average overhaul done in a private shipyard. That is, the higher average production costs in naval shipyards were outweighed by lower average time costs.

These calculations are intended primarily to illustrate a method for comparing production and time costs differences, not to yield final answers. One problem is that the "average" overhauls being compared have different characteristics. However, if the method described above for estimating the value of submarine availability is accepted, it appears that extra time spent in overhaul is costly.

* It should be noted, however, that variables that affect the length of an overhaul besides type of overhaul and type of shipyard have not been held constant in this comparison.
** See appendix C for details.

Further work on the issue of overhaul duration would be useful, for example, to determine why the overhauls in our sample took longer in private shipyards and how much it would have cost to speed up these overhauls. Refinement of our estimate of the value of availability would also be desirable.

CONCLUSION

This study investigated whether overhaul costs differ in public and private shipyards, using data on overhauls of the Sturgeon class of nuclear attack submarines between 1971 and 1979. We began by estimating a cost function and using the regression coefficients to estimate the production cost of a hypothetical overhaul for each shipyard in each year. For the most part, it was found that estimated naval shipyard costs did not differ significantly from estimated private yard costs. There were, however, several instances in which naval yard costs were significantly higher than private yard costs.

Among the reasons for the differences in estimated production costs in our sample were higher wage rates and a lower cost of capital in the naval shipyards. Experience levels also differed among shipyards, but were not consistently higher or lower for the naval shipyards. There may be a difference in overhaul quality, but such a difference did not show up in the measures of material condition that we examined.

One difference that did emerge strongly concerned the length of time per overhaul, which was lower in the naval shipyards. We estimated the cost of extra time in overhaul from information on the amount spent by the Navy to buy and operate a submarine. Using this method in an illustrative calculation, we estimated that, in our sample, the total cost--production cost plus time cost--of an "average" overhaul done in a naval shipyard was lower than the total cost of an "average" overhaul done in a private yard.

Because this study dealt with only one type of shipyard work, we are not justified in drawing general conclusions about costs in naval versus private shipyards. Analysis of other types of overhauls as well as ship construction work would also be necessary in order to get a general picture of relative costs. The cost function methodology employed here appears useful for this type of analysis.

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APPENDIX A

DATA

APPENDIX A

DATA

Table A-1 lists the basic data set. Column 1 is the hull number of the submarine being overhauled.

Columns 2 and 3 are the starting date and ending date, respectively, of the overhaul. The first 2 digits represent the year and the last 3 digits the day.

Column 4 is the shipyard where the overhaul was done

Naval shipyards:	Private shipyards:
1 - Norfolk	9 - Electric Boat
2 - Charleston	10 - Ingalls
4 - Portsmouth	11 - Newport News
6 - Puget Sound	
7 - Pearl Harbor	
8 - Mare Island	

Two naval shipyards--Philadelphia and Long Beach--did no overhauls of Sturgeon-class submarines between 1971 and 1979.

Column 5 is the type of overhaul:

1 - regular

2 - refueling

Columns 6 and 7 are the total cost (C) and the material cost, respectively, of the overhaul (in millions of current dollars).

Column 8 is the total number of man-days for the overhaul, as shown on the Departure Report.

TABLE A-1

THE BASIC DATA SET

1	2	3	4	5	6	7	8
661	71296	72287	4	1	13.798	1.752	110372
650	71203	72204	9	1	12.489	1.753	99461
649	72276	73282	1	1	18.280	2.126	147332
663	72074	73040	4	1	14.586	1.730	112636
662	72320	73287	6	1	17.723	2.026	133430
638	72228	73298	9	1	14.546	2.002	141683
668	73247	74211	1	1	20.137	2.047	151086
646	73182	74128	4	1	15.769	1.712	112695
673	73319	74310	4	1	16.518	1.872	113734
652	73200	74293	6	1	16.787	1.636	134168
639	73015	74093	7	1	21.262	2.919	140505
648	73091	74122	10	1	16.157	2.879	172053
670	74189	75128	1	1	22.357	2.174	149244
669	74115	75189	2	1	27.675	2.546	183359
664	74182	75173	4	1	19.970	2.277	129412
674	74287	75297	4	1	19.441	2.700	118037
666	74343	75312	6	1	18.535	2.046	129447
667	74051	75081	9	1	20.976	2.735	191336
675	75188	76157	1	1	24.561	2.855	142177
676	75013	75345	4	1	18.907	2.880	111144
672	75274	76230	6	1	22.440	2.578	138569
647	75216	76213	7	1	34.416	5.042	175105
660	76019	77037	1	1	33.929	3.782	192222
678	76188	77133	1	1	30.070	3.871	166143
665	76229	77185	6	1	24.495	2.978	139606
679	77017	77336	1	1	33.129	4.743	184741
677	77090	78092	6	1	26.524	3.345	140082
673	78037	79031	1	1	39.860	6.377	204906
651	73273	75122	6	2	25.016	2.224	196586
653	75213	76306	2	2	44.786	4.725	247317
637	76194	77308	2	2	51.908	5.450	267524
638	76258	78188	4	2	49.658	5.138	269862
662	76341	78037	6	2	33.302	3.517	184410
650	76145	78098	9	2	54.204	8.422	352552
661	76061	77279	11	2	36.765	4.330	187829
663	76287	78107	11	2	35.093	4.211	172576
669	77318	79166	2	2	57.180	5.963	285055
648	77284	79096	6	2	44.480	4.646	222893
652	78003	79152	6	2	38.918	4.561	191768
639	78009	79122	8	2	69.857	5.930	322896

APPENDIX B

INDEPENDENT VARIABLES IN THE COST EQUATION

APPENDIX B

INDEPENDENT VARIABLES IN THE COST EQUATION

INPUT PRICE DATA

Capital Price (p_K)

The appropriate price for capital is the user cost of capital, that is, the price of the flow of services from the capital stock. The simplest measure of this cost is r, the interest rate on borrowed funds. If we think of r as including a risk premium, then a priori we would expect r to be higher for private shipyards than for public ones. Because the federal government is the most stable "firm" in the economy, investors should be willing to accept a lower rate of return from the public sector than from private firms.

A more precise but more complicated formula for p_K was developed by Hall and Jorgenson [8]. If a firm maximizes the discounted sum of its profits, then its user cost of capital (in value terms) is

$$c = [q(r+\delta) - \dot{q}]\ (1-k-uz)/(1-u), \quad \text{where}$$

q = the price of capital goods

δ = the rate of replacement of the capital stock (assumed to equal the depreciation rate)

$\dot{q}$ = dq/dt

k = the investment tax credit rate

u = the corporate profits tax rate

z = the present value of depreciation (for tax purposes) per dollar of original cost.

This formula for p_K was used in the empirical work.

In our computation of c, we assumed that q and δ were the same for public and private shipyards. That is, public shipyards buy their capital equipment in the same market as private yards. Under this assumption, c may differ for the two types of yard for two reasons. First, as noted above we expect r to be higher for private shipyards. Second, the "tax factor," (1-k-uz)/(1-u), will differ between yards. Public firms are not subject to tax laws, so for public shipyards, the tax factor equals 1. For private shipyards, this factor may be greater or less than 1, depending on the values taken by k, u, and z. During the 1970s, these values were such that $(1-k-uz)/(1-u) > 1$, widening the gap in the user cost of capital between public and private yards.

The data sources for r, q, δ, k, u, and z are as follows:

r: For public shipyards, r = the average yield on all outstanding bonds due or callable in 10 years or more (from [14]). For private shipyards, r = the composite average of yields on industrial bonds (from [13]).

q: q_S = the implicit price deflator for structures, and q_E = the implicit price deflator for producers' durable equipment (both from [18]).

δ: δ was assumed to equal $2.3/T$, where T is the useful service life of the asset (see [11]). The allowed service life for tax purposes (from [25]) was used as a proxy for the useful service life.

k: k = 0, .07, or .10, depending on the time period. k, u, and z were calculated using information in [4].

u: u = .48.

z: z depends on: the depreciation methods allowed for tax purposes; r; and T.

Wages (p_L)

Before describing the wage data used, it might be of interest to describe the wage-setting process in public and private shipyards. Except for management, employees in naval shipyards are not members of the Navy. Rather, these workers, like other blue-collar employees of the federal government, are paid according to the Coordinated Federal Wage System (CFWS). Under this system, all federal agencies within a given geographical area pay the same wages, but wage rates may differ across regions. Wages within a region are determined by annual surveys of the prevailing wages in that area. The Coordinated Federal Wage System includes separate wage schedules for nonsupervisory, leader, and supervisory employees. In the first two, there are 15 grades with 5 steps per grade; in the third, there are 19 grades with 5 steps per grade.

According to a BLS survey of wages in shipbuilding and repairing, in September 1976 a majority of production workers in private shipyards were covered by collective bargaining agreements ([20], p. 1). Unions also exist in public shipyards; they are active participants in the federal wage-setting process [6].

The ideal measure of the price of labor would be total compensation (wages plus the value of fringe benefits) per man-hour. Since information on fringe benefits is generally not available, we must use the hourly wage rate instead. However, a problem was encountered in that the data on hourly wages that is most readily available is not strictly comparable between public and private shipyards. For public yards, the data consists of copies of the CFWS wage schedules for each shipyard in each year. We also have information on the correspondence between occupations and grades for the WG (nonsupervisory) schedule ([20], p. 21). For private shipyards, in contrast, the primary data is average hourly earnings for production workers in SIC 3731, available for the nation as a whole in [19] and by region in [26]. This average is calculated as total payroll divided by total man-hours worked.

The wage data for private shipyards differs from that for public yards in two respects. First, the former includes premium pay for overtime, weekends, holidays, and late shifts, but the latter does not. More importantly, while we have individual wage rates for public shipyards, all we have for private shipyards is a weighted average of wage rates over all occupations and tenure levels. That is (ignoring the first difference) if w_{ij} = the hourly wage rate for a worker with tenure j in occupation i and MH_{ij} = total man-hours worked by employees with tenure j in occupation i, then for public shipyards, we have a matrix of w_{ij}'s, but for private yards, we have the single value $\bar{w} = \left(\sum_j \sum_i MH_{ij} w_{ij} \right) / \sum_j \sum_i MH_{ij}$.

The data for public shipyards is closer to the ideal measure of the price of labor than is the data for private shipyards. This is because the former represents the exogenous set of wage rates faced by public shipyard managers, while the latter is to some extent endogenous since it reflects private shipyard managers' employment of various kinds of labor.

Given this problem, it was necessary to adjust the private shipyard wage data in some way to make it more comparable to the public yard data. In the BLS survey of wages in shipbuilding [20], distributions of straight-time hourly earnings by occupation and geographical region for September 1976 were reported. Assuming that the observed distribution of earnings is a good representation of the possible range of wage rates, we may interpret the survey information as a set of regional wage schedules for 1976. Similar schedules for the other years of the sample period were then computed. This was done by assuming that the ratio of the wage rate for a particular occupation to the average wage in a given region was the same in the other years as it was in 1976.

Once we had these "wage-schedules" for private shipyards, one problem remained: which wage, or wages, to use as the price of labor in the empirical work. The wages in a wage schedule are too highly related to one another for all of them to be included in a regression equation. Accordingly, it was decided to use the wage rate for one typical shipyard occupation, namely, shipfitters. Moreover, since we did not know exactly how wages vary with tenure in private shipyards, it was decided to use the lowest, i.e., zero-tenure, wage. Thus, the starting wage rate for shipfitters, taken from Step 1 of Grade 10 in the WG schedule for public shipyards and estimated from average hourly earnings for private shipyards, was the measure of the price of labor in the empirical work.

Material Price (p_M)

While it might be expected that the prices of capital and labor differ in public and private shipyards, there is no strong evidence that material prices also differ. Accordingly, the same material price index was used for both types of yard.

The index we used was a composite index based on the Producer Price Indexes for iron and steel, general purpose machinery and equipment, and electrical machinery and equipment. The percentage change in the composite index was calculated using weights of 45 percent, 40 percent, and 15 percent, respectively, for the percentage changes in the three PPIs. According to [5], p. 803: "These weights are used by both MarAd and the Department of the Navy for calculating material cost indexes...."

OTHER INDEPENDENT VARIABLES

A: the age of the submarine at the beginning of the overhaul, in months

T: T represents the year in which the overhaul began (1 for 1971, ..., 9 for 1979)

X: X = the number of overhauls of nuclear submarines (SSNs or SSBNs) begun in the shipyard up to the time of the present overhaul, including the present overhaul. For the purposes of constructing X, both regular and refueling overhauls counted as one unit. Dates and locations of nuclear submarine overhauls were provided by Vitro Laboratories.

In table B-1, X1, X2, and X3 are, respectively, the number of overhauls ever done in the shipyard up to the time of the present overhaul, the number done in the 10 years prior to the present overhaul, and the number done in the 5 years prior.

Y: Y = 1 if the overhaul was done in a naval shipyard; = 0 if done in a private yard.

Table B-1 lists the values of the independent variables for the 40 overhauls in the sample.

TABLE B-1

INDEPENDENT VARIABLES IN THE COST EQUATION

P_K	P_L	P_M	A	T	X1	X2	X3	Y
18.70	4.18	99.50	46.1	1	13	12	7	1
23.84	3.54	98.74	42.8	1	20	18	13	0
19.43	4.24	102.61	43.6	2	9	9	6	1
19.10	4.22	100.30	43.9	2	14	12	8	1
19.53	4.94	103.49	46.9	2	13	13	11	1
24.47	3.87	102.94	46.4	2	22	19	14	0
19.38	4.54	115.24	49.0	3	10	10	6	1
19.64	4.51	109.87	34.6	3	17	15	9	1
19.32	4.62	123.89	42.1	3	18	16	10	1
19.39	5.24	118.34	47.7	3	15	15	12	1
19.56	5.50	106.34	52.2	3	10	9	6	1
24.66	3.24	108.06	48.8	3	4	4	4	0
20.51	4.95	142.51	52.8	4	11	11	6	1
20.64	5.49	139.58	53.3	4	12	11	6	1
20.89	5.07	142.93	65.1	4	20	17	11	1
23.05	5.27	145.79	50.5	4	21	18	12	1
23.94	6.04	147.58	45.8	4	17	17	11	1
26.44	4.21	134.46	56.8	4	27	24	14	0
26.92	5.44	152.31	54.8	5	12	11	6	1
24.46	5.38	147.41	45.9	5	22	19	13	1
27.02	6.57	153.88	48.3	5	19	19	13	1
26.91	6.97	152.82	50.9	5	13	10	6	1
27.42	5.63	158.73	51.2	6	13	12	6	1
27.60	5.73	161.30	53.6	6	14	13	7	1
27.84	7.11	162.84	47.2	6	20	20	11	1
28.66	5.95	167.21	56.3	7	15	14	7	1
29.48	7.50	170.13	59.7	7	22	21	11	1
32.32	6.37	182.82	93.0	8	16	13	7	1
19.85	5.49	128.33	80.7	3	16	16	12	1
27.05	6.26	154.55	99.7	5	13	11	5	1
27.89	6.53	163.12	112.0	6	14	11	6	1
29.24	6.52	169.09	94.9	6	26	20	14	1
28.68	7.36	166.72	95.7	6	21	21	11	1
34.57	5.27	165.71	100.2	6	31	24	13	0
34.18	4.82	161.66	98.5	6	17	17	7	0
34.50	4.98	167.44	99.6	6	18	17	7	0
32.74	7.44	185.58	96.7	7	16	12	6	1
32.05	7.97	181.88	102.9	7	23	21	11	1
32.70	8.04	184.83	100.8	8	24	22	11	1
32.62	8.72	185.53	112.0	8	27	20	14	1

APPENDIX C

THE COST OF TIME IN OVERHAUL

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To estimate the cost of extra time spent in overhaul, we began by computing the life-cycle cost of a Sturgeon-class submarine:

$$LC = P + \sum_{t=1}^{30} OS_t/(1+r)^t$$

where LC = 30-year life-cycle cost

P = procurement cost

OS_t = operating and support costs in year t

r = the discount rate.

The following values were used for P, OS, and r.

P: the average cost of a Sturgeon-class submarine, in 1972 dollars, is $130 million (figure provided by Mr. J. S. Nieroski, Op-96D).

OS: According to [24], the average costs of operating a Sturgeon-class submarine, in millions of FY 1982 budget dollars, are:

Military personnel cost	2.590
Operation and maintenance cost	15.144
Other procurement cost	.753

These numbers are averages for the Atlantic and Pacific fleets. They were converted to 1972 dollars using the Department of Defense deflators for military personnel, operation and maintenance, and procurement, respectively. The result is

$$OS = (2.590)(.5033) + (15.144)(.4408) + (.753)(.4691) = 8.332 \ .$$

For simplicity, it was assumed that operating and support costs are constant over time.

r: We let r = 10 percent.

Substituting:

$$LC = 130 + \sum_{t=1}^{30} 8/(1.1)^t = 205 = \sum_{t=1}^{30} 22/(1.1)^t \quad .$$

Our estimated 30-year life-cycle cost for a Sturgeon-class submarine is \$205 million in 1972 dollars, which is equivalent to a yearly payment of \$22 million for 30 years. According to [24], overhaul interval for the Sturgeon class, the time from the end of one overhaul to the beginning of the next, is 70 months, and overhaul duration is 14 months. That is, the Navy plans on having these submarines out of overhaul $70/(70 + 14) = 5/6$ of the time.

Assuming that a submarine has no value to the Navy while it is in overhaul, the Navy is really spending \$22 million per year for $\frac{5}{6} \cdot 365 = 304$ days of submarine availability, or an average of \$72,000 per day. This is the figure used to value overhaul time in the text.

APPENDIX D

OTHER REGRESSION RESULTS

APPENDIX D

OTHER REGRESSION RESULTS

USING BUILDING AND OVERHAUL EXPERIENCE

We constructed a variable representing a shipyard's experience building nuclear submarines as follows. From Jane's Fighting Ships, we obtained construction dates for SSNs and SSBNs. For each overhaul, B was then defined as the number of submarines begun in the shipyard up to the time of that overhaul.

Nuclear submarine building experience is unevenly distributed among the shipyards in our sample. Four of the naval yards--Norfolk, Charleston, Puget Sound, and Pearl Harbor--built no nuclear submarines. Because new construction was not assigned to naval shipyards after 1967, the building experience of Portsmouth and Mare Island is relatively old. Only Electric Boat and Newport News have recent experience building submarines.

In table D-1, three measures of building experience are shown. B1, B2, and B3 are, respectively, the number of submarines ever built in the shipyard up to the time of the present overhaul, the number built in the 10 years prior to the present overhaul, and the number built in the 5 years prior. These three measures were used together with the three measures of overhaul experience in regressions of the form

$$\ln(C/p_M) = \beta_0 + \beta_1 \ln(p_L/p_M) + \beta_2 \ln(p_K/p_M) + \beta_4 X_i + \beta_5 B_i + \beta_6 A + \beta_7 T + \beta_8 Y + \beta_9 O_i, \quad i = 1, 2, 3 \ .$$

The results are shown in table D-2.

The results in table D-2 differ from those in the text in several respects. The most disturbing result, however, is the positive and significant coefficient of B. This coefficient implies that the more submarines a shipyard has built, the higher the cost of an overhaul in that yard, which is the opposite of what we would expect. It would be difficult to argue that building experience causes shipyards to spend more on overhauls. More likely, B is a proxy for some other variable that is correlated with overhaul cost. It is not clear, however, what that variable is.

Because of this problem, it was decided to drop building experience from the regression equation.

TABLE D-1

MEASURES OF NUCLEAR SUBMARINE BUILDING EXPERIENCE

B1	B2	B3
9	3	0
40	27	10
0	0	0
9	3	0
0	0	0
41	23	9
0	0	0
9	2	0
9	2	0
0	0	0
0	0	0
12	7	3
0	0	0
0	0	0
9	1	0
9	1	0
0	0	0
44	20	9
0	0	0
9	1	0
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0
9	0	0
0	0	0
48	18	9
29	10	7
29	9	6
0	0	0
0	0	0
0	0	0
17	1	0

TABLE D-2

REGRESSION RESULTS USING BUILDING AND OVERHAUL EXPERIENCE

Dependent Variable: $\ln(C/p_M)$

Coefficient (t-statistic)

Equation No.	$\ln(p_L/p_M)$	$\ln(p_K/p_M)$	X	B	A	T	Y	Q_1	Adjusted R^2
1	.743[a] (2.67)	-.067 (-.19)	-.0477[a] (-5.40)	.0307[a] (4.93)	.00297 (1.01)	.1107[a] (4.62)	.635[a] (3.33)	-.288[a] (-2.21)	.83
2	.541[a] (1.87)	-.282 (-.72)	-.0347[a] (-4.58)	.0264[a] (2.68)	.00311 (.97)	.0821[a] (3.53)	.155 (.79)	-.301[a] (-2.07)	.80
3	.405 (1.22)	.189 (.46)	-.0310[a] (-3.09)	.0528[a] (1.78)	.00600[a] (1.74)	.0329 (1.58)	.369 (1.30)	-.148 (-.96)	.74

[a]Significant at the 5-percent level using a one-tailed test.

USING WAGE RATES FOR OTHER OCCUPATIONS

In the regressions in the text, the starting wage rate for shipfitters was used as the price of labor. Regressions were also run using the starting wage rate for other typical shipyard occupations. The results are shown in table D-3. In these regressions, X2 was used to represent nuclear submarine overhaul experience.

There are some differences between the regression coefficients in the shipfitter equation and those in the other three equations. However, when we used the coefficients from the four equations to predict the cost of a hypothetical overhaul, we did not find large differences in estimated costs. We concluded that using the wage rate for shipfitters did not seriously bias the study's conclusions.

TABLE D-3

REGRESSION RESULTS USING WAGE RATES FOR VARIOUS OCCUPATIONS

Dependent Variable: $\ln(C/p_M)$

Coefficient (t-statistic)

Occupation	$\ln(p_L/p_M)$	$\ln(p_K/p_M)$	lnX	A	T	Y	Q_1	Adjusted R^2
Shipfitter (equation 2 in the text)	.409 (1.28)	.117 (.28)	-.246[a] (-2.99)	.00634[a] (1.85)	.0415[a] (1.90)	-.038 (-.21)	-.144 (-.94)	.744
Hand welder	.122 (.39)	.332 (.80)	-.211[a] (-2.67)	.00642[a] (1.83)	.0345 (1.59)	.104 (.69)	-.157 (-.97)	.732
Pipefitter	.076 (.25)	.365 (.88)	-.209[a] (-2.65)	.00639[a] (1.82)	.0337 (1.56)	.114 (.69)	-.161 (-1.02)	.732
Shipwright	.034 (.11)	.394 (.95)	-.208[a] (-2.64)	.00635[a] (1.80)	.0331 (1.54)	.131 (.81)	-.165 (-1.04)	.731

[a]Significant at the 5-percent level using a one-tailed test.

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